World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

EVS24
Stavanger, Norway, May 13-16, 2009

Next Generation Fuel Cell Technology for Passenger Cars and Buses

Dr. Christian Mohrdieck[1]
[1]*Director Fuel Cell and Battery Drive Development, Daimler AG,*
Neue Straße 95, 73230 Kirchheim Teck/Nabern, Germany, christian.mohrdieck@daimler.com

Abstract

Daimler is presenting its latest fuel cell vehicle, the Mercedes-Benz B-Class F-CELL in 2009. Being one of the first series-produced fuel cell vehicles so far, the B-Class F-CELL will be a milestone on the road to commercialization of hydrogen-powered fuel cell vehicles. Equipped with advanced fuel cell technology it is suited for everyday operation and designed to fully meet customers´ expectations. From 2010 onwards, this zero emission vehicle is going to be operated by selected customers in different countries. In addition, a new generation of fuel cell buses, the Mercedes-Benz Citaro FuelCELL–Hybrid is presented in 2009.

Keywords: Fuel Cell, Bus, Passenger Car, ZEV (Zero Emission Vehicle), Hydrogen

1 Introduction

Sustainable drive systems and innovative safety technologies are the mainstays of Daimler's vision of mobility for the future. Vehicles with hydrogen-powered fuel cells provide ideal conditions for environment-friendly mobility that saves natural resources.
As the pioneer of this technology, Daimler already presented the first vehicle with this highly efficient and environment-friendly drive concept in 1994. With more than 100 test vehicles that have altogether covered around four million kilometres, Daimler has the most experience in fuel cell vehicles worldwide – from compact A-Class passenger cars to Sprinter vans and large Citaro fuel cell buses.
The Mercedes-Benz B-Class F-CELL will be one of the first series-produced vehicles with a zero-emission fuel-cell drive. Small-series production of the passenger car will commence in late 2009. A new generation of fuel-cell drive will be used to power this innovative vehicle. The fuel cell system is much more compact while at the same time offering higher performance. It is also completely suitable for everyday use.
The fuel cell system used in the Mercedes-Benz B-Class F-CELL is also demonstrating its suitability for heavy-duty operation in commercial vehicles. By means of combining two B-Class systems with an energy storage unit, a highly powerful aggregate is created for application in the new FuelCELL-Hybrid bus.

2 The B-Class F-CELL

2.1 General Achievements

Compared to the A-Class F-CELL a refined, more compact and efficient system is used in the B-Class F-CELL. The electric motor has a maximum output of 100 kW. This means that the B-Class F-CELL offers high driving performance standards that surpass those of a standard two-litre gasoline engine. At the same time, the zero-emission fuel-cell drive in this family-friendly compact vehicle consumes just about 2.9 litres of diesel equivalent per 100 kilometres.

World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

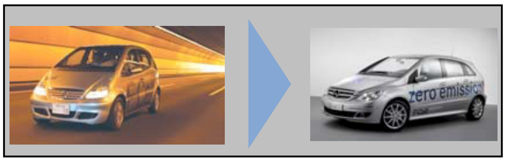

Figure 1: Two generations of Fuel Cell Vehicles

Daimler has made huge progress in terms of size, power, fuel consumption and range of the fuel cell drive train. Also, the reliability of the vehicle has been improved. The B-Class F-CELL has undergone the same quality-ensuring processes applied to all Daimler vehicles.
The B-Class will have a stack lifetime of more than 2000 hours. This clearly distinguishes the car from prototypes and shows Daimler's commitment to commercialize fuel cell vehicles. In just a few years the fuel cell drive train will reach the lifetime of conventional Internal Combustion Engines (ICE).
Another focus has been the packaging of the fuel cell drive train into the compact body of the Mercedes-Benz B-Class. This could be accomplished without any restrictions in regard to passenger and luggage space. The outer body shell remains completely unaltered from a conventional B-Class vehicle. In order to save costs and benefit from synergies, identical parts from other series-produced vehicles are used.
Altogether, the B-Class F-CELL is well-suited to demonstrate full customer acceptance and shows that advanced fuel cell technology is now ready for everyday use.

2.2 Technical Data

The power of the electric motor will be 100 kW. These 100 kW are comprised of the effective outputs of the fuel cell and the battery. In addition, maximum torque has been increased from 210 Nm to impressive 320 Nm. Also, a better power-to-weight ratio could be realized.

Table 1: Technical Data B-Class F-CELL

B-Class F-CELL	
Power	
Effective power fuel cell	80 kW
Effective power electric motor	100 kW
Maximum torque	320 Nm
Accumulator/Consumption	
Capacity accumulator	1.4 kWh
Hydrogen pressure	700 bar
Range (NEDC)	approx. 400 km
Consumption (adjusted)	2.9 l diesel equivalent/100km
CO_2-emissions	0 g/ km
Driving Performance	
Acceleration 0-100 km/h	11.4 sec
Top Speed	150 km/h

According to NEDC cycle testing, the B-Class F-CELL will consume only 2.9 litres of diesel equivalent per 100 kilometres. The range will be extended to approximately 400 km due to enhanced hydrogen tank storage capacity with 700 bar technology. At modern hydrogen fuelling stations it can be completely refilled within less than 3 minutes.

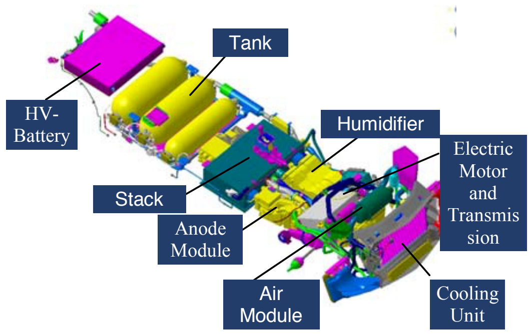

Figure 2: Drive Train B-Class F-CELL

2.3 Fuel Cell Stack and System

Fuel cell stacks have made significant progress within the last 5 years regarding weight and volume due to improved stack engineering and new materials. Thus, the stack powering the B-Class F-CELL is now 40% smaller and at the same time 30% more powerful than its predecessor in the A-Class F-CELL.
However, the fuel cell itself is just one part of the system. The entire fuel cell system is integrated in the sandwich-floor of the B-Class F-CELL so that the available passenger and luggage space is not affected.
The system-box-concept of the A-Class F-CELL has been abandoned for a system-module-concept. The module concept of the B-Class F-CELL allows for more packaging flexibility and better maintainability.

World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

Figure 3: Cross-Sectional Model with Stack

2.4 Cold Start Ability

The B-Class F-CELL will be able to start without problems at temperatures above minus 25°C. Previously, cold start ability has always been a challenge. Now having switched to a passive humidifier system, based on gas-to-gas membrane humidification, the B-Class F-CELL is well suited for colder regions, too. This has been recently confirmed by winter testing in Sweden. In addition, the complexity of the system and the number of components could be reduced.

2.5 Battery

To improve the overall efficiency of the car, Daimler uses a lithium-ion battery instead of the nickel-metal-hydride (NiMH) battery employed in the A-Class F-CELL. This leads to an improved overall efficiency and provides for more power at low temperatures. In addition, the power density could be increased.
Daimler was the first car manufacturer to adapt lithium-ion batteries, previously mainly used for consumer electronics, to automotive requirements. A decisive element in this process was the integration of the battery into the air conditioner cooling circuit of the car. Thus, the accumulator can permanently operate at temperatures between 15°C and 35°C which are best suited for a long lifetime and optimum performance.

2.6 Electric Drive Train

The B-Class F-CELL is equipped with a permanent magnet motor, in contrast to the A-Class F-CELL's asynchronous (AC induction) motor. Daimler has made this change in order to realize higher efficiency, more power and torque. For the new B-Class F-CELL a compound-planetary transmission with bevel gear differential will be employed.

2.7 Cooling System

Wherever possible, identical parts from other vehicles are used for the cooling system of the B-Class F-CELL. This strategy assures high quality at reasonable costs. Other improvements are the reduction of weight and an overall simplification of the cooling system. To make the cooling system more compact, a minimized ultra pure water loop is used.

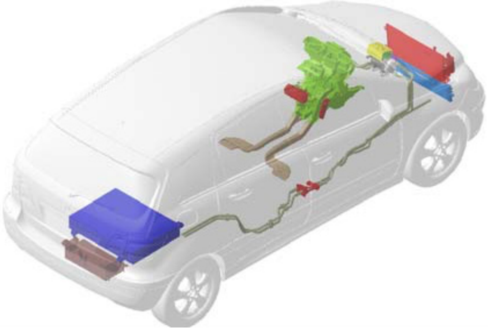

Figure 4: Cooling System

3 The Mercedes-Benz Citaro FuelCELL-Hybrid Bus

3.1 General Achievements

This year Daimler is presenting its new Mercedes-Benz Citaro FuelCELL–Hybrid. It is powered by two B-Class fuel cell systems. In contrast to the previous Citaro fuel cell bus, the new Citaro FuelCELL-Hybrid bus is also equipped with a HV-lithium-ion battery. This, together with other efficiency-enhancing measures, helps to realize significantly lower consumption and higher reliability.

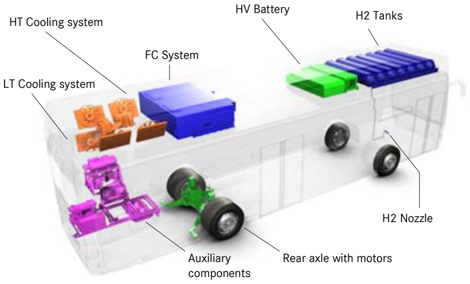

Figure 5: Citaro FuelCELL-Hybrid

World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

3.2 Technical Data

Fuel consumption could be reduced from 20-24 kg of hydrogen per 100 km to only 10-14 kg hydrogen per 100 km. Also, the reliability of the next generation fuel cell bus could be further increased compared to the previous generation.

Table 2: Technical Data Citaro FuelCELL-Hybrid

Citaro FuelCELL-Hybrid	
Power	
Power fuel cell system	120 kW
Drive power	160 kW
Accumulator/Consumption	
Capacity accumulator	26.9 kWh
Power accumulator	180 kW
Hydrogen pressure	350 bar
Range	> 250 km (planned)
Consumption	10-14 kg hydrogen per 100 km
CO_2-emissions	0 g/ km

3.3 Fuel Cell Stack and System

In order to gain synergies with the passenger car program the next bus generation will use two B-Class F-CELL fuel cell systems. Thus, the Citaro FuelCELL-Hybrid is able to benefit from advancements made in the development process of the new B-Class F-CELL. These include cold start capability, a higher power density and the modular concept.

The Citaro FuelCELL-Hybrid marks a significant step forward in terms of fuel cell technology. The durability of fuel cell stacks could be increased. Evobus, the Daimler subsidiary producing the Citaro, now expects a warranty of 12,000 hours or six years.
The weight of the fuel cell system could be reduced from 1040 kg (without air supply) to only 688 kg (including air supply).

3.4 Battery

In contrast to its predecessor, the next generation bus is equipped with a powerful lithium-ion battery. It has a capacity of 26.9 kWh and a maximum power of 180 kW. The liquid-cooled battery weighs only 285 kg and is maintenance-free. Also, it can be diagnosed and a replacement of modules is possible.

3.5 Electric Drive Train

The Citaro FuelCELL-Hybrid has an all-new electric drive train with wheel hub motors, serving as generators for recuperation. The e-motors are liquid-cooled and enable stepless acceleration. This is not only highly efficient but also leads to more passenger comfort.
The wheel sets were optimized in order to reduce noise. Still, the standard Mercedes-Benz Citaro disc brakes and suspensions are used for the new Citaro FuelCELL-Hybrid.

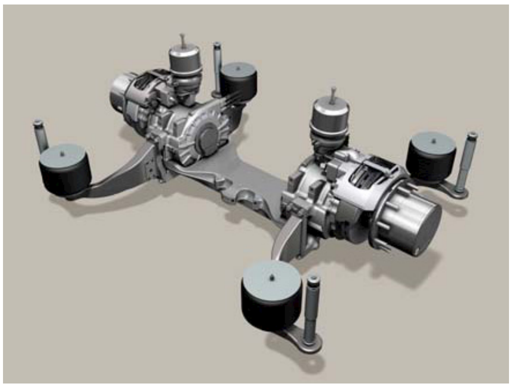

Figure 7: Citaro FuelCELL-Hybrid: Electric Drive Train

3.6 Tank System

The storage capacity of the tank system could be reduced in comparison to the previous fuel cell bus due to energy recuperation and a higher overall efficiency. As space limitations in contrast to fuel cell passenger vehicles are less of a problem for the fuel cell bus tank system, a tank pressure of 350 bar is sufficient for the Citaro FuelCELL-Hybrid. The storage capacity of 35 kg of hydrogen enables a sufficient range for a city bus.
Proven components of the previous generation tank system were carried over to the next generation fuel cell bus.

3.7 Electrification of Auxiliaries

For the new Mercedes-Benz Citaro FuelCELL-Hybrid auxiliaries like the air conditioning compressor or the steering pump are electrified. This results in higher efficiency and lower maintenance.

World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

4 Commercialization of Fuel Cell Vehicles

Daimler is convinced that fuel cell vehicles will be the best long-term solution when it comes to commercializing a zero-emission vehicle technology that will be competitive with conventional vehicles in every respect.

The lead application in the development of fuel cell vehicles at Daimler are passenger cars. The fuel cell technology for vans and buses is derived from the passenger car technology.

To commercialize fuel cell vehicles Daimler has identified 5 steps along the way towards mass production:

The first step has been the technology demonstration with the A-Class F-CELL fleet. The B-Class F-CELL, being the second step, will meet customer requirements and thus gain customer acceptance. The aim of the following 3rd generation will be to reduce component costs. In the 4th generation, costs will be reduced even further and fuel cell vehicles will be publicly available in larger quantities. For the balance of components and the reduction of costs, Daimler pursues three strategies:

- Optimization by developing or choosing superior operating principles, materials and operation strategies
- Simplification by smart design of the fuel cell stack - system interface
- Minimization up to elimination of components

The drastic reduction of costs paves the way for the fifth step. This will be the mass production of fuel cell vehicles within the next decade.

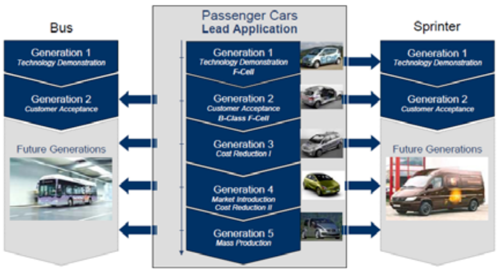

Figure 7: Daimler's Fuel Cell Commercialization Roadmap

However, the demonstration project hydrogen fuelling infrastructure is not sufficient for the envisaged commercialization roadmap. For full customer acceptance an area-wide and convenient hydrogen filling station network is necessary.

In cooperation with a partner company Daimler has analyzed a possible network of 1,000 hydrogen fuelling stations for Germany. This is not comparable to the existing gasoline fuelling stations infrastructure, but would be sufficient. A network of this density would require an investment of 1.5 to 2 billion Euros. This, however, is not prohibitive but cannot be shouldered by one company alone.

5 Summary

Within the last years, Daimler has made significant progress with fuel cell technology. Advanced fuel cell vehicles like the Mercedes-Benz B-Class F-CELL are coming close mass market readiness. Daimler is determined to commercialize this promising technology. Yet, Daimler and other OEMs can not succeed without the assistance and cooperation of societal, governmental and economic actors.

Author

Dr. Christian Mohrdieck has been a Director of Fuel Cell Drive System Development at the Daimler Group Research and Advanced Engineering Division since 2005. After studies of physics in Germany and France, Dr. Mohrdieck joined Daimler-Benz Research in 1989. In 1995 he became head of the Executive Office of the Member of the Board responsible for Research and Technology in Stuttgart. From 1999 on Dr. Mohrdieck has been a Senior Manager Fuel Cell Systems with DaimlerChrysler Corporation in the USA. Back in Germany, he became a Director of Structural Materials at Daimler AG and afterwards in 2003 Director of Alternative Energy- and Drive Systems.