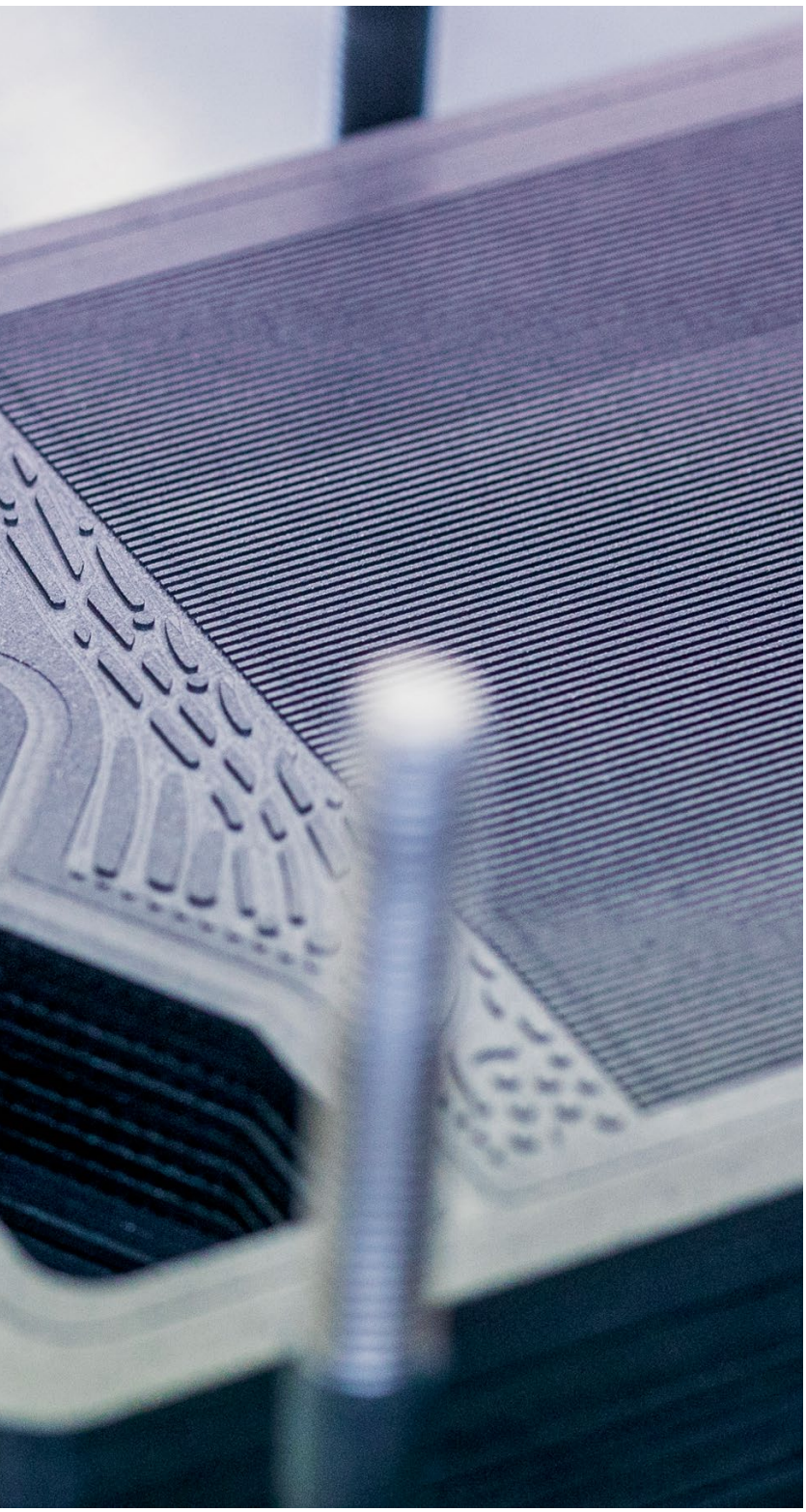
Research for Efficient and Economical Fuel Cells

The multi-faceted mix of future concepts for defossilizing industry and transport also includes energy conversion using fuel cells. Research projects initiated by FVV provide fundamental insights into the future development of highly efficient and economical fuel cell systems which tap into new potential applications.

1 WIDE RANGE OF APPLICATIONS

Used for energy conversion, fuel cells offer the potential to further reduce greenhouse gas emissions in industry and transport. Applications in the transport sector include powertrains for passenger cars and commercial vehicles, both on-highway and off-highway. In industry, fuel cells are chiefly used for stationary power generation. FVV's research projects encompass a wide variety of different fuel cell components enabling companies to develop systems that are perfectly tailored to specific requirements and operating conditions. The research remit includes hydrogen, air and thermal management in the cell, materials and component characteristics, and optimization at stack and system level.



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Dr. Michael Harenbrock is Principal Expert Electric Mobility at Mann+Hummel GmbH.
"Researchers at FVV are working on issues related to fuel cells that are highly relevant to industry. The program we are implementing ensures that all individual projects are interlinked, creating a bigger picture from many individual parts."

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Dirk Weberskirch works in the Advanced Engineering Energy Storage Division at Traton R&D Germany GmbH and coordinates the Fuel Cell Expert Group of FVV e. V.
"FVV's pre-competitive collective research offers an ideal platform for both SMEs and industrial companies to tackle the various fundamental challenges in the design and operation of fuel cell systems from a scientific perspective."

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Jana Müller is Project Manager at FVV e. V. and Expert in Fuel Cell Systems and Components.
"Fuel cells as highly efficient energy converters have been an integral part of FVV's research strategy since 2017. We will continue to initiate important research projects that help companies and institutes make the vision of carbon neutrality and zero-impact emissions a reality – all thanks to efficient fuel cell systems."

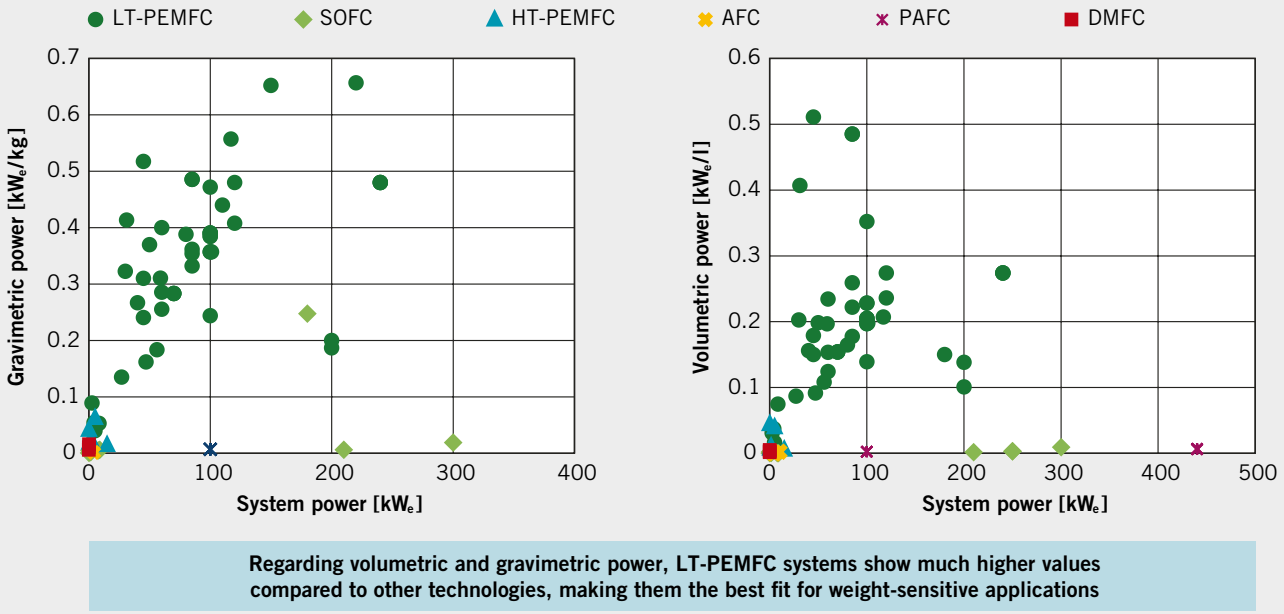


FIGURE 1 Market readiness of different fuel cell systems in 2024 according to their volumetric (left) and gravimetric power (right) (© ICE-2)

2 COMPARISON OF TECHNOLOGIES

The range of applications for fuel cells has seen continual expansion in recent years. Technology development needs to be targeted precisely to meet the new requirements for fuel cell systems. In addition, there are new prospects for possible combinations of fuel cell types and applications that need to be investigated in order to fully exploit the versatility and flexibility of the individual technologies.

As part of the FVV study "Technology Comparison Fuel Cell Technologies" [1] carried out by Jülich Systems Analysis (ICE-2) at Forschungszentrum Jülich, a methodological framework was developed for a quick and easy comparative evaluation of such combinations based on different application scenarios. This allows companies to determine the most suitable technology for their specific requirements right from the conceptual phase of their fuel cell project. The study was based on comprehensive market and literature research, accompanied by interviews with experts. A Pugh Matrix tool developed during the research project enables the collected data to be visualized in a context-based way and additional user functions to be implemented.

The Key Performance Indicators (KPIs) of fuel cells include system efficiency and gravimetric power [kW/kg] and power density [kW/l], **FIGURE 1**. The comparison of technologies shows that Low-temperature Polymer Electrolyte Membrane Fuel Cells (LT-PEMFCs) and Solid Oxide Fuel Cells (SOFCs) offer considerable advantages over other concepts in terms of application-specific performance parameters. These systems also cover a wide range of today's applications, potentially cementing their place among the most important fuel cell technologies into the future. Research projects on LT-PEMFCs look at applications both in the transport sector and in stationary power generation, **FIGURE 2**. Off-grid stationary power generation in large-scale plants remains the most important application of Molten-carbonate Fuel Cells (MCFCs). The need to supply the cathode of MCFCs with CO_2 makes this technology an attractive option for carbon capture projects, especially for on-board power generation for ships. As with SOFCs, the aim is to achieve optimum heat integration. Besides market expansion into the shipping sector, system integration ranks among the most important aspects for Phosphoric Acid Fuel Cells (PAFCs). Direct Methanol Fuel Cells (DMFCs) are less of a focus today, due to the challenges caused by methanol slippage, system service life and cost. Research into Alkaline Fuel Cells (AFCs) is focused on membrane-based electrolytes, electrocatalysts and improving CO_2 tolerance.

Comparing current KPIs with application-specific requirements, MCFCs for marine applications and High-temperature (HT-)PEMFCs for grid-bound stationary applications were identified as feasible solutions for the future, provided that adequate improvements are implemented for individual KPIs. Even though both technologies were categorized in the mid-performance range in the study's technology assessment, both systems offer application-related advantages that make them more favorable than other fuel cell systems, supposing that their performance is improved through future developments.

3 FUEL CELL REFERENCE SYSTEM

Both industry players and academic institutions are currently engaged in extensive research activities on fuel cell systems. While delivering valuable insights and driving technical progress, this work also means that many research findings are protected

by patents or the like, thus restricting or even fully preventing pre-competitive collaboration, particularly that of and with research institutions. The FVV project "Reference System with Generic Fuel Cell Stack" [2] therefore aims to establish a fuel cell system with a polymer electrolyte stack (Proton Exchange Membrane, PEM) to facilitate pre-competitive research and foster the exchange of information. Conducted jointly at the Institute for Applied Hydrogen Research, Electro- and Thermochemical Energy Systems (H2Ohm) in the Systems for Hydrogen Use in Stationary Applications in Energy Technology research group of the Technische Hochschule Nürnberg Georg Simon Ohm and at Chemnitz University of Technology's Institute for Automotive Research, the work is based on the FVV project "Generic Fuel Cell Stack." The current research project takes the stack developed as part of that project and adds the required subsystems (balance of plant) to it to create a complete fuel cell system.

The fuel cell system designed in this project, **FIGURE 3**, will consist of a PEM fuel cell stack (100 kW output), an air supply system, hydrogen recirculation, a cooling loop and electrical connections. While this is a laboratory system not intended for use in vehicles, it can be operated in the typical automotive power range. A detailed system description will be a decisive factor for ensuring a high degree of utilization of the fuel cell concept and making the research results from different institutes comparable. Accordingly, it will encompass parameters such as power output, operating conditions, flow configuration, gas and liquid specifications, leakage rates, and stack interfaces. Other characteristics include operating limits for pressure, mass flow, temperature and stack voltage, and factors such as pressure losses, heat generation, water production and inertization rates. In addition, operating guidelines will be defined for system start-up and shutdown, normal operation, standby, storage, flushing and draining.

Besides the design and description of hardware components, the research work also includes developing the control software for the fuel cell system. To make the system easy to set up and operate, it should preferably consist of commercially available components with a sufficiently high degree of technical maturity. However, it should enable flexible configuration in order to facilitate a wide range of different research focuses. A digital twin of the fuel cell system provides support for system and component design, **FIGURE 4**. The modular design ensures that individual components can be easily exchanged during the simulation. The project began in early 2025 and is scheduled to run until the end of 2026.

4 LIFETIME SIMULATION OF ION EXCHANGE FILTERS

The state of the art for efficiently dissipating the heat generated in fuel cells is to ensure a flow through the bipolar plates using integrated cooling channels. As short circuits must be prevented, dielectric cooling media with low electrical conductivity are used. However, ions washed out of the cooling loop components during operation can contaminate the coolant and increase its conductivity. This effect is influenced by factors such as the composition and temperature of the coolant, the flow velocity and the materials used. Ion exchange filters with a defined capacity are integrated into

FIGURE 2 Current and future areas of application of the fuel systems investigated in [1] and four identified potential technology application pairings (© ICE-2)

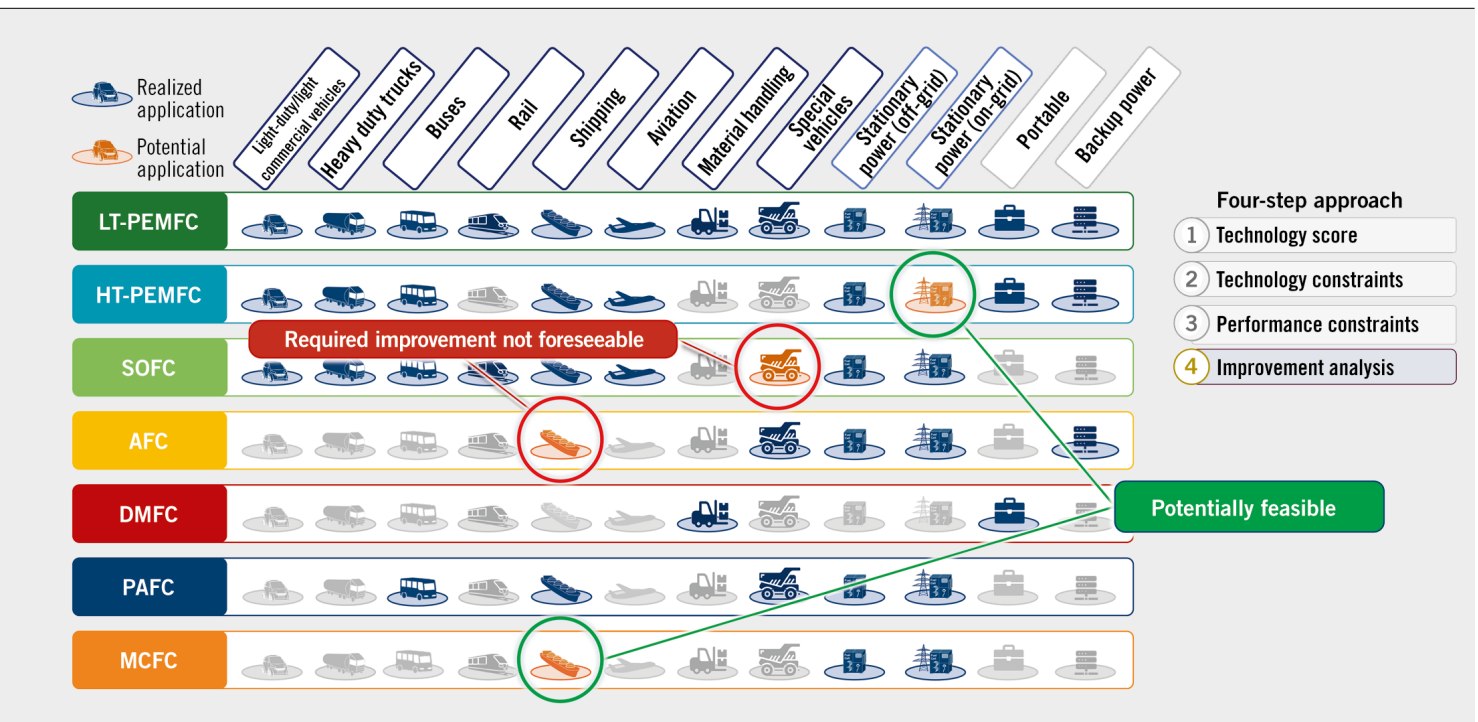


FIGURE 3 Concept of the Fuel Cell (FC) system developed in [2], including balance of plant (simplified representation); HT/LT cooling = high temperature/low temperature cooling (© H2Ohm)

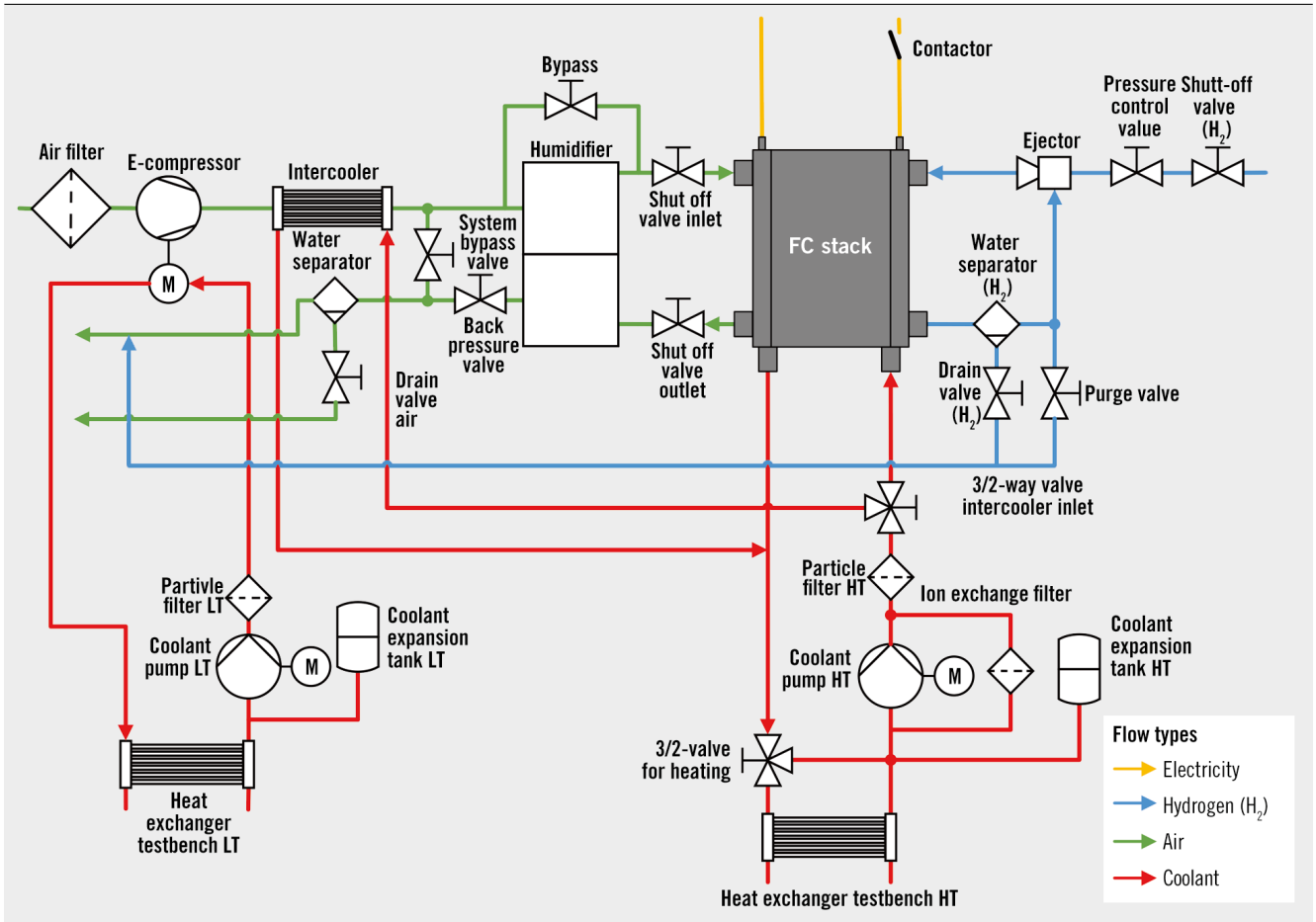
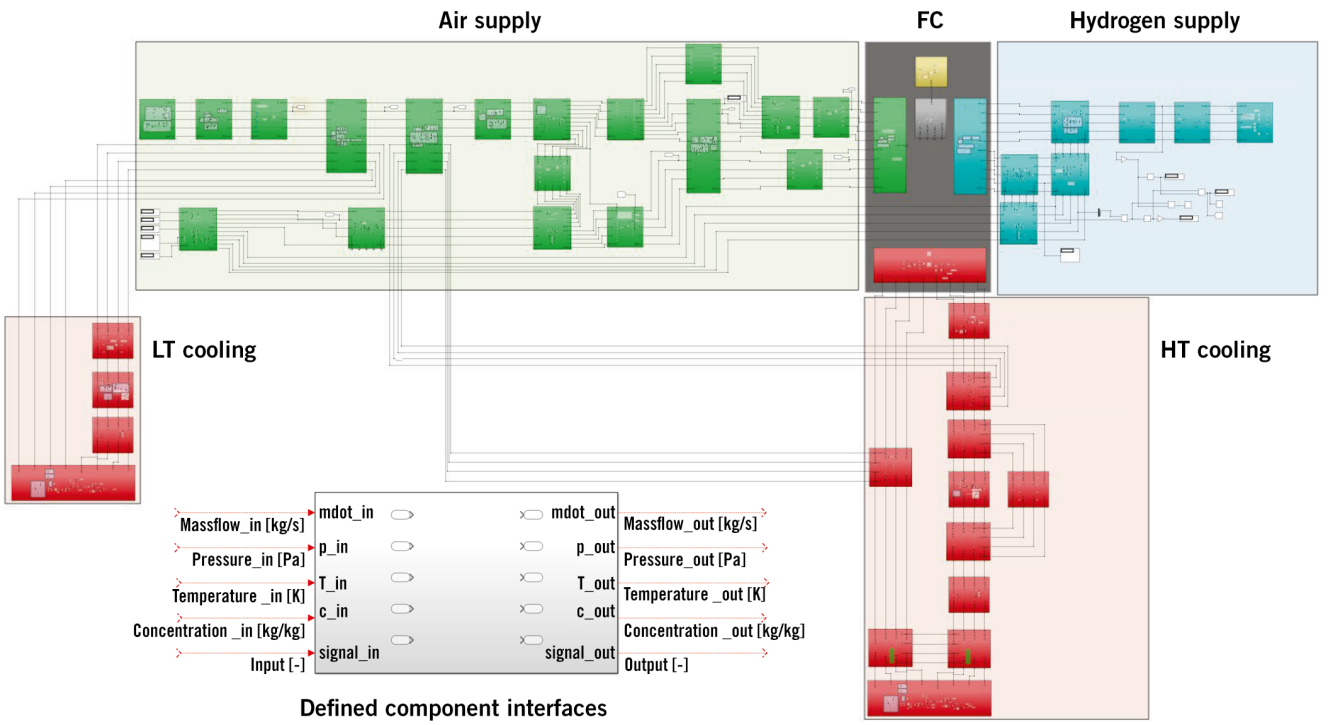


FIGURE 4 System layout of the digital twin for simulations (© H2Ohm)



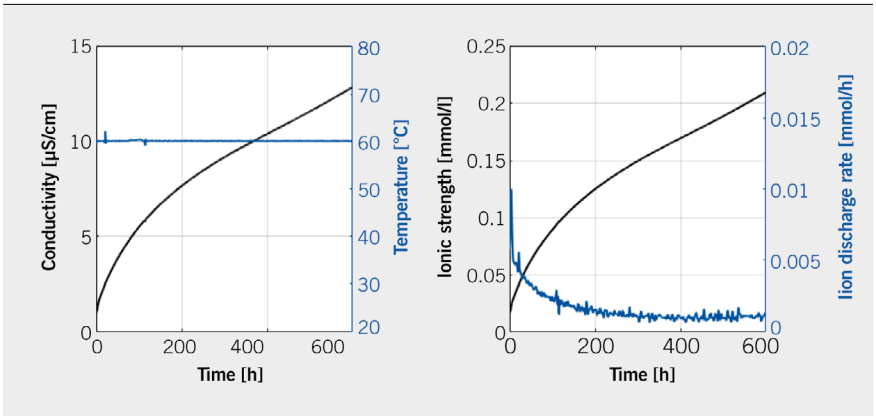


FIGURE 5 Measurement of the increase in conductivity (left) and calculation of the ionic strength and determination of the ion discharge rate (gradient of ionic strength) (right) (© TME)

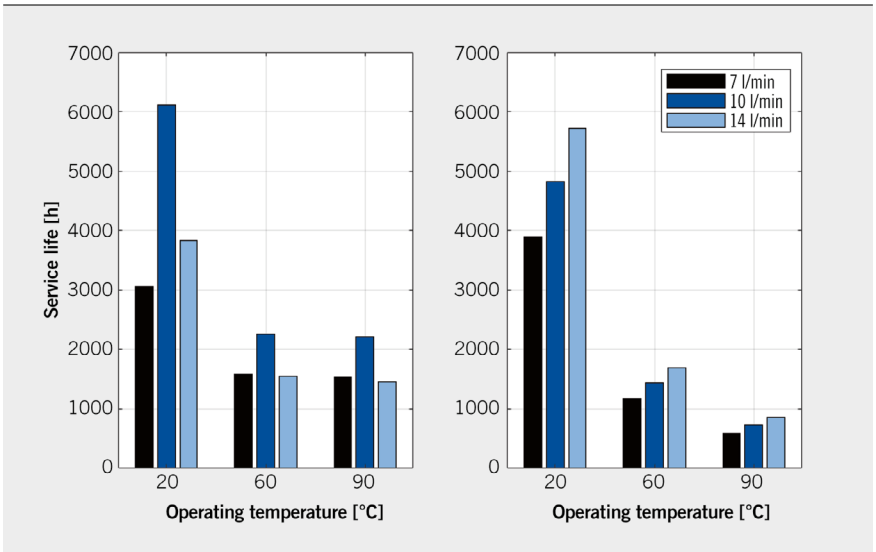


FIGURE 6 Service life of a typical ion exchange filter at coolant temperatures of 20, 60 and 90 °C and flow rates of 7, 10 and 14 l/m as a result of data-based simulations (left) and solely based on physical determination (law of diffusion) (right) (© TME)

the cooling loops to keep conductivity at a low level in the long run. Nevertheless, the mechanisms that contribute to an increase in conductivity have yet to be identified or quantified.

Funded by the German Federal Ministry for Economic Affairs and Energy (BMWE) as part of the Industrial Collective Research (IGF) program, the research project "Lifetime Simulation of Ion Exchange Filters" [3] is geared towards providing a knowledge-based estimation of the service life of an ion exchange filter. A simulation model was set up for this, taking into account various parameters such as temperature, coolant composition, flow velocity and materials used. Research activities were conducted at the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University and at the premises of OWI Science for Fuels.

In order to quantify the basic parameters of ion discharge, the first step was to define the experimental constraints. After several preliminary tests, a mixture of ethylene glycol and demineralized water (50/50 vol.%) was used as the coolant. Static exposure tests with materials including polypropylene, cast aluminum and steel were conducted at various temperatures to determine the temperature dependency of the ion discharge. In addition, tests on individual components were conducted under laminar and turbulent flow conditions. Finally, a cooling loop similar to the actual system was set up to measure how the flow velocity affects the increase in conductivity, **FIGURE 5**.

The model for calculating ionic strength was developed based on the findings from literature research and physical tests. It is used to set up individual coolant loops and to assess how factors such as material selection, operating temperature, flow velocity and coolant composition can influence the service life of the ion exchanger, **FIGURE 6**. The simulation model is supplemented by a material database, enabling targeted material selection during the design phase of the cooling system. Built-in tools are intended to facilitate the development, design and optimization of ion exchange filters in the future.

5 CONCLUSION

Fuel cells may very well play a key role in defossilizing industry and transport. However, there are still a few hurdles to overcome in the technology's development before it is suitable for broad market use. With the results of its research projects, FVV is creating a pathway for the targeted development of future fuel cell systems. The research findings enable companies of all sizes, but most of all small and medium-sized enterprises (SMEs), to increase the efficiency and profitability of future fuel cells and widen their range of applications.

REFERENCES

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[2] FVV research project: "Design of a reference system with the generic fuel cell stack of FVV and representation of the most important operating parameters and a reference cycle." Coordinator: Dirk Weberskirch (Traton R & D Germany GmbH). RTD performer(s): Prof. Dr. Florian Uhrig (H2Ohm, TH Nürnberg) and Prof. Dr. Thomas von Unwerth (Institut für Automobilforschung, Chemnitz University of Technology)

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