

# German Developments in Fuel Cell Technology

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**Abstract :** Within Europe Germany has the strongest political and economic commitment to fuel cell technology as exemplified by a ten year funding scheme of € 0.7 billion in total, which will end in 2016 but is already confirmed to be renewed. Daimler as one of world's leading fuel cell companies is now accompanied by BMW and Volkswagen/Audi, who have re-entered the fuel cell business based on strong international co-operations. Regarding stationary fuel cells, German companies have decided to strongly rely on Japanese technology and have already started entering the market. Backed by these market developments, German component suppliers are also re-entering the market after having reduced their activities over the last years. Concurrently, manufacturing and plant engineering companies are increasingly more active in technology development. With respect to niche markets such as material handling and back-up power but also regarding portable devices and military applications, German companies have faced difficult years recently, with very reluctant implementation of fuel cell technology. However, recently examples, projects and installations are creating new research and market optimism.

**Key Words :** Fuel cell technology, Infrastructure, Automotive, Stationary, Niche markets, Components, Production

## 1. Background

Due to its historically strong automotive industry and the long-term involvement of Daimler in fuel cell (FC) technology since the early 1990s, German industry is amongst the leaders in the FC market. A highly committed political environment and vision supports this market position with, as long ago as 2006 the two ministries responsible for transport (BMVI) and economy (BMWI) agreeing on a ten year FC technology funding programme<sup>1)</sup>. Furthermore, the German ministry for research and education (BMBF) has also provided notable funding for FC and hydrogen technology development. Thus based on this support, German FC science was able to make good R&D progress, involve suppliers and attract niche market applications. Further finance mechanisms have recently been confirmed, for example a € 160 million program for the next three years, but exact details are not yet confirmed<sup>2)</sup>.

## 2. Mobile Fuel Cells

The German automotive industry is strengthening its know-how via international co-operation. A well-known example of this is the Automotive Fuel Cell Co-operation (AFCC; Vancouver, Canada). This is a joint venture from Daimler AG and the Ford Motor Company. Through this venture, the Daimler/AFCC/NuCellSys partnership has established a long-term development for FC electric vehicles. Here, AFCC is responsible for cell and stack development whilst NuCellSys concentrates



Fig. 1 Daimler B-Class F-Cell. Fraunhofer ISE is operating two F-Cells since 2003.

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on the FC system design. Concurrently, Daimler AG and Mercedes-Benz Fuel Cell (Vancouver, Canada) focus on production technologies. Recently, Daimler announced the forthcoming market introduction of a FC-powered GLC class sports utility vehicle in 2017, with sales beginning in 2018. This is the first time a concrete vehicle model has been named by Mercedes<sup>3)</sup>.

BMW entered a co-operation with Toyota and implemented testing facilities and recruited staff over the last years, but has not officially announced a time schedule for market introduction. A demonstration BMW 5 Gran Turismo model was unveiled to the public in 2015<sup>4)</sup>. The Volkswagen group is co-operating with Ballard (Burnaby, Canada) via a consulting contract, whilst Audi AG has purchased intellectual property from Ballard in 2015<sup>5)</sup>. Over the last years, Volkswagen has presented several demonstration models within the HyMotion series. Last year, Audi presented a FC-powered vehicle based on the A7 Sportback h-tron. Latest news announced that Audi will push forward the fuel cell vehicle development within the Volkswagen group.

Within Europe, German FC companies play a leading role, as exemplified by the European project consortium AutoStack-CORE. This project focuses on the development of a state of the art automotive Polymer Electrolyte Membrane (PEM)-based FC stack and as a consequence encourages European harmonization activities concerning test protocols for Membrane Electrode Assembly (MEA) testing<sup>6)</sup>.

Several FC buses are in operation in Germany, especially in Hamburg and Cologne, but mainly for demonstration purposes. There is currently only one German FC bus manufacturer: Daimler AG / Evobus GmbH (Mannheim). Regarding current developments, also the MAN group has signed a letter of understanding with European FC bus manufacturers, in which they promise to produce 500 to 1000 FC buses before 2020<sup>7)</sup>. Regarding the Small-to-Medium sized enterprise (SME) level, the company Proton Motor is delivering stacks and propulsion technology to Czech developer Skoda Electric<sup>8)</sup>.

Further FC development or demonstration projects in Germany are targeting applications including range ex-

tenders as well as auxiliary power units for cars, trucks, ships, or airplanes. In general these systems are still under development and it is not foreseeable when they will reach product status.

At the national level, FC automotive stakeholders in Germany are organized in a grouping referred to as the Clean Energy Partnership, in order to connect expertise and know-how in preparation for further market development.

## 3. Hydrogen Infrastructure

Perhaps the key to success in FC mobility applications is the implementation and installation of hydrogen infrastructure. Therefore, in October 2015 the H2Mobility group was founded, composed of stakeholders from the gas industry, operators of filling stations and Daimler AG as automotive Original Equipment Manufacturer (OEM)<sup>9)</sup>. The target of this group is the installation of 50 public hydrogen refilling stations (HRS), to be in operation by the end of 2016 and 400 stations by 2023. At the time of writing, there are 19 HRS in operation<sup>10)</sup>. An overview of installations and an online indication of operation status are provided by the Clean Energy Partnership web tool<sup>11)</sup>.



Fig.2 Freiburg solar hydrogen filling station at Fraunhofer ISE. Photovoltaic modules generate power and a PEM electrolyser and produces hydrogen at 30 bar. The hydrogen then is compressed and pre-cooled so that the dispenser operates according to the SAE J2601 protocol. Slow fill at 350 bar is possible. The filling station is approved by German CEP.

## 4. Stationary Fuel Cells

Utility and micro-Combined Heat and Power ( $\mu$ CHP)

companies initiated the "Initiative Brennstoffzelle" to co-ordinate marketing and harmonization activities for stationary FCs in Germany. Analogously to the automotive industry, most FC/ $\mu$ CHP companies have decided to push forward with their developments based upon international co-operations. Most companies intend to start sales in 2016 at the latest. Field test experience was gained via the funded project Callux, based on the use of 474 FC installations<sup>10)</sup>.

Buderus and Junkers, subsidiary brands from Bosch Thermotechnik, have integrated solid oxide (SO) technology from Aisin Seiki and Kyocera for their FC unit<sup>12)</sup>. Senertec / BAXI Innotech collaborate with Toshiba Fuel Cell Power Systems regarding PEMFC technology. Vailant is currently using German technology, namely a SOFC stack from the firm Sunfire (Dresden). Viessmann and Panasonic have joined efforts to market a PEMFC-based  $\mu$ CHP plant. Additionally Viessmann has acquired the assets of HEXIS (Switzerland) to develop an additional SOFC model. Ceramic Fuel Cell, a former Australian company with a German subsidiary, was recently acquired by the Italian company Solid Power, with the aim to develop further  $\mu$ CHP units based on SOFC technology<sup>13)</sup>.

While the above mentioned companies address the FC power range around 1 kW<sub>el</sub>, the Munich based company Elcore favors a high temperature PEMFC operating at 300 W<sub>el</sub> to cover the base load of a typical one family house in Germany. In contrast, inhouse Engineering, based in Berlin, offers a 5 kW<sub>el</sub> low temperature PEMFC for multi-family houses or small industries. Both SMEs

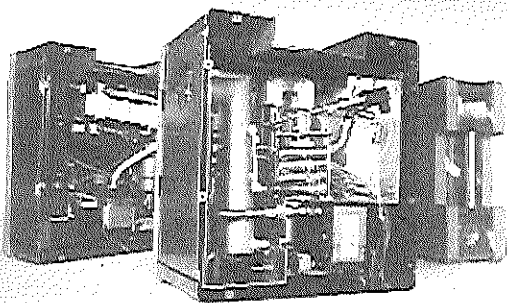


Fig.3 Prototype development for a stationary fuel cell system fueled by ethanol. Fraunhofer ISE.

develop their own proprietary FC technology.

In the high power range (i.e. 50 kW<sub>el</sub> to several MW<sub>el</sub>), some companies in Germany are currently promoting their developments: Sunfire offers demonstration units for Power-to-Gas (PtG) or Power-to-Liquid applications based on German Staxeras SOFC stack technology. Fuel Cell Energy Solutions, a joint venture between the American Fuel Cell Energy company and the German institute Fraunhofer IKTS, offers Molten Carbonate FC power plants, operating between 250 kW<sub>el</sub> and 60 MW<sub>el</sub>, as reliable power sources for industrial customers and utilities. Fuel Cell Energy has successfully installed over 300 MW<sub>el</sub> worldwide<sup>14)</sup>. Etogas (formerly known as SolarFuel) offers turn-key ready PtG plants. For example, Etogas has successfully implemented a 6.3 MW<sub>el</sub> Power-to-Methane plant in co-operation with Audi's e-Gas project<sup>15)</sup>.

## 5. Fuel Cells in Niche Markets

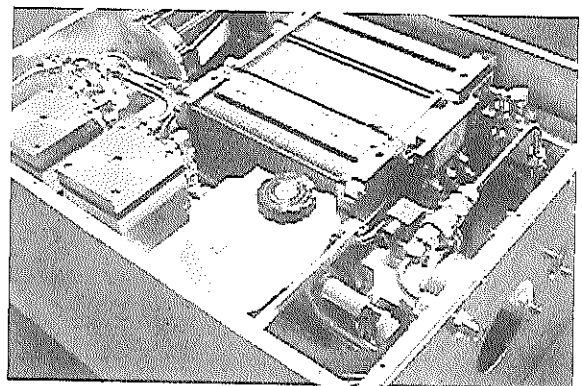


Fig.4 Fuel cell system for an energy autonomous telecommunication station. Development of Fraunhofer ISE within a French-German co-operation (RENESTA).

Niche markets were traditionally referred to as "special markets" within German funding programs. Within these markets, companies are organized typically within the "Clean Power Net" or Verband Deutscher Maschinen-und Anlagenbau FC networks. A wide range of applications are addressed mostly by SMEs, including camping, military, and portable devices. Currently, FCs for material handling and back-up power as well as different applications at airports are envisioned. Well-known niche market companies include: Bosch Engineering (PEMFC

for off-road vehicles), ElringKlinger (PEMFC; with Austrian Fronius for material handling), eZelleron (micro-SOFC for handhelds), Heliocentris / FutureE (PEMFC for back-up power), new Enerday / ElringKlinger (SOFC for boats and leisure), Proton Motor (PEMFC for back-up power and range extenders), SFC Energy (Direct Methanol FC for portable devices, camping and military). Whilst SFC Energy has already sold over 34,000 FC products<sup>16)</sup>, the other mentioned companies are still at the early market phase.

## 6. Components

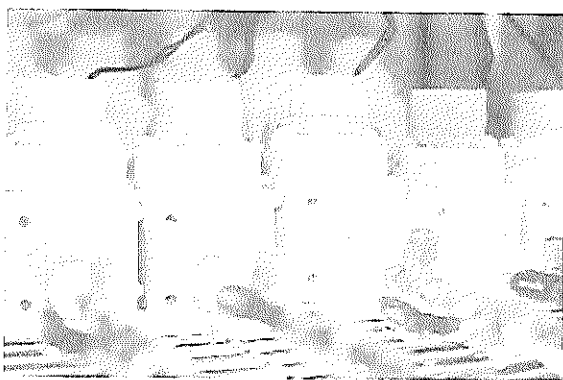


Fig.5 Testing of hydrogen valves at extreme climate conditions by Fraunhofer ISE.

Traditionally, German automotive suppliers from Tier 1 to 3 have a strong global market position and it seems the majority of these companies are now re-assessing their strategy towards FC vehicles after some years of reluctant investment. This covers products including valves, pumps, compressors, sensors, tubing, and system control units.

Regarding PEMFC electrodes, the joint venture of Solvay and Umicore SolviCore was acquired in 2015 by the Japanese company Toray and has been renamed as Greenerity. Besides this, Heraeus and Merck have announced catalysts, electrode and MEA developments aiming at automotive applications. BASF was engaged in high temperature PEMFC development. The only German membrane developer is currently FuMA-Tech, a company of the Austrian BWT Group.

Within the field of bipolar plates, the automotive sup-

pliers Reinz and ElringKlinger currently offer technology. SME Graebener Maschinentechnik and the German subsidiary of Belgium firm Borit, target also additional markets. After Schunk closed their bipolar plate activities, the SME Eisenhuth is the only German manufacturer of graphitic bipolar plates.

Regarding gas diffusion layers Freudenberg and SGL are well-established German suppliers. Freudenberg also delivers humidifiers through its Japanese partner NOK, and sealing technology. Within the field of air filtration, besides Freudenberg the German companies Mann + Hummel as well as Mahle are also involved.

## 7. Production Technologies

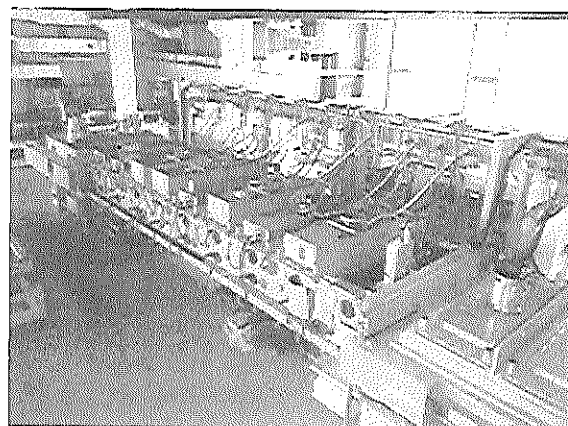


Fig.6 Sputter technology for substrate dimensions of up to 150 × 400 cm<sup>2</sup>, e.g. for coating of metallic bipolar plates. Fraunhofer ISE.

Several German enterprises offer solutions for series production of FC stacks and components. Companies like Coatema, HarroHoeffiger, FIX, Manz, Siemens, and others have already delivered devices to their customers.

## 8. Research Activities

Due to the German research politics, a broad variety of research institutes address many scientific aspects of FC and hydrogen technology. Long-term research since the 1990s has been performed at the state funded, Helmholtz institutes of the DLR (Stuttgart) and Juelich. Partially third party financed research organizations with a particular focus on FC technology includes the Fraunhofer

Society and its institutes including the Institute for Chemical Technology (ICT; Pfinztal), the Institute for Ceramic Technologies and Systems (IKTS; Dresden / Hermsdorf), and the Institute for Solar Energy Systems (ISE; Freiburg), as well as other institutes such as the Centre for Fuel Cell Technology (ZBT, Duisburg), and the Centre for Solar Energy and Hydrogen Research (ZSW, Ulm). These institutes cover a broad range of topics from material through to system research.

## 9. Future Perspectives

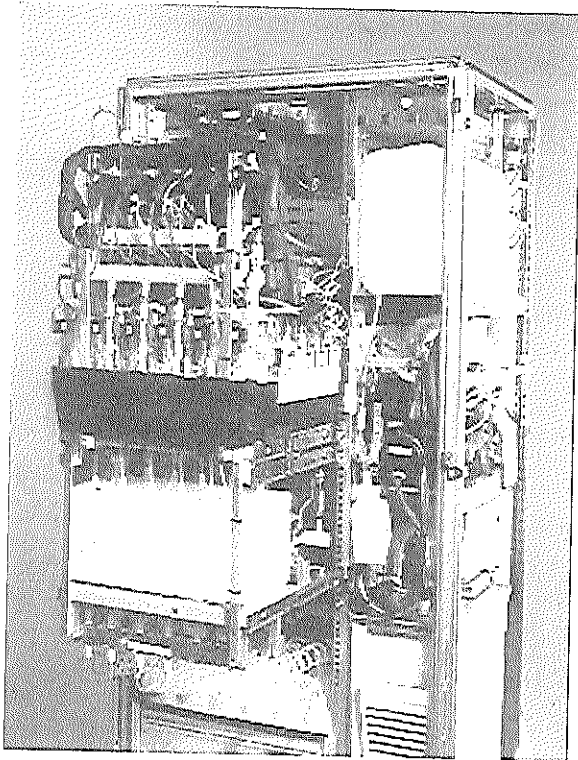


Fig. 7 Test rig for simultaneous operation of 30 PEMFC test cells in order to evaluate influences of air contamination in the field. Fraunhofer ISE.

For the forthcoming years until 2020, a dynamic market development is expected in all the aforementioned market segments. As Asian FC cars from Hyundai, and Toyota have already started sales in the German market and Honda will follow soon, the pressure on German car manufacturers is increasing. As mentioned earlier, Daimler AG has announced a GLC class FC model for 2018 and accordingly has promised a high ramp-up of production for the following years. Regarding power, around 300 back-up FC units were installed within the last two

years in Germany, with local companies offering products for stationary FCs and it is expected that sales will rise soon.

FC research is more and more focused on investigations regarding certain phenomena through accelerated stress testing and issues of contaminants in air, hydrogen or cooling. Also, material research regarding MEA or bipolar plates is emphasized. In general, research politics indicates the need and desire for international collaborations not only for the market players but also at the scientific level.

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