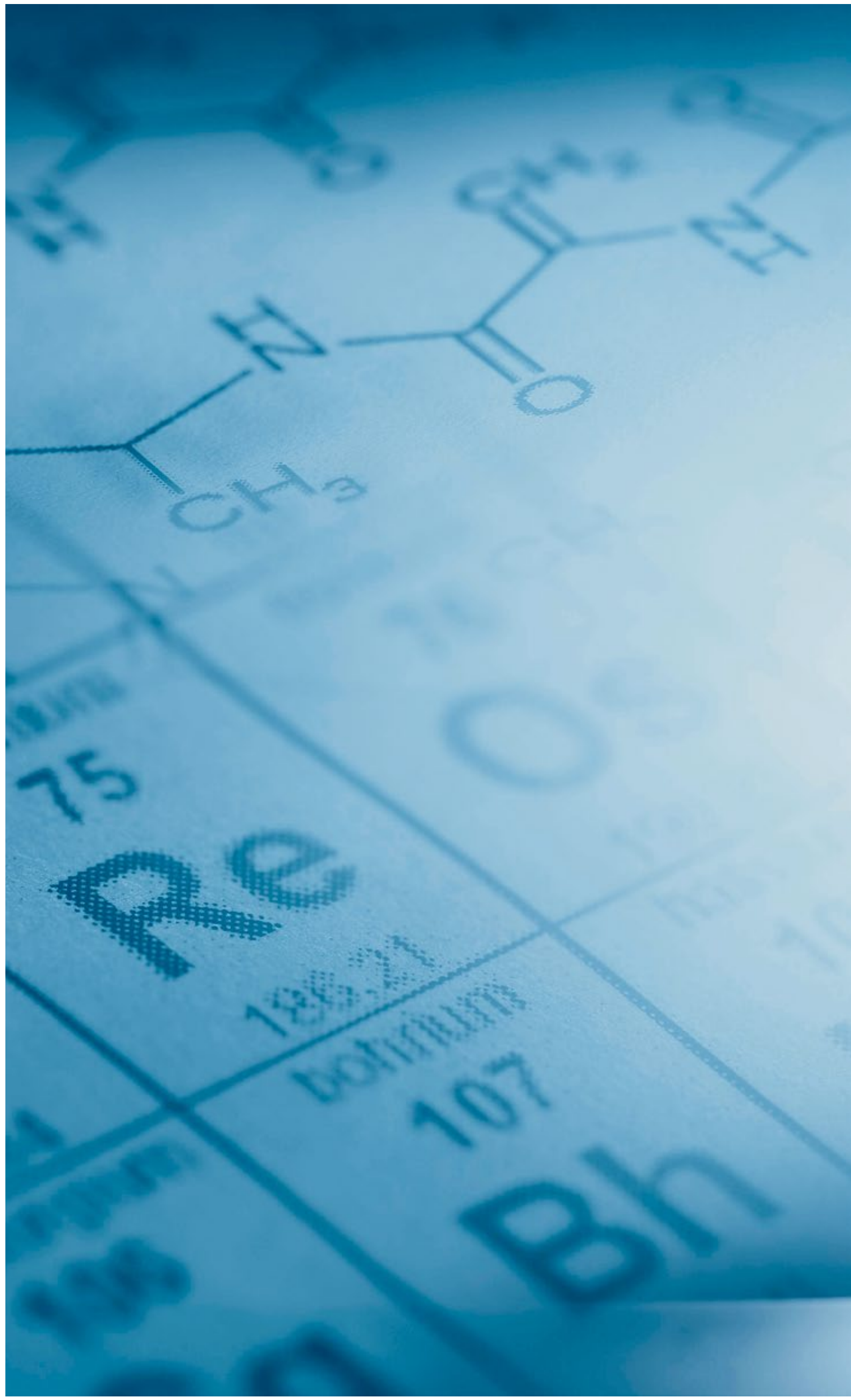
Research into Interactions between Internal Combustion Engines and Fuels

The chemical composition of fuel has considerable impact on the operational and emission behavior of internal combustion engines. Moreover, CO_2 emissions of engines and turbines depend not only on the carbon content of the fuel but also on its production pathway. Investigating interactions between fuel and combustion is therefore one of the core tasks of internal combustion engine research.



1 MOTIVATION

Emission behavior and operational safety of internal combustion engines are, to a large degree, characterized by fuels. The interactions between engines and turbines, on the one hand, and between fuels and lubricants, on the other, have therefore always been a recurring topic in FVV's research projects. Whereas issues such as operational stability were the focus when the FVV was founded more than 60 years ago, throughout the years, the impact on exhaust emissions has become increasingly important. FVV projects have contributed to explaining essential correlations in particulate formation in direct injection spark ignition engines and catalytic converter ageing as a function of fuel composition. Although a thorough understanding has already been developed, this line of research can by no means be considered complete. In particular, physical processes on a molecular level have not yet been comprehensively understood.

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VOICES FROM FVV

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Prof. Dr. sc. techn. Thomas Koch is Head of the Institute of Internal Combustion Engines (IFKM) at the Karlsruhe Institute of Technology (KIT)
"We have really learned a lot about the interaction between combustion engines and fuels, but the more we have understood, the more questions have come up."

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Dipl.-Wirt.-Ing Ralph Thee is Project Manager at FVV and Specialist in Advanced and Alternative Liquid Fuels
"If we are serious about CO_2-neutral mobility without usage restrictions, we will have to consider the entire energy chain."

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Dipl.-Ing. Wolfgang Maus is Senior Advisor of the Management Board of Continental Emitec GmbH and Member of the FVV Executive Committee
"The FVV's fuel studies have verified the high CO_2 reduction potential of synthetically produced fuels."

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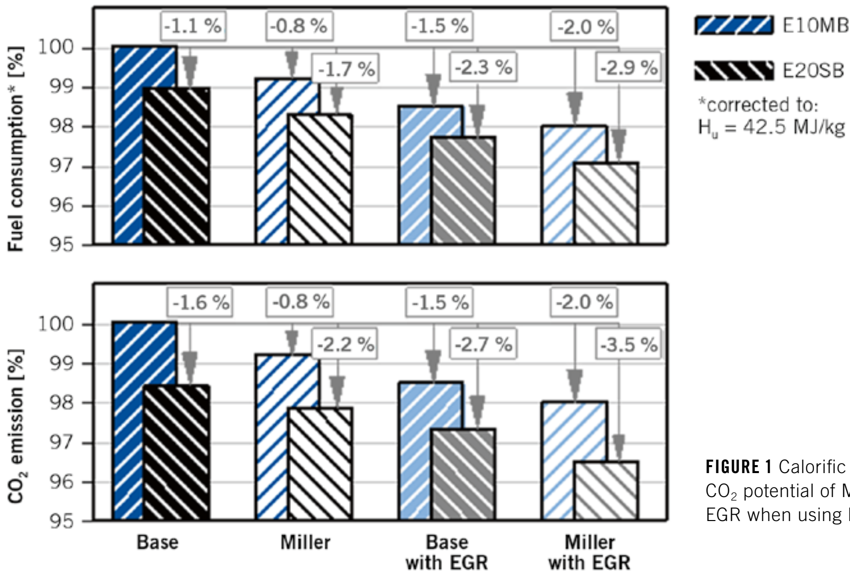

FIGURE 1 Calorific value-adjusted comparison of the CO_2 potential of Miller cycle and cooled external EGR when using E10 and E20 in NEDC (© VKA)

The political demand for long-term CO_2 neutrality of energy supply and transport has brought considerable momentum to research into alternative fuels since the turn of the millennium. After focusing on biogenic fuels initially, investigations have increasingly looked at synthetically produced fuels. The role of FVV is to initiate research that deals with the use of alternative fuels in the internal combustion engine.

2 SELECTED CURRENT RESEARCH PROJECTS

2.1 FATIQUE CAUSED BY CORROSIVE FUELS

High pressures and pressure variations in the injection system of an internal combustion engine lead to mechanical cyclical load in fuel-carrying components. For fuels of fossil origin currently used in the field, there are specific design criteria for these components, the safety margins of which are highly conservative. However, in the long term, this approach appears to be problematic for two reasons: the power densities of engines – and thus requirements on the injection system – are still increasing, and fuels are becoming more diverse due to the addition of blend components from different biogenic sources. These components have hydrophilic properties. Due to the entry of water and other chemical components (contaminants) under very high mechanical cyclical load, they can thus favor corrosion and subsequent crack formation in metallic components. A joint research project analyzes the interaction of corrosion and fatigue processes and their impacts on steels in biogenic fuels. In their research, the Technische Universität Darmstadt as well as the Fraunhofer Institute for Structural Durability and System Reliability LBF and the Foundation Institute for Materials Engineering (IWT) in Bremen will describe both the damaging mechanisms and the causes of the interactions. The objective is to develop a mechanistic and practicable model, verified by means of a demonstrator component, which can be used in industrial practice to select materials. The results of the research project, which is funded cooperatively by FVV and DFG [1], will be available in the first half of 2018.

2.2 DOWNSIZING WITH BIOFUELS

The combination of exhaust gas turbo charging and high pressure direct injection can be used in gasoline engines to achieve very high specific performances. If, in exchange, cubic capacity and the number of cylinders are reduced, considerable reductions in consumption can be achieved in wide ranges of the characteristic map. The addition of ethanol increases the octane number and thus the knock resistance of the combustion process. The design must be such, however, that if availability bottlenecks occur, the engine can also be operated using commercially available premium-grade gasoline (ROZ 95 E10). In higher load ranges, this increases the need of additional mixture enrichment in order to reduce exhaust gas temperature and lowers the consumption benefit. In the context of a research project subsidized by the FVV's CO_2 special research programme, the Institute for Internal Combustion Engines (VKA) at RWTH Aachen University investigated what low-consumption operation could look like for various fuel compositions [2]. To this end, a three-cylinder research engine that had been designed for a previous project with a displacement of 799 cm^3 was equipped with two new technology options. Firstly, operation based on the Miller cycle was enabled via modified camshaft control. Additionally, cooled external exhaust gas recirculation was used. The measurements showed that the combination of the two technologies increases the consumption benefit of the already highly efficient engine by a further 2 %. In the low load range, efficiency increased by 3 % when the Miller cycle was applied. Cooled exhaust gas recirculation was shown to be especially advantageous at high loads. When operated with E10 fuel, the engine's nominal output increased by more than 8.5 % without the need for fuel enrichment **FIGURE 1**.

2.3 FUELS FOR PLUG-IN HYBRID DRIVES

Vehicles equipped with a plug-in hybrid drive provide a good compromise between local emission-free and long-distance suitability. When these vehicles are used mainly for short-distance commuting and regularly connected to the power grid while parked, progress in battery technology gives reason to believe that the combustion engine will be used only occasionally, for example on holiday trips. This considerably increases residence times of fuel in the tank, which could affect fuel specification. In a study financed with FVV's own funds, the Oel-Waerme-Institut (OWI), the Technology Transfer Centre at the University of Coburg and further project partners are investigating the long-term behavior of fuels for spark ignition and diesel engine, with a focus on the following questions:

- In many markets, fuel composition varies seasonally. In Germany, for example, there is "winter diesel". What is the impact on cold-temperature drivability if fuel filled in the tank during summer is not used before winter? Is there a need for a year-round fuel specification?
- Which methods are suitable to investigate main characteristics of aged fuels and their chemical composition?
- What impact does the addition of alternative fuel components of biogenic or synthetic origin have, and how do mixtures of different components behave?
- What is the impact of additives in the fuel?

The project investigates aged fuels of at least six months, both in the field and in targeted lab tests **FIGURE 2**. The results of the research project [3] are expected to be available in the first half of 2018.

3 FVV FUEL STUDIES

The idea of generating fuels synthetically by using regenerative electricity has enjoyed increasing support since 2010. Power-to-X methods are seen as an opportunity to even out and chemically store the temporary energy surpluses that typically occur in energy systems based on regenerative production paths. Many of the potential generation paths are based on proven plant and process technologies. However, this diversity creates a level of complexity that makes it more difficult to set up clear research targets. It was in this context that the FVV board initiated its first fuel study back in 2011. The most important motivation of the study, which was carried out by Ludwig-Boelkow-Systemtechnik (LBST) was to investigate general feasibility. Results were presented in 2013 [4]; they confirmed general feasibility and identified significant environmental potential for synthetic fuels generated from green electricity. Effective CO_2 emissions across the entire chain of generation, transport and consumption are near zero, regardless of whether the electricity is transformed into gasoline, diesel, methane or hydrogen.

Three methods for generating synthetic fuel from electricity were rated especially positively by researchers [5]. Firstly, excess electricity can be used to separate pure hydrogen from water. This hydrogen can then be processed to methane or can, to a certain extent, be directly fed into the natural gas grid. In both cases, the gas can be used for combustion in natural gas engines and thus supplies energy without increasing CO_2 emissions. Secondly, hydrogen generated this way can also be processed into other hydrocarbons, such as Oxymethylene Ether (OME). The properties of OME make it very similar to diesel fuel, but OME has a decisive advantage: The avoidance of carbon double bonds and its higher oxygen content makes combustion very clean. Thirdly, the hydrogen can be processed into methanol in a first step. A mixture of liquid hydrocarbons consisting mainly of gasoline, diesel and kerosene can then be produced in several intermediate steps.

The first FVV fuel study also showed that production costs of synthetic fuels

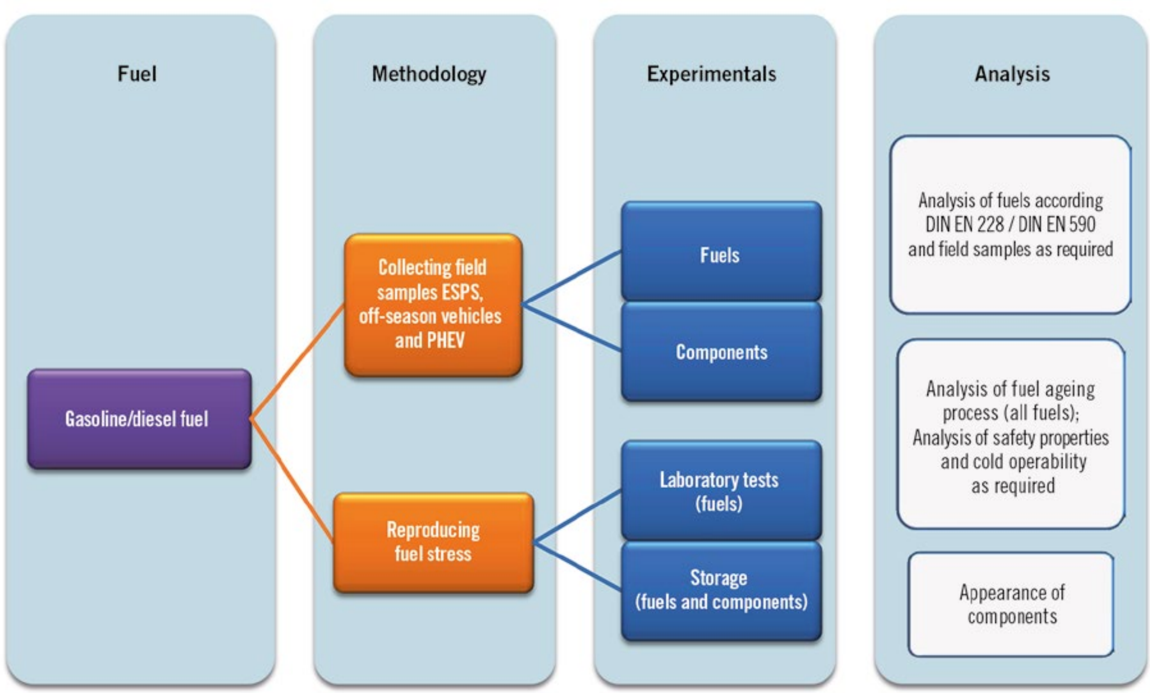

FIGURE 2 Analysis approach of fuels for plug-in hybrid vehicles research project (© OWI)

depend largely on assumed electricity prices. For energy policymakers, the question of the effect of the production of larger quantities of synthetic fuels on the entire energy system – also when compared to a transition to electrical drives and energy storages – is decisive, but this question remains unanswered. To clarify these impacts, FVV commissioned a second fuel study, which considers power transmission and fuel scenarios for 2050 under the boundary condition of carbon neutrality. The key findings of the study were [6]:

- Depending on the scenario, the need for electricity in the European Union could increase by a factor of 3 to 4.5. In general, the increased need will be covered within the EU but not individually in all countries.
- Producing competitive liquid fuels synthetically requires CO_2 sources with a high concentration, high-temperature electrolysis and at least 4000 h of full load plant operating time. The green electricity used must not cost more than 5 cents per kWh.
- Distribution costs are not significant; electricity cost, the anticipated overall efficiency, and investment/depreciation costs for the production plants are more relevant.

In conclusion, the fuel study has demonstrated that a transition of the transport sector to CO_2-neutral mobility is generally feasible [7]. According to the study, more research is needed, to investigate the interaction between synthetic fuels and semi-electrical drivetrains, as well as the impact on exhaust gas aftertreatment systems. The authors' main recommendation is that, bearing in mind a gradual market penetration, the addition of synthetic fuels to fossil fuels and the potential of these blends should be investigated in view of their CO_2 potentials and exhaust emissions.

4 OUTLOOK

If the objective of completely CO_2-neutral mobility is pursued exclusively on the basis of the balance of "tank-to-wheel" emissions, battery-electric and fuel cell drives are the only options that remain for the future. But since there will be considerable usage restrictions for these drives in the foreseeable future, it makes sense to widen the balance framework to include a "well-to-wheel" analysis. CO_2 emissions are ignored if they are fully compensated in the framework of energy supply, **FIGURE 3**.

Several optional paths, including synthetic fuels to operate internal combustion engines, are available for achieving 100-% CO_2-free mobility under the boundary condition of a "well-to-wheel" analysis. There is still considerable need for research, not only in view of the production and composition of such fuels but also their interaction with the engine, including engine operation with pure fuels and the combustion processes for adding synthetic to fossil fuels.

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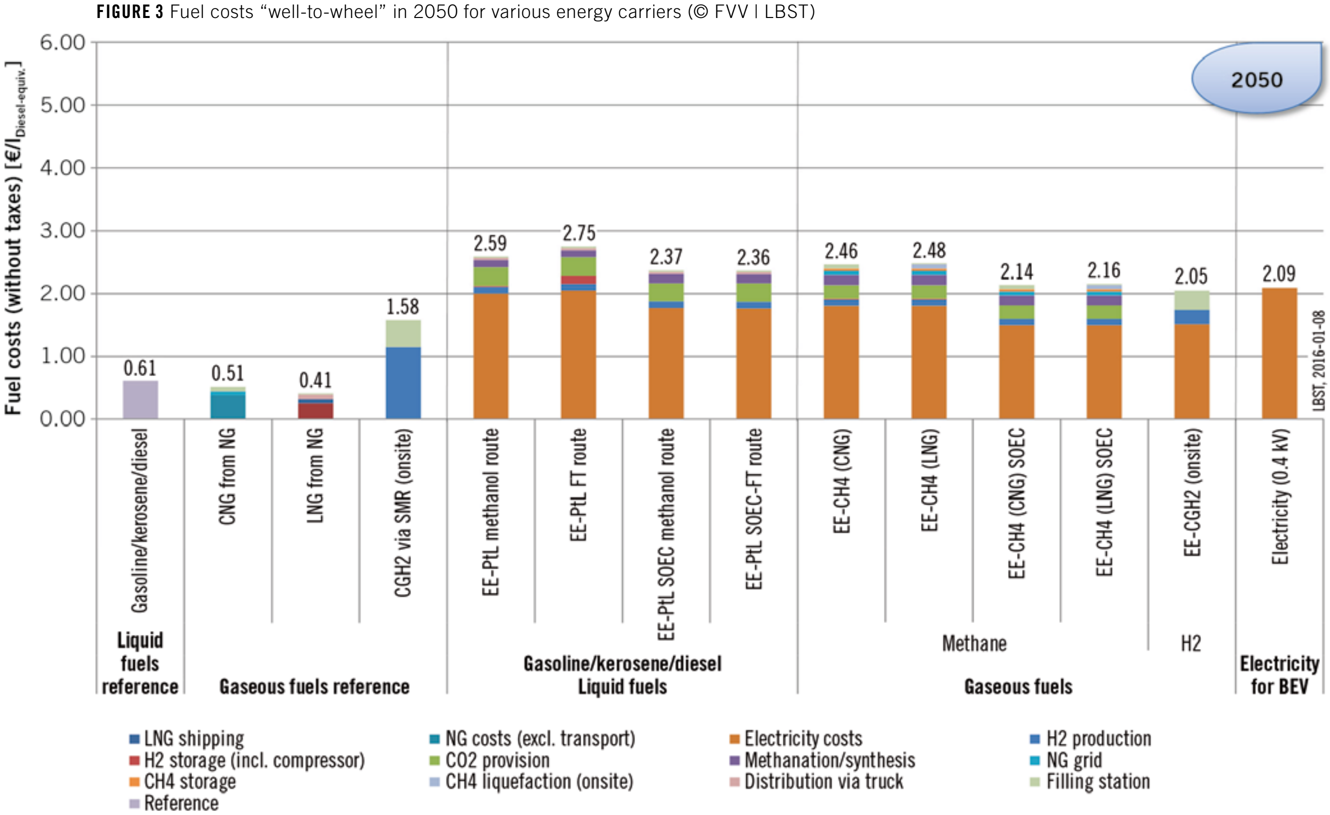
FIGURE 3 Fuel costs "well-to-wheel" in 2050 for various energy carriers (© FVV I LBST)



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