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Fuel cell plug-in hybrids: Long-distance emobility with batteries and fuel cells

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Summary

Fuel cell plug-in hybrids combine the advantages of batteries and fuel cells – short driving distances are covered in battery electric operation, a downsized, low cost fuel cell system enables long distance emission free mobility and short refuelling times. A consortium of industry and R&D partners developed a compact 30 kW fuel cell system and integrated it into a battery electric vehicle as a functional demonstrator. The paper focuses on the development of the automotive stack that features metallic bipolar plates with an active area of 300 cm² and achieves high performances of more than 1.0 W/cm² without cathode humidification.

Keywords: fuel cell vehicle, PHEV, PEM fuel cell

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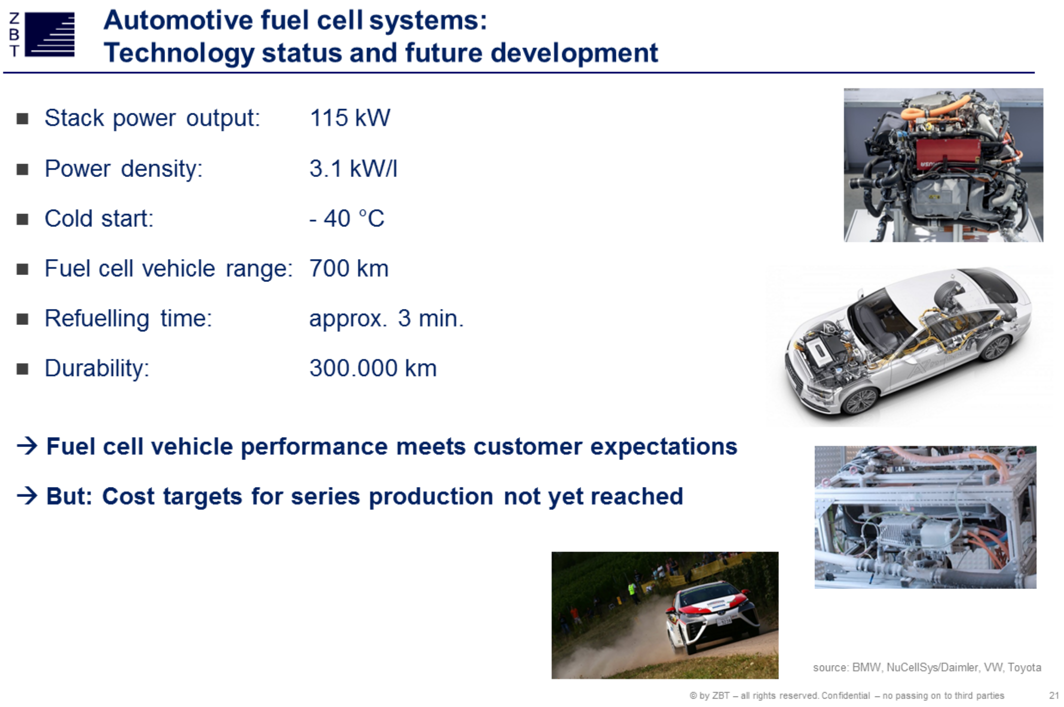
1 Motivation

Fuel cells enable emission free long-distance emobility and short refueling times. Significant technological progress has been made over the last years. High-performance MEA and thin metallic bipolar plates enable extremely compact fuel cell stacks, since the year 2000 the volumetric power density has increased by the factor of six from 0.5 kW/l to more than 3 kW/l ([1], [2]). Freeze start capability has been demonstrated down to -40 °C [3], the vehicles achieve a driving range of up to 366 miles [4], refueling is possible within minutes [2]. Current fuel cell vehicles meet the customer's requirements, however for a widespread market introduction, further cost reductions are necessary.

The fuel cell vehicles that are currently introduced into the market by the different OEMs feature a high performance fuel cell stack in the power range of 80-120 kW and in most cases a small battery system of approx. 1-2 kWh for braking energy recuperation [5].

But different options exist for the dimensioning of battery and fuel cell system in a hybrid powertrain configuration. A fuel cell plug-in hybrid covers short driving distances in battery electric operation, a downsized, low cost fuel cell system enables long-distance emission free mobility and short refueling times and is dimensioned for the average vehicle power demand up to motorway speeds. In cooperation with the partners FEV, Gräbener Maschinentechnik and RWTH Aachen University within the project BREEZE, ZBT has developed such a fuel cell plug-in hybrid electric vehicle that combines the advantages of battery and fuel cell.



Automotive fuel cell systems:
Technology status and future development

- Stack power output: 115 kW
- Power density: 3.1 kW/l
- Cold start: - 40 °C
- Fuel cell vehicle range: 700 km
- Refuelling time: approx. 3 min.
- Durability: 300.000 km

→ Fuel cell vehicle performance meets customer expectations

→ But: Cost targets for series production not yet reached

source: BMW, NuCellSys/Daimler, VW, Toyota

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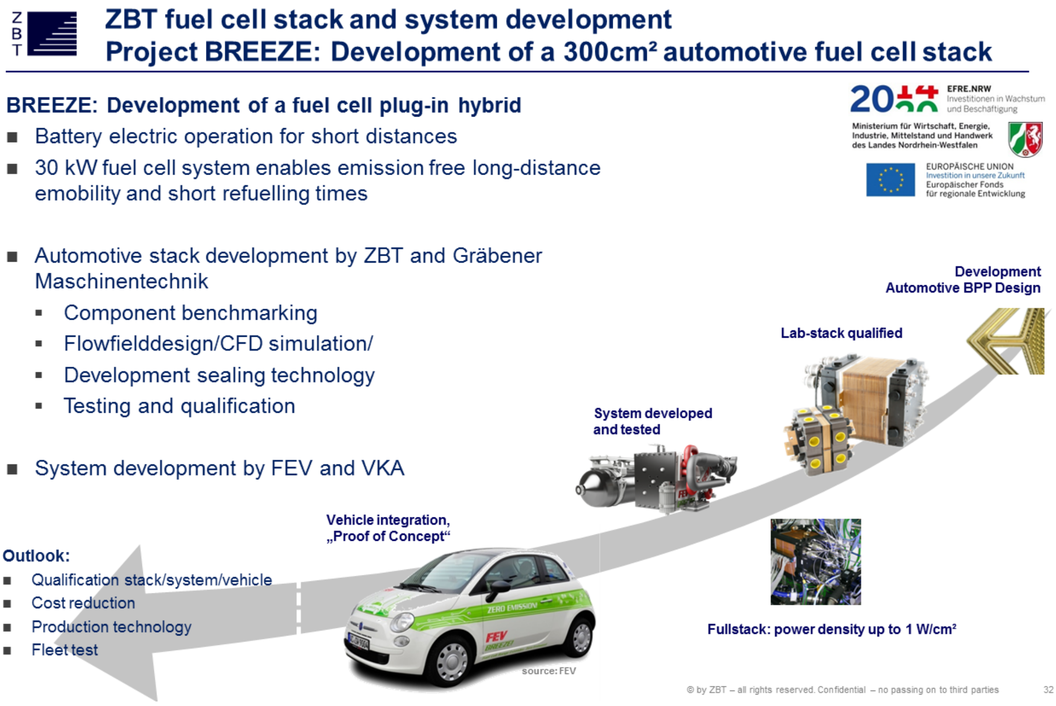
Figure 1: Technology status fuel cell systems for automotive applications (sources: Toyota, Honda, NuCellSys/Daimler, VW)



ZBT fuel cell stack and system development
Project BREEZE: Development of a 300cm² automotive fuel cell stack

EFRE.NRW
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EUROPÄISCHE UNION
Investition in unsere Zukunft
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BREEZE: Development of a fuel cell plug-in hybrid

- Battery electric operation for short distances
- 30 kW fuel cell system enables emission free long-distance emobility and short refuelling times

- Automotive stack development by ZBT and Gräbener Maschinentechnik
  - Component benchmarking
  - Flowfielddesign/CFD simulation/
  - Development sealing technology
  - Testing and qualification

- System development by FEV and VKA

Development Automotive BPP Design

Lab-stack qualified

System developed and tested

Vehicle integration, „Proof of Concept“

Fullstack: power density up to 1 W/cm²

Outlook:

- Qualification stack/system/vehicle
- Cost reduction
- Production technology
- Fleet test

source: FEV

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Figure 2: Project BREEZE: Development of a fuel cell plug-in hybrid demonstrator

2 Development of an automotive fuel cell stack at ZBT

The target vehicle for the project is a subcompact class Fiat 500 vehicle. The Li-ion battery is installed under floor, the fuel cell system is packaged behind the rear axle in the area of the spare wheel compartment, and the hydrogen tank is installed in the packaging space of the original fuel tank. With this packaging arrangement the vehicle integration can be performed without restrictions to passenger and payload compartment.

Figure 3: BREEZE demonstrator vehicle and fuel cell system integration (source: ZBT/FEV [6])

For the integration in the spare wheel compartment, the 30 kW fuel cell system has to be extremely compact. To realize this, different approaches were taken in the project:

- Development of a high performance stack with a power density of more than 1 W/cm², metallic bipolar plates and a cell pitch of 1.2 mm (volumetric power density of the active stack parts: 3.5 kW/l)
- Dedicated stack design that allows elimination of cathode humidification to reduce overall system cost and packaging space
- Utilization of compact, low cost automotive components (e.g. coolant pump, electrically driven automotive radial compressor, hydrogen metering device, sensors and valves)
- Integration of balance-of-plant components into cast-aluminum endplates

The finalized system is shown below.

Figure 4: BREEZE fuel cell system (source: FEV [6])

The different development steps to realize the high performance automotive stack are described in the following chapters

2.1 Component benchmarking

At the beginning of the development a detailed benchmarking of available membrane electrode assemblies (MEA), sealing materials and coatings for the metallic bipolar plates was performed. ZBT has developed a standardized test cell based on commercially available test hardware that allows the in-situ benchmarking and investigation under realistic automotive operating conditions with metallic bipolar plates at power densities of more than 1.2 W/cm². An active area of 25 cm² enables testing also of early-development phase components that are available only in small sample sizes.

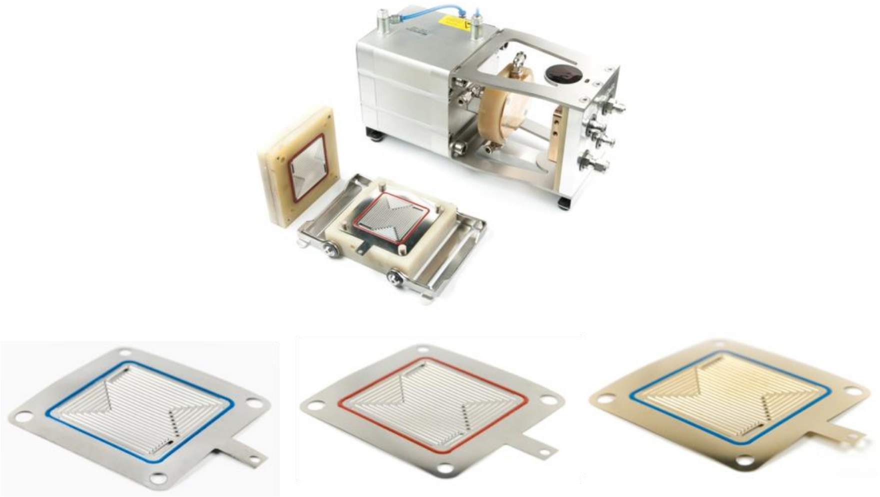

Figure 5: ZBT in-situ test cell with metallic bipolar plates for performance and durability testing of cell components

In the ZBT test cell, different coatings for metallic bipolar plates are analysed regarding initial cell performance and 1 kHz impedance. While some coatings still have a higher contact resistance resulting in a reduction of cell performance, there exist precious metal free low cost coatings that show the same cell performance than the reference PVD gold coating. In order to also qualify the durability of the coatings, accelerated in-situ stress test protocols have been developed by ZBT.

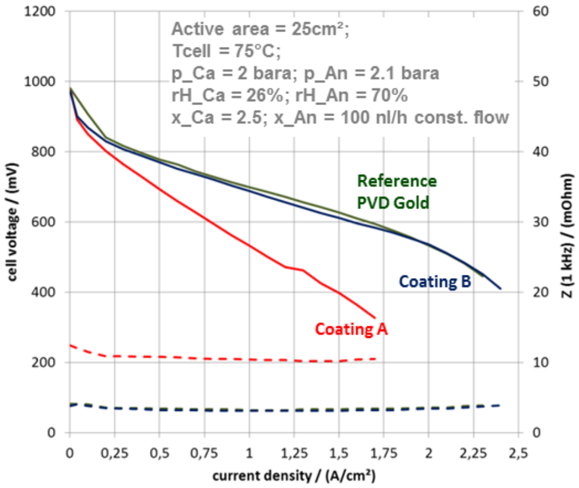

Figure 6: In-situ benchmarking of coatings for metallic bipolar plates

In order to eliminate the external cathode humidifier from the fuel cell system, also commercial MEA were tested in-situ to analyse their performance for dry cathode air supply. The tests clearly show that by selecting suitable MEA in combination with an adapted flow field design and an optimized anode water management, the performance can be significantly increased.

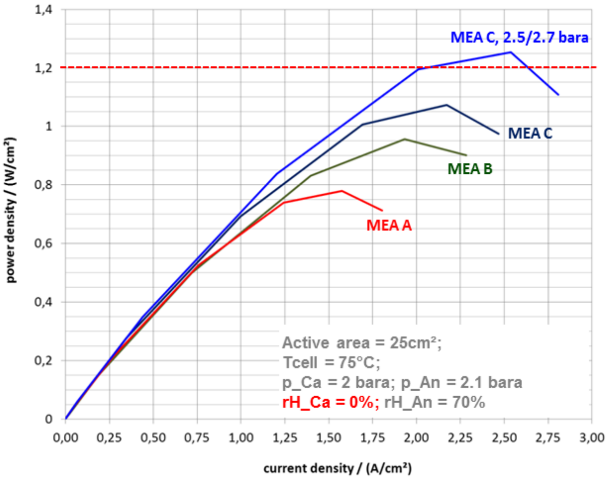

Figure 7: In-situ benchmarking commercial MEA

2.2 CAD flow field design

Based on the benchmarking results the CAD design for the high performance automotive stack was developed. The close involvement of the manufacturing partners for MEA, bipolar plate and sealing as well as the system developers is important to ensure a production-optimized design. The specific packaging situation of the BREEZE project required a square bipolar plate design that is shown in figure 8. In order to ensure homogenous flow distribution of air, hydrogen and coolant, and to optimize liquid water management, CFD simulations have been performed.

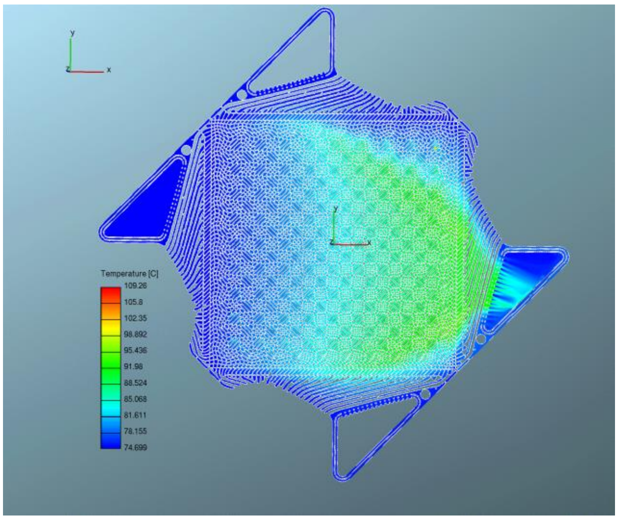

Figure 8: CFD simulation BREEZE flow field design

Besides CFD simulations, ZBT also performs µ-PIV (Particle Image Velocimetry) measurements in order to measure the flow distribution in the single channels of the fuel cell. It is possible to measure the real flow in a cell including the interaction with a GDL by including an optical access in the channel areas of a specifically designed test cell. The results from the flow measurements allow a validation of the CFD simulations (a comparison between CFD simulation and µ-PIV measurements is shown in figure 10).

Figure 9: ZBT µ-PIV flow laboratory

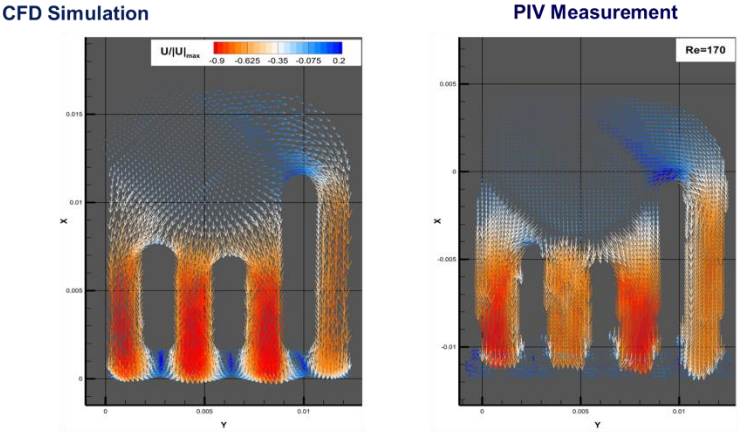

Figure 10: Comparison of CFD simulation results and µ-PIV flow measurements

2.3 Rapid prototyping of flow field design

The manufacturing of metallic bipolar plates requires tooling for hydroforming or stamping of the very thin (50-100 µm) metal sheets. Since the development and manufacturing of the tooling is time consuming and costly, the performance of cell designs is validated at ZBT in rapid-prototyping tests, where different metallic bipolar plates design variants are milled in graphitic bipolar plates. Using dedicated micro-milling machines, it is possible to reproduce the metallic bipolar plate designs in graphite, including all necessary bending radii and draft angles.

Rapid prototyping allows fast design iterations with which the performance of the flow field design for the specific dry cathode operating conditions could be increased significantly for identical operating parameters and MEA (compare figure 12).

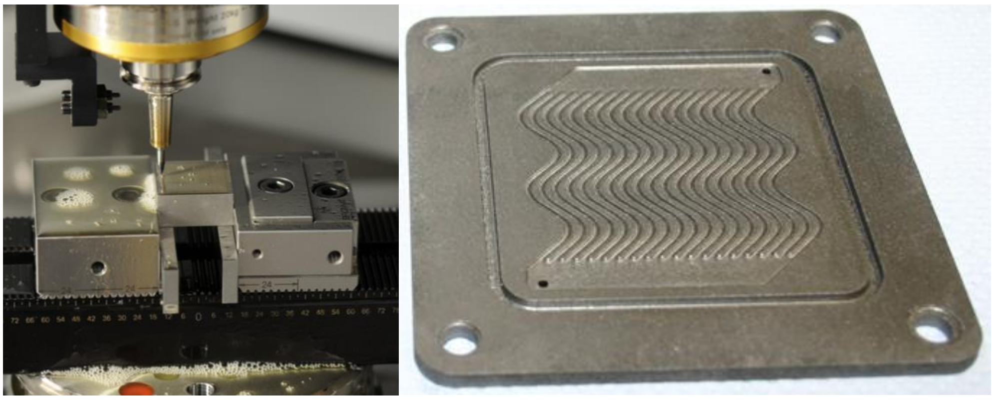

Figure 11: Rapid prototyping of flow field designs by micro-milling

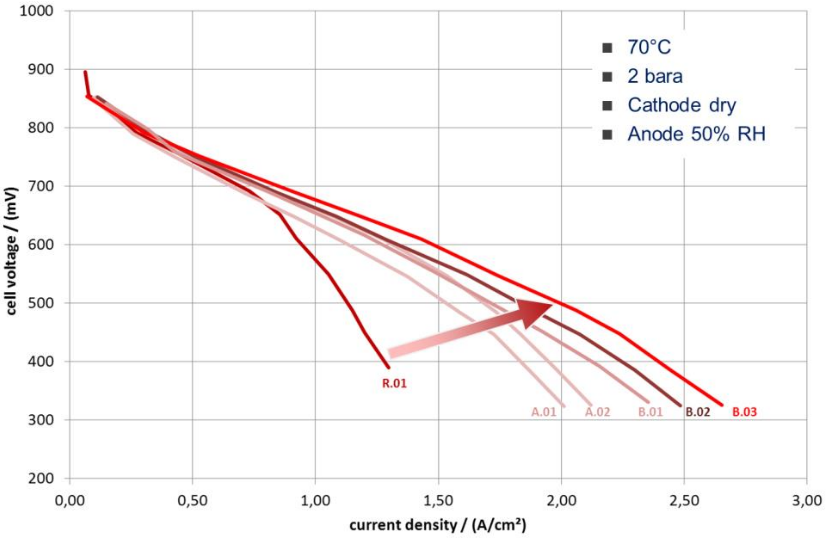

Figure 12: Results rapid prototyping flow field performance optimization

2.4 Sealing application

The sealing of the bipolar plates has to ensure both a leak tight stack under a wide range of operating conditions (thermal loads, gas pressures, shock and vibration) as well as an optimized contact pressure between the lands of the flow field and the GDL for optimum cell performance. ZBT uses screen printing, injection molding and dispensing for the application of seals on bipolar plates. For the specific automotive stack design, a dispenser based sealing solution was developed and applied on the bipolar plates that provides excellent leak tightness and high cell performance. Dispensing has the advantage that it doesn't require tooling, provides high design flexibility and allows the utilization of a wide range of materials. Complex geometrical sealing structures and gas-bubble free sealings can be realized and the cycle times are faster than injection molding, allowing the dispenser process to be scaled up from prototype production to large series production.

Based on the development within the BREEZE project, ZBT has set up a technical center for sealing application, supporting different stack manufacturers with the development and application of dedicated sealing solutions.

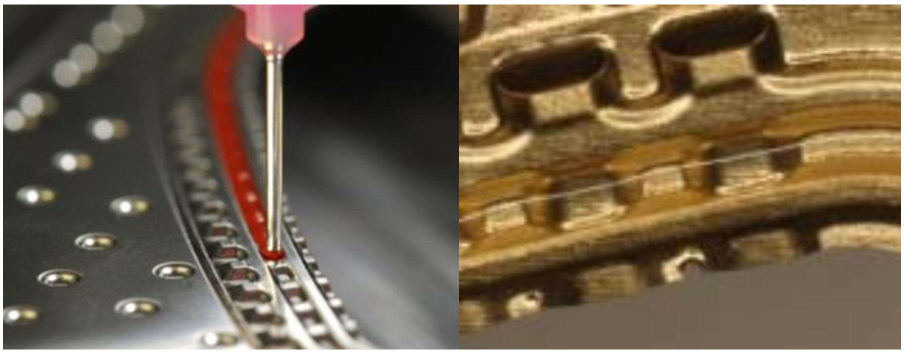

Figure 13: Dispenser based sealing development and application / gas bubble free sealing design

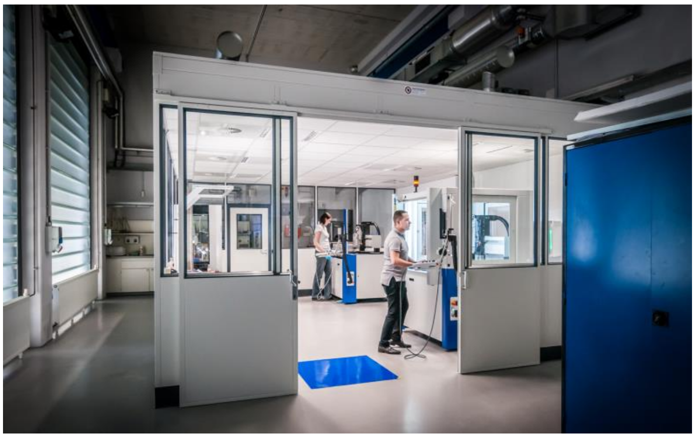

Figure 14: ZBT technical center for sealing application

2.5 Testing and qualification

Performance and durability of the BREEZE automotive stack design were investigated in short stack, full stack and system tests at ZBT. Based on the flow field design optimization within the 25 cm² rapid prototyping, a 100 cm² active area design was realized for laboratory testing purposes, with which the results from the 25 cm² tests could be validated. Then the performance could be successfully scaled up to the final bipolar plate design with 300 cm². Without using cathode humidification and with the constraint that anode and cathode had the identical design due to the project’s constraints regarding tooling cost, an excellent performance was achieved with the BREEZE automotive fuel cell stack, exceeding power densities of 1.0 W/cm².

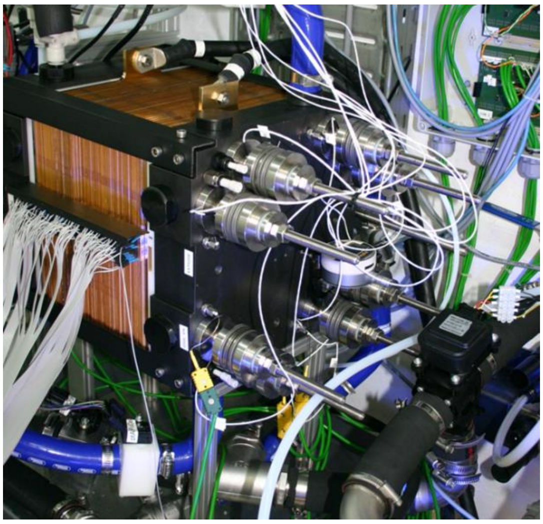

Figure 15: Performance testing of BREEZE 150 cell stack

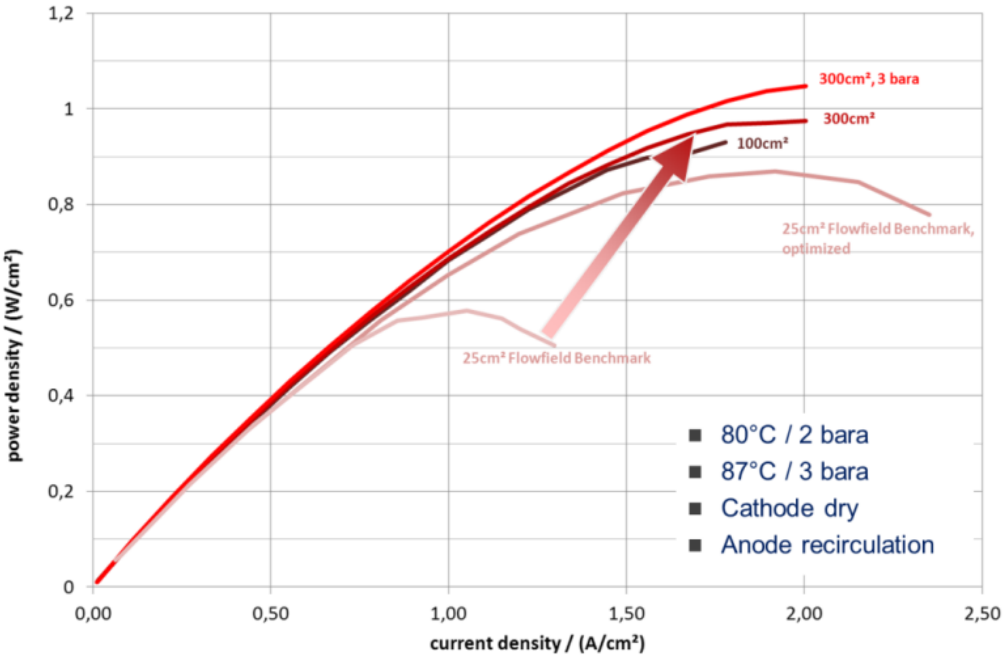

Figure 16: Increase of power density during scale up of BREEZE automotive stack design development

3 Conclusion

In cooperation with partners, ZBT has developed a fuel cell plug-in hybrid electric vehicle that combines the advantages of battery and fuel cell. The vehicle covers short driving distances in battery electric operation, a downsized, low cost fuel cell system enables long-distance emission free mobility and short refueling times and is dimensioned for the average vehicle power demand up to motorway speeds.

Two high performance automotive stack designs were realized in the project, covering a power range of 2-10 kW (V2-100 stack) and 6-75 kW (V1-300 stack). The high performance stacks with metallic bipolar plates are available from ZBT as testing and evaluation platforms for automotive fuel cell stack and system developments.

Table1: BREEZE automotive stack designs

	V2-100	V1-300
Power range	2-10 kW	6-75 kW
Power density	0.9 W/cm²	1.0 W/cm²
Active Area	92 cm²	300 cm²
Cell size	175x175 mm	267x267 mm
Cell pitch	1.2 mm	1.2 mm
Cooling	liquid	liquid
Cathode humidification	not required	not required
Cell components	different MEA, coating and sealing options available	different MEA, coating and sealing options available

Acknowledgments

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