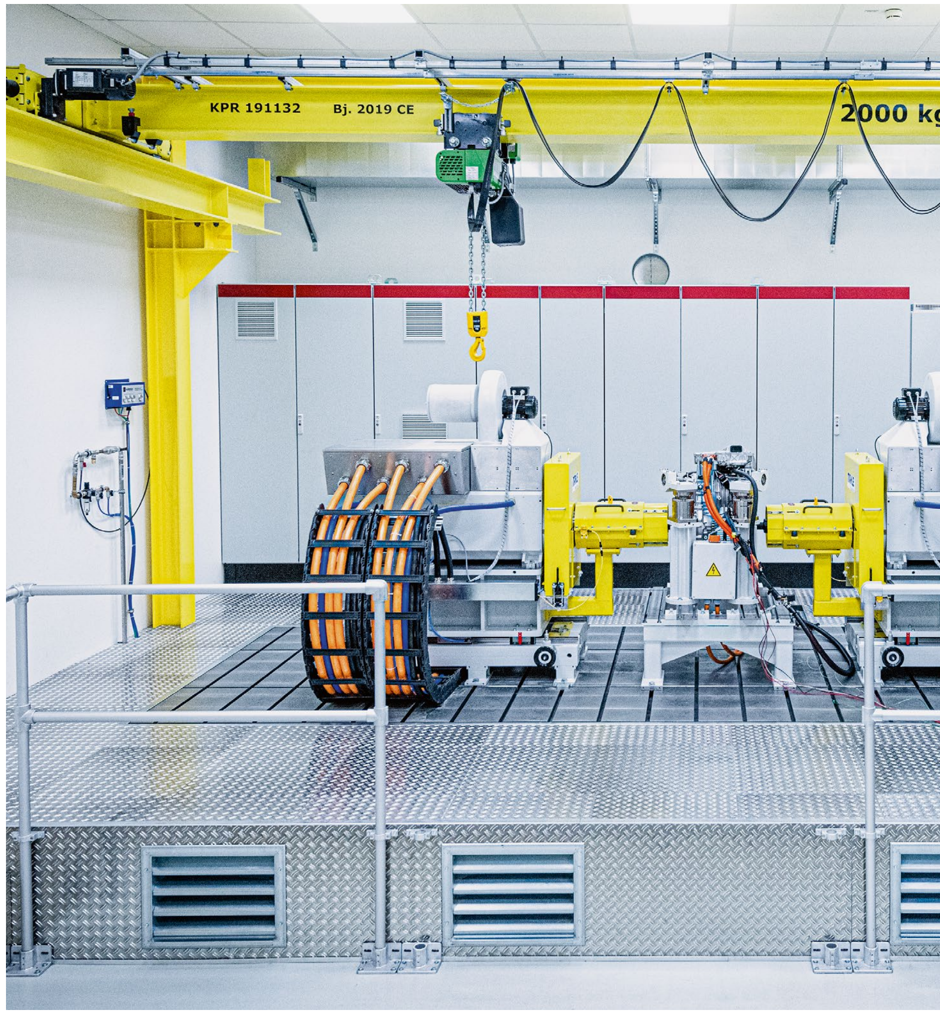
FVV Research Priority – Electric Motors

In the FVV network, companies, research institutes and associations engage in joint, pre-competitive research into powertrain solutions to achieve climate neutrality in the transport sector. All concepts that can potentially contribute to CO_2 reduction are considered, whether these be battery electric solutions, the use of hydrogen in fuel cells or thermal conversion systems, or other alternative energy sources. The association's activities in the area of battery electric powertrains have recently been pooled in the new "Electric Motors" expert group.



1 COLLECTIVE RESEARCH FOR THE GREEN TRANSFORMATION IN TRANSPORT

With the "Green Deal", the EU is aiming to complete its transition into a world-leading industrial hub in which added value is to take place in harmony with climate protection. The goal of achieving net-zero CO_2 emissions by 2050 poses major challenges for industries in global competitive markets, as in many cases they need to adapt previously successful product orientation and business models. In the EU, the combustion of fuels in road traffic was responsible for around 740 million metric tons of CO_2 emissions in 2021 [1], making the transport sector responsible for around a fifth of total CO_2 emissions in the EU. The responsibility it bears in reducing emissions is correspondingly great – but so is the impact of the green transformation on this economic sector.

FVV's pre-competitive collective research plays a key role in developing and launching powertrain systems for sustainable mobility as quickly as possible, as it taps into synergies in the network and raises the efficiency of research as a whole. Increasing complexity requires new development methods, which must also be available to smaller and medium-sized companies, thereby contributing to their competitiveness. Innovative solutions to reduce emissions need not diminish economic prosperity; they can support it or even increase it.

2 ELECTRIC MOTORS EXPERT GROUP

The FVV research program pursues fact-based criteria, such as how a sustainable and economically feasible energy supply can be achieved for the mobility sector, or the potential of new energy sources and conversion systems based on renewable resources. In doing so, a fully-fledged diversification strategy is pursued that considers all concepts of powertrain technologies in combination with sustainable energy sources. In each case, the need for research is determined in expert groups, where the corresponding projects are designed, initiated and accompanied, **FIGURE 1**. The expert groups responsible for energy conversion systems and their terms of reference are summarized in **TABLE 1**. The research activities in the field of electric powertrains were pooled in the recently established "Electric Motors" expert group. The focus is on the following topics:

– improvement of the properties of electric motors in mobile applications

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– electrical energy storage systems (batteries)
– power electronics of the electric motor and the electrical energy storage system
– application-based modification of the corresponding components and (sub)assemblies
– development and improvement of the associated development tools (like for simulation), and measurement and testing methods.

In addition to research activities within the FVV, the expert group carries out cooperative projects as part of the E-Motive program with the Research Association for Drive Technology (FVA) and the Machinery and Equipment Manufacturers Association (VDMA). E-Motive is a working level coordinating interface for research topics that are relevant to both research associations. For example, FVV conducts research on hybrid engines, while FVA contributes its expertise in specific matters relating to battery research. The members of both associations have access to the results. As such, E-Motive is a unique networking platform for research activities on individual components of electrified powertrains, linking the

VOICES OF THE FVV

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Carsten Weber is Manager Engine & Powertrain Systems and Research & Advanced Engineering in the Energy, Propulsion Systems & Sustainability department at Ford-Werke GmbH.
"Even today, electric powertrains have a high level of technical maturity, although this can still be improved further. Here, the focus is on the optimized use of sustainable materials, profitability and on improving the higher-level system as a whole."

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Dr. Alexandra Tokat is Technical Expert Electromagnetics and Electric Machine Design at Aurobay – Powertrain Engineering Sweden AB.
"We strive to create sustainable mobility solutions without compromising on performance by combining conventional and newer technologies. To achieve this, research cooperation with FVV is an important building block."

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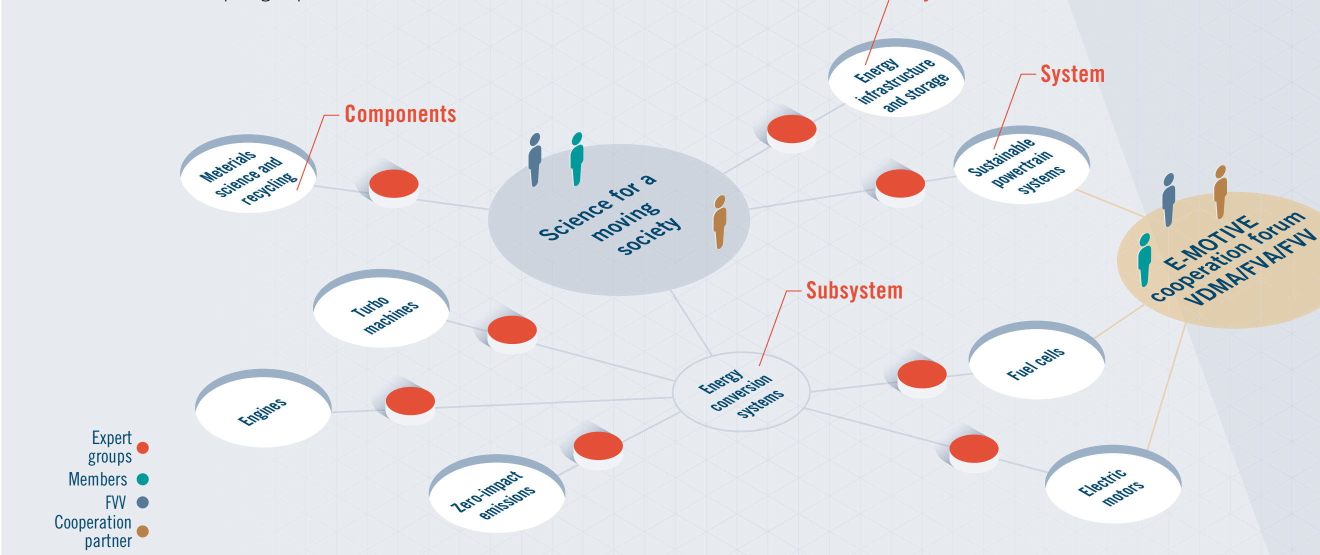
Martin Nitsche is Deputy Managing Director of FVV e. V.
"Through our research activities, we tap into potential to increase the efficiency and lower the costs of the electric powertrain."

FIGURE 1 Breakdown of expert groups at FVV (© FVV)



expertise of both associations' external research partners and bringing together the existing innovation and research platforms. The bridge to the VDMA exists through its mechanical engineering division, which focuses on automotive, production and recycling technologies. FVA's core topics within the E-Motive program are:

- electric traction (electric motor/transmission)
- energy storage and charging technology in vehicles
- control systems with power electronics and sensor technology.

FVV's in-house research projects primarily concern the powertrain at a system level, that means, the optimized interplay of the electric motor, inverter and battery, **FIGURE 2**. The research content is based on current issues with relevance for short- and long-term product development. These include efficiency enhancement, thermal management, and fast-charging capability, but also resource conservation and recycling at the end of the vehicle's service life. Three projects are presented below as examples of the research activities currently planned by the expert group Electric Motors.

3 HIGH FLEXIBILITY AND LESS COMPLEXITY IN THE ELECTRIC POWERTRAIN

In contrast to combustion engines, electric powertrains do not need multi-gear transmissions for traction applications due to the electric motor's ability to operate efficiently over a wide speed range. The electric powertrain with single-speed transmission can deliver the required top speed and acceleration while also maintaining a relatively high degree of efficiency for various driving cycles. This configuration is often used in vehicles to reduce complexity and save costs, space, and weight. However, since the load profiles of the various driving cycles (such as in cities, on highways or on country roads) differ significantly, a vehicle with single-speed transmission does not offer the maximum degree of efficiency for every operating range. For example, a conventional electric traction motor has a high constant torque at low speeds and a broad constant speed range. The high torque at low speeds is required for some climbing or towing operations and for rapid acceleration. On the other hand, the conventional driving cycles require operation in the partial load range at medium to high speeds.

The aim of the research project "Superior E-Drive Attributes & Tailored Complexity" is to help identify suitable measures to better balance the trade-offs between torque and operating range in future electric powertrain system design. Expanding the speed range will further enhance customer satisfaction among owners of Battery Electric Vehicles (BEVs), while also bridging the gap between today's combustion engine vehicles equipped with high-tech manual and automatic transmissions.

To avoid compromising or even worsening other attributes of the vehicle at the same time, the measures must concentrate on technological solutions, for example, to raise the electric motor's maximum speed or to incorporate flexible transmission ratios or variabilities in relation to the number of pole pairs/phases of the motor and the control logic. The aim is to reduce the complexity of the topology, improve system efficiency and thus expand the range of BEVs without the need to modify the battery. By identifying the most suitable dimensioning strategy, resources are to be conserved to contribute to sustainability during manufacturing. The envisaged result of the project is a general topology comparison that reveals the optimization levels for the vehicle use cases analyzed. The optimization must meet the specified objectives for the system and properties and support a cost-benefit analysis of the technological solutions. In the process, attention must be paid to certain raw materials that are subject to volatile market situations and pricing.

The planned project "Variable Pole Traction Machines for BEVs" investigates electric motors in greater technical detail, with the aim of expanding the speed range. Due to the high spread necessitated by the differing load profiles, many contemporary electric powertrains feature a design with a high torque density to achieve a high maximum torque. Thus, for most cyclical loads, the motors tend to be oversized. By using multi-speed transmissions, the motor size can be reduced while maintaining the same high starting torque and improving efficiency in the partial load range. To circumvent the implementation of a complex mechanical multi-speed transmission in the powertrain, the integration of a traction motor with variable poles is to be investigated. By using the input signal to change the number of poles while leaving the motor geometry unchanged, the electric motor can work in the same way as a mechanical transmission. The motor design and inverter complexity of such a solution are to be investigated and the benefits of a variable-pole motor as a traction motor to be analyzed. The Asynchronous Motor (ASM) is an ideal starting point for this investigation, as the rotor flux is induced by the stator current and, accordingly, the number of poles of the stator and of the rotor do not need to be controlled individually.

4 ANALYZING BATTERY AGING QUICKLY AND PRECISELY

Upcoming EU regulations stipulate the return and collection of used powertrain batteries, with increasing rates in 2027 and 2030. Targets for reparability, reuse and recycling have also been set, although the precise figures still need adjusting. Accordingly, a high degree of precision when determining the State of Health (SoH) of a battery is essential to make prudent decisions regarding its further use. Alongside the mere precision of the SoH value, which has so far been expressed as a percentage of the rated capacity, the actual power dissipation, and its underlying degradation mechanisms of the inner components of the battery are of great interest.
The registration of traction batteries required by the EU means that automobile manufacturers will have to check the SoH of hundreds of batteries every day and make a quick decision regarding the further use of each individual battery. Current SoH information based on data from the Battery Management System (BMS) is not sufficient for this, as today's capacity and performance tests are not precise enough and/or require too much time. Moreover, the scope of current test methods needs to be expanded from individual cells or modules to cover entire battery packs. It is therefore necessary to develop a rapid test that, on the one hand, offers a much higher degree of precision for SoH information that is not solely based on the current capacity and, on the other hand, provides the very fast results needed for handling high quantities of batteries.

Energy conversion systems			**Sustainable powertrain systems**
Innovative and/or optimized energy conversion systems minimizing environmental impact and maximizing process efficiency and engine performance			Road/rail vehicles: classic powertrains with internal combustion engines, hybrid/electrified powertrains; aircraft engines, marine propulsion; mobile machinery; power systems
▹ Engines	**▹ Electric motors [Interface to E-Motive platform]**	**▹ Fuel cells [Interface to E-Motive platform]**	**▹ Energy storage within the application** **▹ System efficiency** **▹ Air pollution, global warming, noise, sound, radiation** **▹ E-machine combined with battery**
+ All conventional engine development topics	+ Improvement of electric motor properties in mobile applications	+ All conventional topics of fuel cell research	+ Questions on energy storage in the aforementioned applications
+ Optimization and development of new energy conversion processes, for example, focusing increasing process efficiency of future varieties of fuels (including hydrogen)	+ Electrical energy storage systems (battery)	+ Air and hydrogen system path, media conditioning and purification	+ System efficiency of energy conversion processes (charging, system control/regulation, sensor technologies …)
+ Reduction of the environmental impact	+ Power electronics of the electric motor and electrical energy storage system	+ Thermal management of the fuel cell stack	+ Thermal management
+ Process-focused adaptation of related components and (sub-) assemblies	+ Application-focused adaptation of related components and (sub-) assemblies	+ Optimization of fuel cell specific components and (sub-) assemblies (ion exchanger, compressors …"	+ Zero-impact emissions, greenhouse gas emissions (for example CO_2), noise, sound, Electromagnetic Compability (EMC)
+ Effects of increasing electrification to the >engine< subsystem and its aggregates	+ Design and improvement of development tools (simulation tools …), and measurement and testing methods	+ Research on materials/components under fuel cell specific conditions and stresses (bipolar plates, membranes, sealings …) concerning stack performance, loading characteristics, ageing (durability, degradation), humidification …	+ E-machine combined with battery/internal combustion engine **[Interface to E-Motive platform]**
+ Digitalization		+ Improvement of stack performance/efficiency (performance effects of component and assembly tolerances …)	+ Impact of legal, social, and political requirements onto powertrain systems; circularity
+ Design and improvement of development/engineering tools based on changing application/subsystem requirements		+ Safety requirements and definitions	+ Development/engineering of tools such as for the system architecture and interaction of powertrain assemblies
		+ Development of defined evaluation methods towards industry standards (generic, >best practice<)	
		+ Technology comparison Proton Exchange Membrane (PEM), high-temperature PEM, Solid Oxide Fuel Cell (SOFC)	
		+ Design and improvement of fuel cell specific development tools (simulation tools …), and measurement methods (impedance analysis …)	

TABLE 1 Research activities in the field of energy conversion systems and sustainable powertrain systems as well as interfaces to the E-Motive networking platform (© FVV)

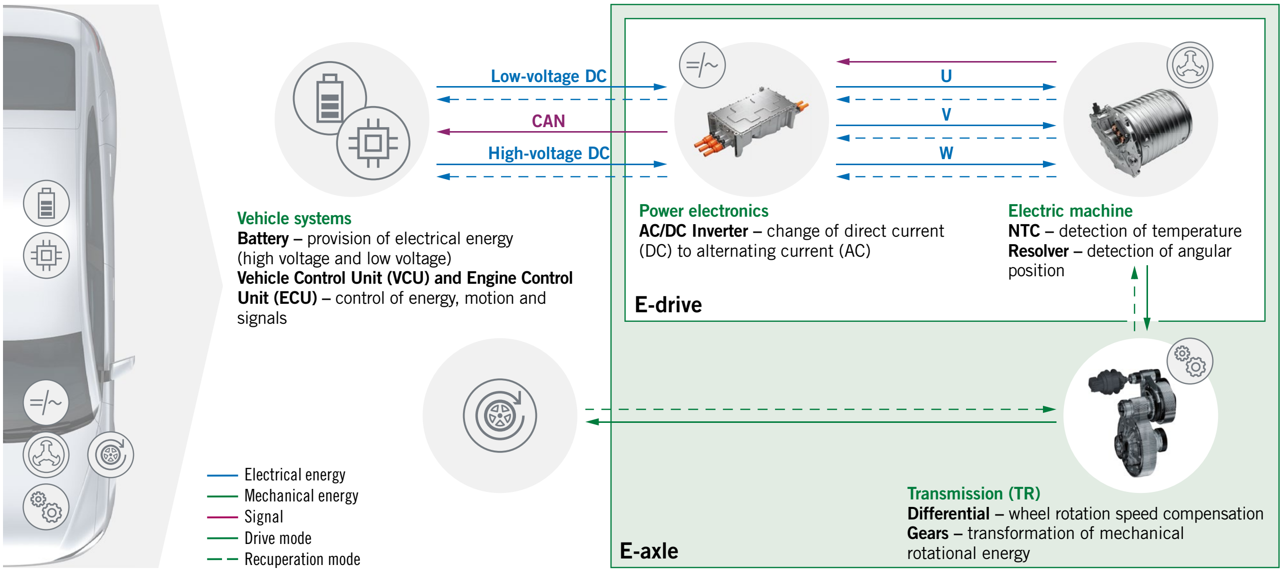


FIGURE 2 Optimization of electromobility as a systemic approach (© Bosch Engineering)

To establish the fast, high-precision and reliable identification of the aging mechanisms, FVV is planning the research project "Detection Quality of Traction Battery SoH," in which a development tool combined with a statistical analysis of battery data and a corresponding test method will be elaborated. Electrochemical Impedance Spectroscopy (EIS) and impulse current testing (so-called Current Injection Test, CIT) appear suitable for this and will be reviewed for achievable accuracy. To handle the number of batteries expected, the method-related test duration per battery must also be shortened considerably. The tests will be combined with a statistical analysis of the data from the BMS and validated by comparing new batteries with specially aged samples. With the corresponding test device, the SoH value should not only be determinable after removing the battery from the vehicle, but possibly already in the vehicle or in the workshop in the installed state.

5 DIVERSIFICATION TO COMBAT CLIMATE CHANGE

The activities of the new Electric Motors expert group harmonize perfectly with FVV's diversification strategy, which considers all concepts for reducing the amount of CO_2 generated by the European transport sector [2]. This strategy is the logical consequence of the results of a broad range of studies in which FVV performed a life cycle assessment of the various technologies. This included all industries that were involved in the entire energy chain, plus research institutions from the fields of technology and business. In total, more than 60 experts from all over the world participated in the studies. The entire "cradle to grave" CO_2 chains were considered, including all energy sources and conversion systems that are currently deemed to offer potential for reducing CO_2 and that are the object of research and development activities at research institutes, engineering service providers or industrial companies. In a nutshell, the series of studies concludes that all CO_2 reduction concepts offer comparable potential, and none particularly stands out, that the speed at which the solutions establish themselves in the market is of existential importance in the fight against climate change, and that diversification makes the transport sector more robust while also taking into account the different needs of a global customer base. FVV will therefore continue to promote all energy sources and conversion systems with the potential to reduce CO_2 in the transport sector and will base its research broadly in accordance with this.

REFERENCES

[1] Destatis (ed.): Straßenverkehr: EU-weite CO_2-Emissionen seit 1990 um 21 % gestiegen. Online: https://www.destatis.de/Europa/DE/Thema/Umwelt-Energie/CO2_Strassenverkehr.html, access: July 6, 2023
[2] FVV (ed.): How we are speeding up the green transformation. Online: https://www.fvv-net.de/en/science/how-we-are-speeding-up-the-green-transformation, access: July 6, 2023