Sustainable Powertrain Systems – Research for the Mobility of the Future

In its pre-competitive collective research, FVV pursues a technology-neutral approach in which all sustainable powertrain systems and energy sources are considered equally. This mix allows the individual concepts to fully leverage their specific advantages for the respective applications and fields. To quickly achieve the climate and energy policy goals, research for sustainable mobility of the future is being conducted in parallel in several projects.

1 LEVERAGING THE SPECIFIC ADVANTAGES OF POWERTRAIN CONCEPTS

Climate protection and shrinking fossil energy resources necessitate the rapid introduction of sustainable powertrains. However, this problem cannot be solved by solely focusing on powertrain technology, as it is not the powertrain itself that determines how sustainable a mobility concept is, but rather the entire energy supply chain. To achieve the climate goals, it is therefore crucially important to cease using fossil energies as soon as possible.

To compare the sustainability potential of the various powertrain concepts on a scientifically substantiated basis, the FVV study “Transformation of Mobility to the GHG-neutral Post-fossil Age” (Fuels Study IV) [1, 2], published in 2021, investigated seven different vehicle powertrain technologies for the European transport sector, including their total infrastructure requirements, their costs, and all Greenhouse Gas (GHG) emissions on a cradle-to-grave basis. It revealed

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Dietmar Goericke
is Managing Director of FVV e. V.
“With our technology-neutral research approach, we create the basis for the widespread introduction of carbon-neutral powertrains – and therefore sustainable mobility solutions.”

© Stefan Kaimer

Dr.-Ing. Stefan Kaimer
is Research Engineer in the Research & Analysis Propulsion Systems Engineering Division of Ford-Werke GmbH.
“The cold starting ability of fuel cell systems is an essential prerequisite for their use in vehicle applications.”

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Prof. Dr.-Ing. André Casal Kulzer
is Holder of the Chair of Automotive Powertrain Systems and Managing Director of the Institute of Automotive Engineering (IFS) at the University of Stuttgart.
“Sustainable powertrain systems are driven in a CO_2-neutral way on the basis of electrochemical and molecular storage.”

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that the cumulative GHG emissions of the various powertrain types, for example electric motors and combustion engines, barely differed – assuming the use of GHG-neutral energy.

The speed with which sustainable solutions are introduced is much more important than the technology path chosen: The faster a defossilized vehicle fleet is available, the lower the cumulative GHG emissions and thus the negative impact on the climate. Moreover, as demonstrated in the study, the heavy concentration on only a few or even only one sustainable mobility significantly impedes defossilization and therefore leads to an unnecessary strain on the climate.

2 FOLLOW-UP FUELS STUDY FOR RAPID DEFOSSILIZATION

In the recently completed FVV Fuels Study IVb [3, 4], the results of [1, 2] for the transition of the European road transport sector to climate neutrality by 2050 were investigated in greater depth. The researchers considered, as realistically as possible, in particular the maximum achievable ramp-ups of new vehicle technologies, the necessary power generation capacities, the infrastructure for the value chain up to the end user, and the quantitative availability of raw materials. Coordinated by FVV and Frontier Economics, more than 50 experts from over 40 companies and organizations determined the optimum technically achievable ramp-ups for the production and installation of GHG-neutral mobility paths – including the associated value chain of vehicle production and the power supply and energy distribution infrastructure for the respective powertrain/energy pathway. Taking these ramp-up potentials into account, Frontier Economics performed an analysis that included, among other things, a combination of different technology paths to achieve GHG neutrality as soon as possible and to bypass the technical impediments of singular mobility paths. This analysis comprises single-technology approaches and a GHG-optimized mixed-technology scenario in which all GHG-neutral solutions were available for the optimization simulation, **FIGURE 1**. The results can be summarized as follows:

- A mix of technologies significantly accelerates the transition to GHG neutrality – thereby considerably lowering cumulative GHG emissions by 2050 – as this combined approach largely circumvents the technical bottlenecks that arise when ramping up single-technology paths. For example, a scenario concentrating solely on BEVs as an alternative mobility path would result in 39 % higher cumulative GHG emissions by 2050 compared to an ideal mix of GHG-neutral powertrain technologies. Moreover, a transformation path focusing purely on BEVs would achieve a defossilization

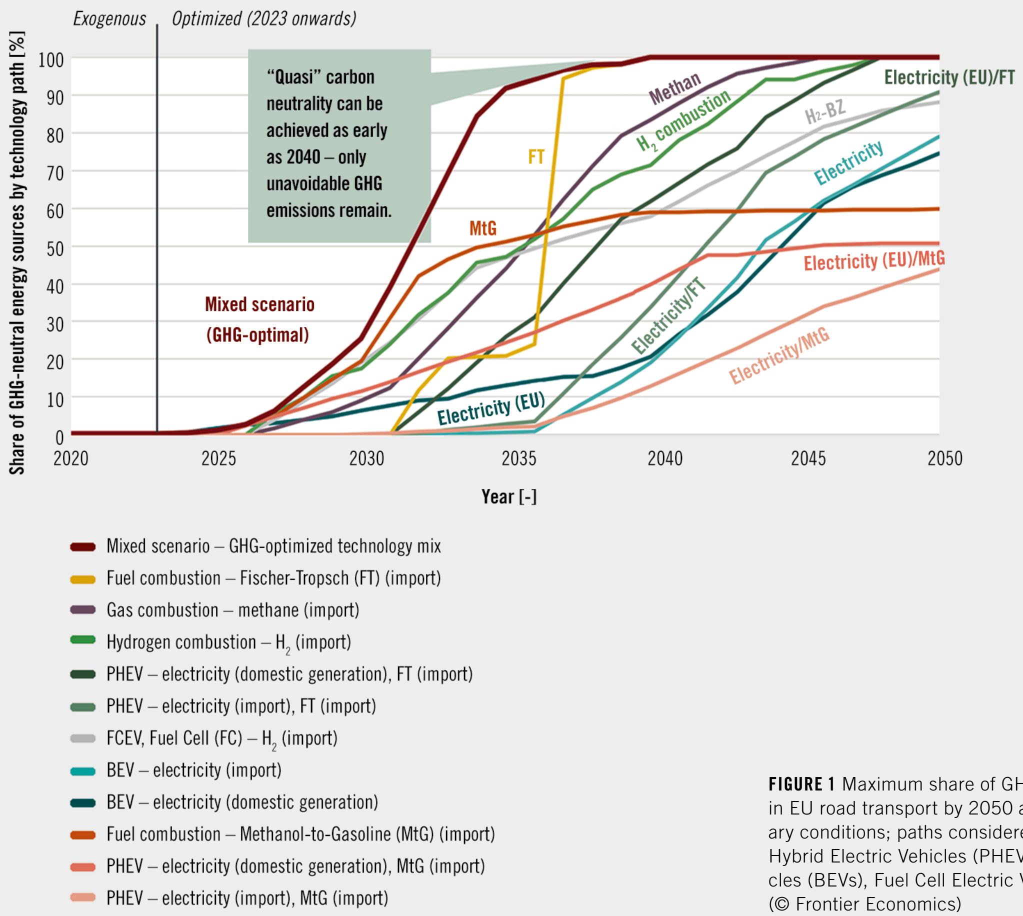

FIGURE 1 Maximum share of GHG-neutral energy sources in EU road transport by 2050 at ideal regulatory boundary conditions; paths considered among others: Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs) (© Frontier Economics)

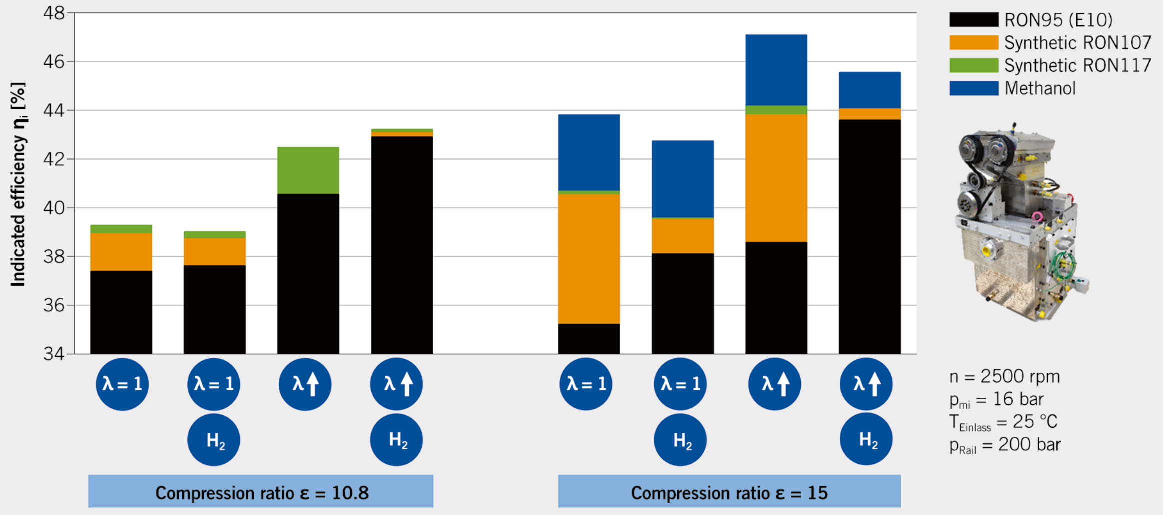

FIGURE 2 Indicated efficiency of different fuels at a compression ratio of 10.8 (left) and 15 (right) at λ = 1 and in lean operation – respectively with and without the addition of H_2 (© TME)

rate of the vehicle fleet of only 76 % by 2050, whereas a mixed-technology scenario would enable the European transport sector to achieve GHG neutrality (100 % defossilization rate) as early as 2039 –assuming that the regulatory framework conditions are ideal in both cases. Another argument against the BEV-only path is that the infrastructure is not available fast enough for sustainable energy supply: Even under ideal regulatory conditions, the expansion of the power grid can hardly be driven forward as required.

- Crucial to minimizing GHG emissions is phasing out fossil fuels as quickly as possible. To this end, bottlenecks in terms of infrastructure and raw materials must be remedied immediately through the creation of ideal regulatory framework conditions.
- Thanks to their backward compatibility, e-fuels offer a unique technological option for the climate-neutral operation of existing fleets and therefore have the potential to significantly accelerate GHG reduction.
- An EU-wide ban on combustion engines from 2035 onward would lead to higher GHG emissions than necessary, as it would increase dependencies on the ramp-up of specific infrastructure and limit the opportunities to use climate-neutral e-fuels.

3 HIGH-EFFICIENCY COMBUSTION ENGINE IN A HYBRID SYSTEM

Research project “ICE2030: Limits of SI engine efficiency in hybridized powertrains” [5] investigates what a future combustion engine could look like as part of a hybrid system for passenger car applications. The objective of this research project was to determine the potential efficiency of gasoline engines in an optimized hybrid powertrain by using various conventional and alternative fuels together with hydrogen to raise combustion performance while at the same time minimizing CO_2 emissions. The aim was to achieve a total degree of efficiency of 50 % or higher. Furthermore, simulation models were calibrated for extremely lean combustion (λ ≥ 2). A total of four research institutes were involved in this project: the Institute for Internal Combustion Engines and Powertrain Systems (vkm) at the Technical University of Darmstadt, the Institute of Automotive Engineering (IFS) at the University of Stuttgart, the Institute for Internal Combustion Engines (IVB) at Technical University of Braunschweig and the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University.

The vkm conducted comprehensive complete vehicle simulations as a basis for the more detailed investigations. Among other things, the researchers compared the various hybrid configurations and combustion engine technologies as part of a benchmark analysis. A P2 hybrid system (electric motor between gearbox and combustion engine), a high-voltage battery and a combustion engine with two-stage turbocharging emerged as a pairing with particular potential to save further CO_2 emissions while ensuring a high degree of efficiency.

A large amount of highly complex processes take place in the spark-ignition engine during very lean combustion. Since no fully validated models exist for hydrogen combustion or gasoline- respectively methanol-hydrogen mixtures, a corresponding approach was developed at the IFS and implemented in FVV’s existing simulation tool.

The research project culminated in single-cylinder engine tests at the IVB and TME. At the IVB, the addition of hydrogen to the combustion process was investigated with different efficiency-boosting technological elements. At the TME, the combination of hydrogen injection into the intake manifold and various directly injected liquid fuels was analyzed on the single-cylinder engine. It became evident that the addition of hydrogen to a liquid fuel with poor anti-knocking properties inhibit knocking, which in turn has a positive effect on the degree of efficiency, **FIGURE 2**. When added to knockproof fuels, however, the efficiency benefits are only minor. At an increased compression ratio, the benefits of adding hydrogen to normal gasoline are enhanced, while no efficiency improvement can be ascertained for knockproof fuels.

4 OPTIMUM COLD START OF A FUEL CELL

Hydrogen is also a promising option for cars, commercial vehicles and off-highway applications of the future as an energy source for fuel cells. One of the challenges of fuel cell technology today is starting at low ambient temperatures. The water vapor that forms during the reaction in the fuel cell stack can condense and freeze in the cells, thereby lowering the performance. During the "PEM-FC Cold Start Simulation" research project [6], a simulation model for the cold start of a fuel cell was developed at the TME and the Hydrogen and Fuel Cell Center ZBT in Duisburg. To this end, an existing model kit and the integrated 1-D-2-D stack model [7] were expanded to allow simulative cold start analyses to be carried out. To verify the additional function, the TME conducted Computation Fluid Dynamics (CFD) tests, which were in turn validated by measurements taken on segmented test cells on the ZBT test bench, **FIGURE 3**. It was revealed that the cell/system model replicates the real behavior of a fuel cell to a very high degree of accuracy. Final cold start simulations made it clear that the new development tool is suitable for detailed investigations into the cold starting ability of various fuel cell systems. As a result, FVV provides in particular small and medium-sized enterprises with a tool forthe efficient enhancement of fuel cell stacks.

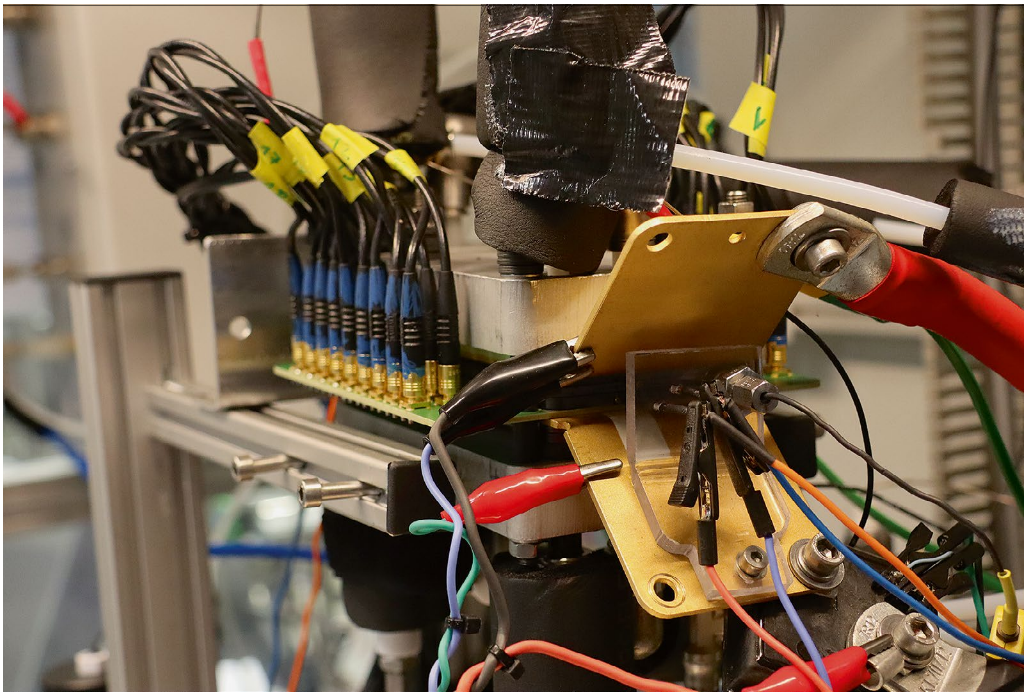

FIGURE 3 Test cell with sensors for spatially resolved measurements on the fuel cell test bench (© ZBT)

5 SUMMARY AND OUTLOOK

For sustainable mobility in the future, alloptions – encompassing the different powertrain concepts through to the various energy sources – must be subjected to further parallel research. The one-sided preferential treatment of individual technologies inhibits the process of defossilization and slows down the urgent decarbonization of the entire transport sector. Evidence to back this up includes the results of the comprehensive Fuels Study IV and IVB. Based on these projects, FVV derives from this a clearly structured research roadmap that focuses on the potential of all energy converters and sources that utilize renewable resources. Future hybrid powertrains for passenger cars with a system efficiency of more than 50 % and fuel cells optimized for cold starts that enable reliable everyday operation are just two examples. FVV is therefore making a decisive contribution toward the open-ended competition between solutions for sustainable mobility, which can be implemented as quickly as possible for the benefit of the environment.

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