Electric Vehicle Symposium – EVS 26

Technology Maturity of Fuel Cell System installed in Mercedes B-Class during the World Drive

Author: Dr. M. Venturi Nucellsys GmbH

Abstract
Fuel cell technology is gaining more public, political and industrial awareness after the success of the Mercedes-Benz World Drive. The B-Class F-Cell is equipped with the Nucellsys fuel cell system and accomplished more than 30,000 km in real world condition over 4 Continents without failures. Operating temperature from -15°C up to 35°C, altitude of more than 2000m, desert heavy rain, highway and heavy traffic jam were challenging the fuel cell system.
The technology maturity has been publically demonstrated and important customer and real use information's has been collected which will further improve the next generation system. This paper gives an up-date of the fuel cell system technology maturity and the outlook of next generation challenges.

Key Words: Fuel Cell System, Automotive, F-Cell, World Drive, Mercedes-Benz

Introduction
The environmental public awareness' is increasing especially after the last catastrophic events of the oil spill in the Mexican Gulf and the nuclear issues in Fukushima. More people are questioning the way we are consuming the energy been produced and are asking politician and industry to give more answer to environmental issues. Energy issues and the use of the resources are not only belonging to cars meaning to a Tank-to-Wheel discussion, but are more involving the whole energy chain, from the production to the consumption.
Under these aspects, there are for example in one hand the Global Warning (considering the CO2 as well as the emission in general) and the impact to the environment, on the other the commitment of the car industry to meet certain CO2 targets.[Figure 1]
From an energy perspective, hydrogen offer several advantages particularly if produced by green energy. In addition hydrogen can be produced from different energy sources and its "fuel" is all over present (energy diversification). The car industry in order to meet the target is bringing into the market several powertrain solutions in which the fuel cell technology is playing a primary role to achieve the perspective of "zero emission vehicle", with significant vehicle range.

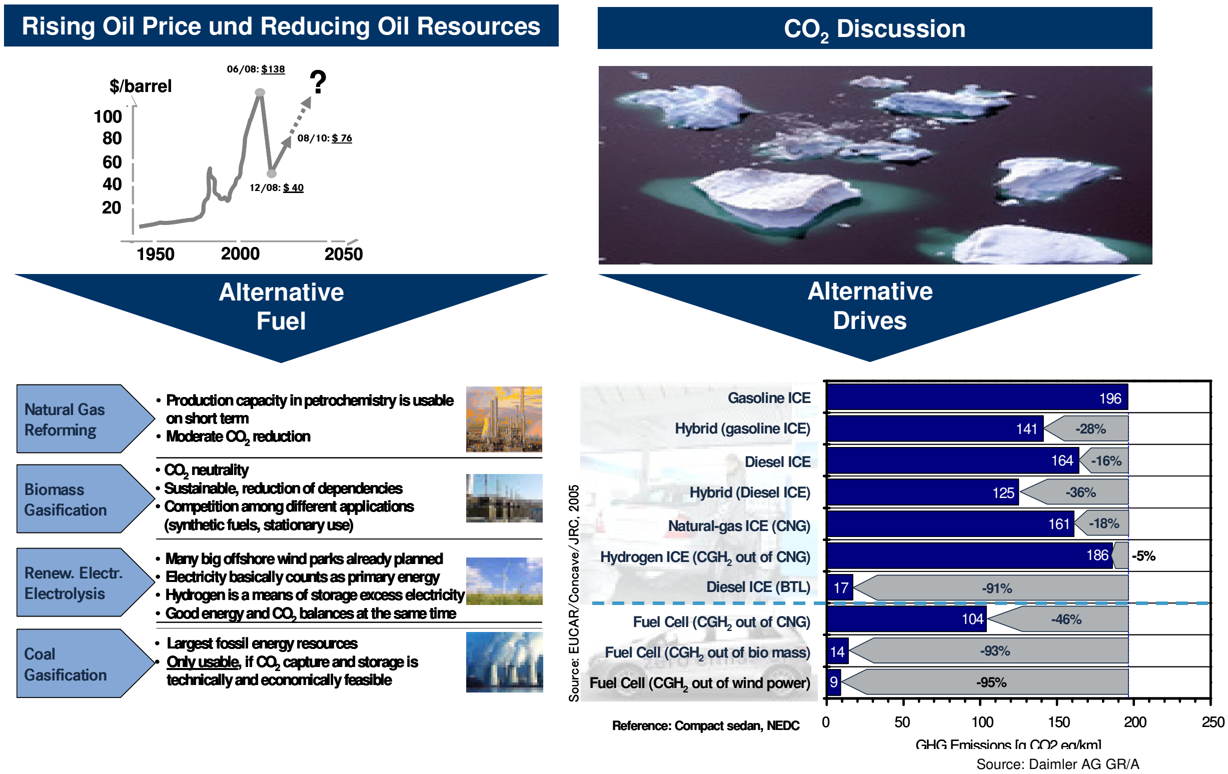

Figure1. Motivation for hydrogen fuel cell vehicles: increasing oil prices and the need to reducing global CO_2 emissions, ask for energy diversification and alternative drives. On the left side a list of powertrain solutions to reduce GHG emissions.

In the last five years, all the major and most innovative car manufacturers had demonstration programs aiming to promote the fuel cell technology and to explore the potential market. All these demonstration programs including the construction of a refuelling station were mainly used by one OEM. A “Chicken-and-Egg” problem discussion started and was delaying the construction of the hydrogen infrastructure. A first step to break this issue has been the “H2 Mobility” initiative with the objective to build 1000 refuelling stations in Germany.

To strength this initiative and to demonstrate that the fuel cell technology is ready for market introduction, mid of last year Mercedes-Benz top management proposed to the development team the World Drive. 3 F-Cell B Class shall be driven around the world, with Press of all over the world.

The F Cell World Drive

On Januar 29, 2011 in coincidence with the 125th Birthday of the “car patent” of Carl Benz, 3 F-Cell B-Class left Stuttgart on the way to Paris.[Figure 2] From Paris the cars went southwards to Lyon and to Barcellona and than to Portugal, where they left Europe by plane to Miami. The cars were always driven by international journalists and accompanied by a TV team, a service team and a mobile hydrogen pump installed in a Mercedes Sprinter. This mobile fuel station was necessary since there is no sufficient hydrogen fuel station network in place. Worldwide there are just around 200 hydrogen fuel stations existing yet. With the help of the mobile hydrogen refuelling station it was possible to refuel the F-Cells after distances of about 300-400km within short time to continue the daily legs.

Figure 2. Start of theF-Cell World Drive at the Mercedes-Benz Museum in Stuttgart on january 29, 2010 [Source: Mercedes-Benz]

After passing Europe at chilly weather, the F-Cells crossed North America from east coast starting in Florida to west coast through the southern states at sunny weather and hot temperatures in the deserts without any problems.

Reaching the west coast the three F-Cells cruised northbound along the pacific coast and reached Vancouver in Canada after 19 days and almost 8,000km. Crossing North America was the fastest leg and also the one with the lowest average fuel consumption of 1.18kg/100km (1.25kg/100km in Europe) and the fuel economy record of the whole tour with a consumption of 0.88kg/100km. The good fuel economy was caused by long distances between cities and almost constant speeds. In California it was also possible to refuel the F-Cells at two of the few public hydrogen fuel stations.

From the wet northern Pacific climate in Seattle the three F-Cells then switched to the dry and hot climate in Australia, where they crossed the continent from Sydney to Perth in eight days, using the long straight roads trough the desert. Also this leg caused no problems for the fuel cell cars. The only problems so far was a flat tire.

The three F-Cells continued their tour through China, Kazakhstan, Russia towards the northern European countries. This continent was the most challanging for all vehicles of the convoy. Not just the fuel cell cars had to fight aginst dusty roads, extreme traffic and air pollution in the bigger cities. One of the cars was involved in an accident in Kazakhstan, receiving damage to its bumper and rear axle, but was able to continue after repairs.

Figure 3. F-Cell World Drive through 4 continents, 14 countries over a distance of more than 30.000 km within 125days [Source: Mercedes-Benz]

After spending 70 days driving through 14 countries on four continents, three Mercedes-Benz hydrogen cell vehicles have successfully completed their 30,000km (18,641-mile) F-Cell World Drive. The three B-Class F-Cells left Stuttgart on January 30th, along with a convoy of support vehicles and crossed the finish line in front of Stuttgart's Mercedes-Benz Museum on June 1, 2011.[Figure 3 shows the complete World Drive trip among all the Continents]

The fuel cell system

The Mercedes-Benz F-Cell B-Class is equipped with a Nucellsys fuel cell system composed by an air system, hydrogen and humidification module, a fuel cell stack and the power distribution unit. Nucellsys is also providing the fuel cell system control strategy and control unit which communicates via CAN with the vehicle control unit. Figure 4 shows the packaging of the fuel cell system modules as well as the battery and the hydrogen tank system in the F-Cell B-Class.

Figure 4. Packaging of the F-Cell B-Class, showing from left to right: high voltage battery, hydrogen tank, fuel cell stack, hydrogen module and in the front the air the air system placed above the electric drivetrain in the engine compartment.

The air module is positioned in the front of the vehicle and is providing the necessary air (the oxygen) for the operation of the fuel cell stack. The air module consists mainly of the compressor driven by an electric motor. The air intake as well the air exhaust are supported respectively by intake muffler and a combination of muffler with intercooling components. These two components were required to reduce the sound quality specifically. To avoid structure born noise the whole air supply system is decoupled from the vehicle frame by specifically developed decoupling elements. For the reduction of air born noise the air supply system was mounted inside an overall noise cover. [1] Figure 5. shows the complete air module with and without the noise cover. The performance of the screw compressor is shown in Figure 6.

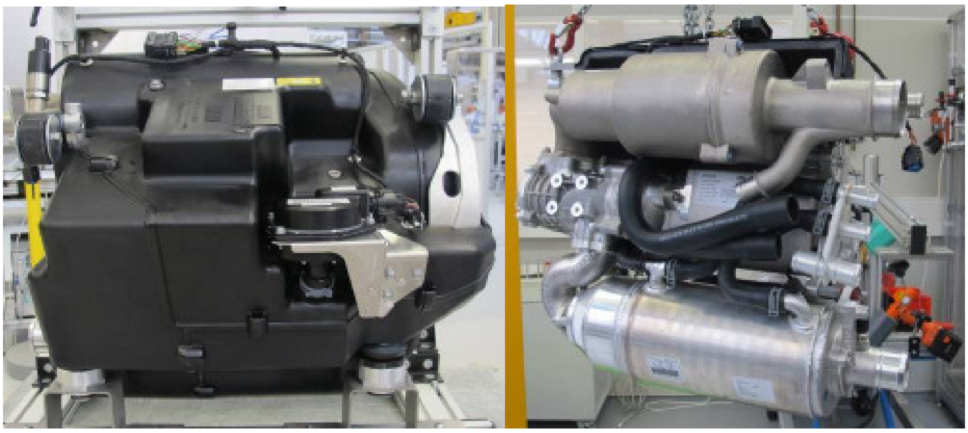

Figure 5. The air module, left with noise cover and right without. From the top are visible the air intake muffler, the screw compressor and electric motor and the exhaust muffler.

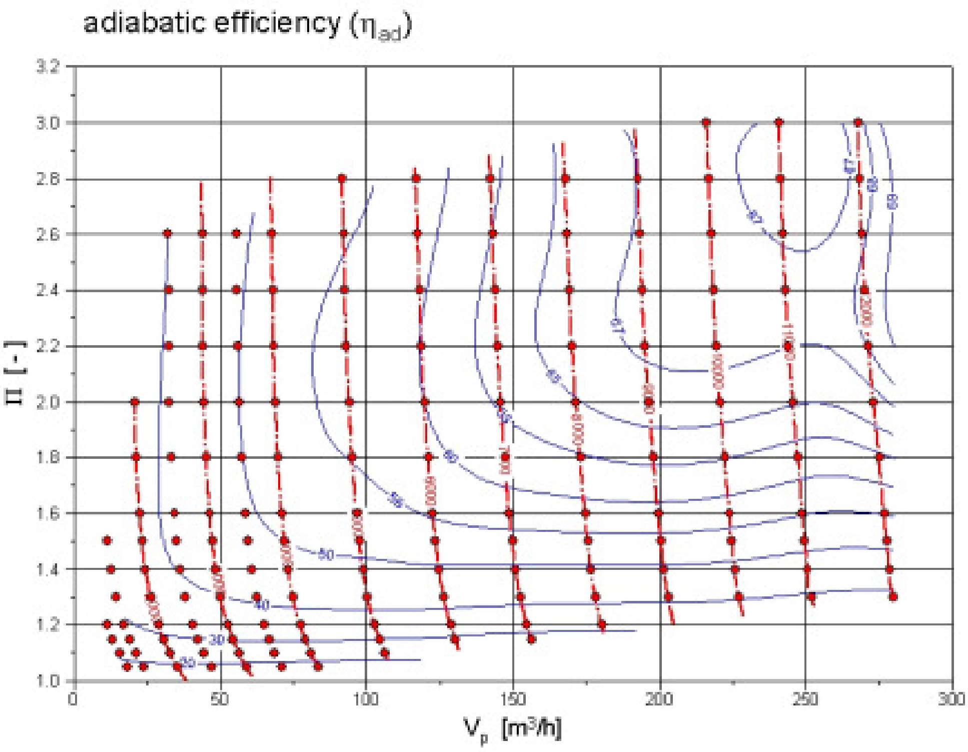

Figure 6. Performance of the current generation of air system

Air entering the fuel cell stack need to be humidified by a separated module, as shown in Figure 7. The core of this type of passive humidification is the membrane that needs to have good water transfer ratio and very low performance degradation at freezing as well as during hot operation over the whole vehicle life. The performance is shown in Figure 8.

Figure 7. Humidification module coverd by a thermal protection

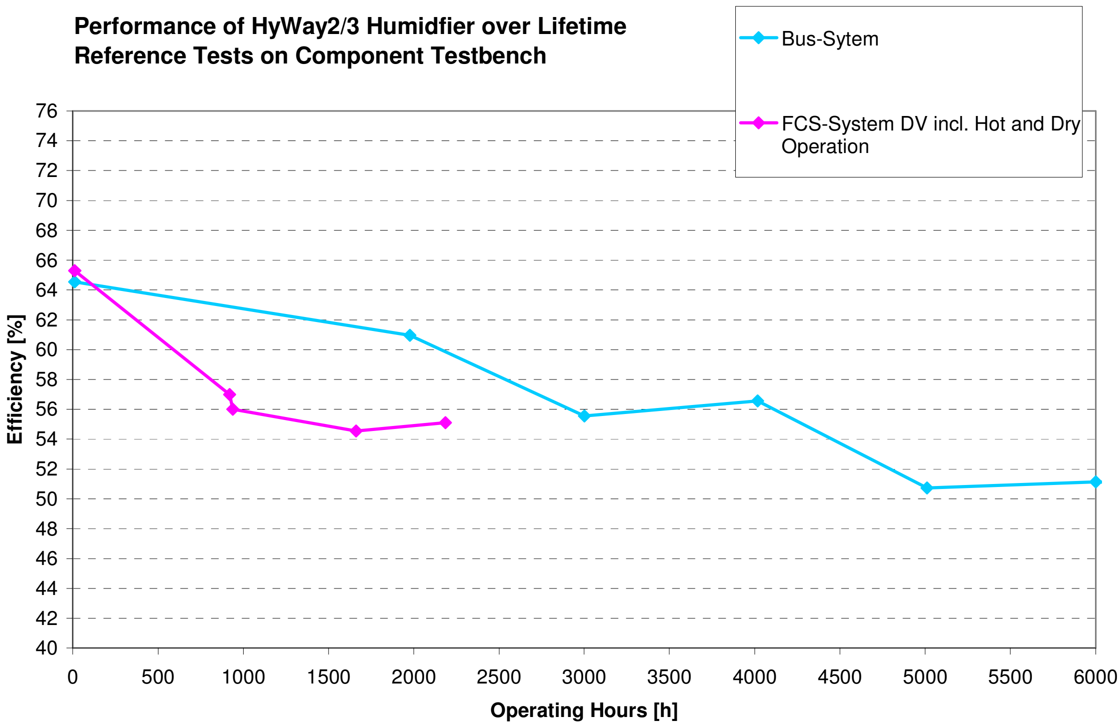

Figure 8. Performance of the current generation humidifier over time at different loads

The hydrogen module has the function to provide the hydrogen for the stack at the right conditions. It has to regulate accurately the hydrogen pressure in function of the required current as well as to balance the air pressure present on the other side of the membrane. It also has to provide the hydrogen at the intended humidity and the right concentration. The hydrogen module is composed mainly by a hydrogen recirculation blower (HRB), a pressure control valve (HPCV), and water knock-out unit. In addition pressure and hydrogen sensor as well as the structure frame, complete the assembly. Figure 9 shows the complete hydrogen module assembly.

Figure 9. Hydrogen module, mainly consisting of pressure regulator, recirculation blower and water knock-out

The fuel cell system has a net power of 80kW and a peak power of 90kW for some minutes. The power develops dynamically in less than 1s from idle to 90% providing the driver excellent acceleration capability as well as hill climbing performance. Freeze start up has been one challenge during the development work of the fuel cell system and has been successfully demonstrated in laboratory as well as during several winter tests in Sweden. Of course during the World Drive the cars were driven and started and temperature below freezing.

The World Drive was a great opportunity for the development and production teams to have all extreme real world conditions like cold and hot weather, dry and humid conditions, sea level and altitude operation, dusty air and unpaved roads [Figure 10], but more important, many different drivers which enjoyed the emission free driving [2]

Figure 10. Pictures of some of most challanging ambient condition during the World Drive.

Fuel cell system outlook

Fuel cell system technology is advancing in fast manner providing more power, very compact and reliable systems at reduced cost. The improvements are achieved by integration of component functions to reduce the weight and volume and to reduce the number of components. A good example of this advance development is the air system. The air system of the new generation is featured with a different technology. If the previous and current generation compression technology was “constant displacement”, the future uses the “turbo concept”. This significant change is reducing the weight of the air module by 50% and the volume by approximately 70% maintaining the same performance! [3]. Figure 11 shows the prototype of the electrical turbo charger to equip future Mercedes fuel cell cars.

Figure 11. Prototype of a turbo compressor for the next generation system

The volume reduction is achieved since turbo machines have much higher shaft speeds than the currently used screw compressor. This on the other hand requires a higher auxiliary power at up-transients. Another challenge is to control the mass flow of a turbo compressor, since the lines of constant speed are very flat [Figure 12]. Furthermore a surge operation has to be avoided in order not to damage the device. Therefore turbo compressors require a accurate and high dynamic control.

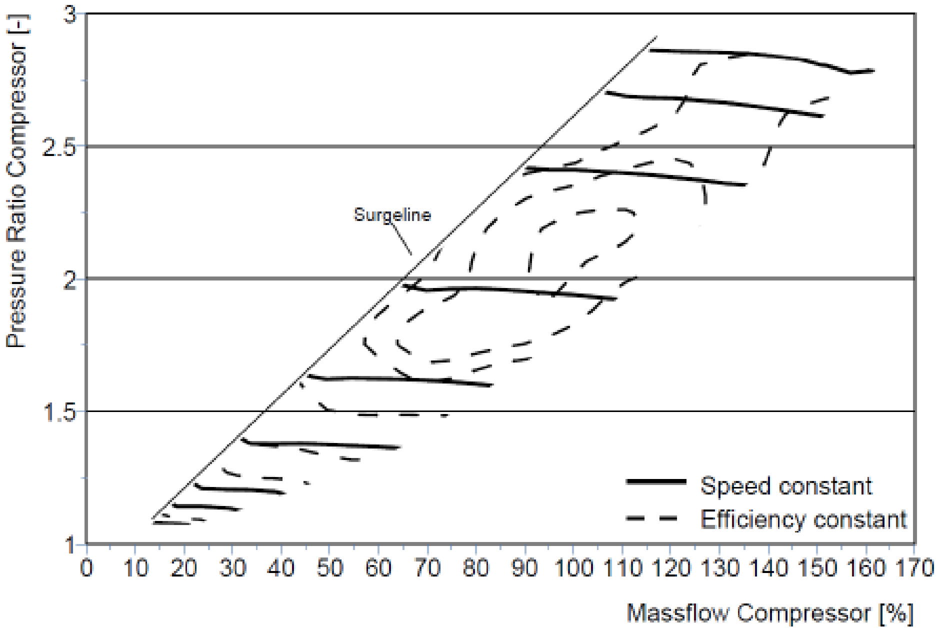

Figure 12. Performance map of a turbo compressor with lines of constant speed and lines of constant efficiency.

Due to the significant volume reduction of the new generation air supply system it is now for the first time possible to fit the whole fuel cell drive train in the engine compartment of a conventional passenger car. With this step vehicle platforms which were originally designed for internal combustion engines (ICE) can also be equipped with fuel cell engines (FCE). The next figure shows the improved performance of the new humidification system. The humidification system can sustain freezing and hot temperature by maintaining the good efficiency over the life time.

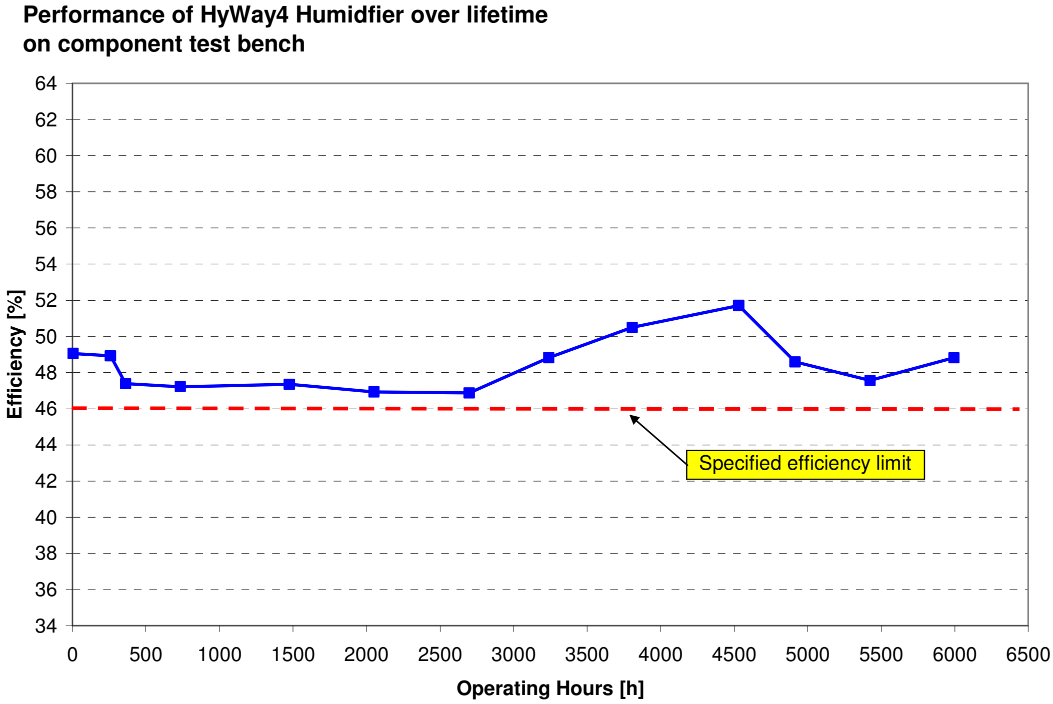

Figure 13. Performance map of the newly developed humidifier, over different test environmental conditions.

An improvement of at least 5% in total efficiency is to be expected as well as a significant reduction in catalyst loading by improved polarization curve.
Improvements in manufacturing technologies', especially for the stack are necessary in order to meet the quality and reproducibility targets.
To reach the fuel cell powertrain cost similar to the diesel hybrid we have simultaneously to operate in 3 main directions: a) technology development reducing the number of components by increasing functional integration and improving stack performance, b) supplier competition to avoid monopolistic situations and c) production volume and scale effect.
Nucellsys is very active in all the 3 directions with strong R&D and innovations describing the technology road map to reach the target cost.

Conclusion
The Mercedes-Benz World Drive has been a great success in all aspects. Overall more than 30,000 km have been driven, mainly from journalists and guests. The fuel cell system had confirmed in all road, traffic and environmental condition excellent performance and durability. No hardware failures occurred during the whole trip and the development team was able to gather useful information's to further develop and improve the fuel cell system. The success of the World Drive has been also the great opportunity for Daimler and Linde to announce the build of 20 hydrogen refuelling stations with begin by the launch of the next generation fuel cell car.

Acknowledgement
I acknowledge the Daimler Management and the Project leader who involved the Nucellsys team J.Sang, H. Badowsky, A. Knopp, S. Ecker and myself to take part to this adventure. In addition all the development teams in Daimler and Nucellsys that constantly monitored the performance and reliability of the Mercedes B-Class F-Cell during the whole World Drive.

Reference

[1] "NVH-Challenges of Air Supply Systems for Automotive Fuel Cell Applications" SAE Int. J. Engines 1(1): 258-266, 2008

[2] "Mercedes-Benz F-Cell World Drive – In 72 Tagen um die Welt", auto-motor-sport Special Edition Nr.3 2011

[3] "Air Supply System for Automotive Fuel Cell Application"; Dr. Massimo Venturi; SAE 2012-01-1225