Development Progress of Small Fuel Cell Systems for Future Vehicles

M. Bauer, G. Götz, W. Strobl

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 5: Strategic Analyses / Safety Issues / Existing and Emerging Markets
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-5
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-655-2

Development Progress of Small Fuel Cell Systems for Future Vehicles

Michael Bauer, **Georg Götz**, **Wolfgang Strobl**, BMW Group Research and Technology, Germany

1 Introduction

One of the biggest challenges for car makers in the future is the introduction of hydrogen as an alternative energy carrier. The BMW Group has been continuously working on hydrogen vehicles for over 30 years.

BMW Group Research and Technology is cooperating with *UTC Power* in order to investigate the feasibility of PEM fuel cell systems as an Auxiliary Power Unit (APU) for hydrogen vehicles. In the second decade of cooperation, the major challenges such as lifetime, freeze capability and dynamic response are mostly tackled.

Today's vehicle concepts use an internal combustion engine (ICE) to ensure the driving performance in urban and non-urban areas. Electrical energy, needed for the auxiliaries, will be generated with the alternator to supply these components in the car. This electricity is produced in an uneconomic way with approximately 20 % efficiency due to the serial connection of the IC engine and the generator.

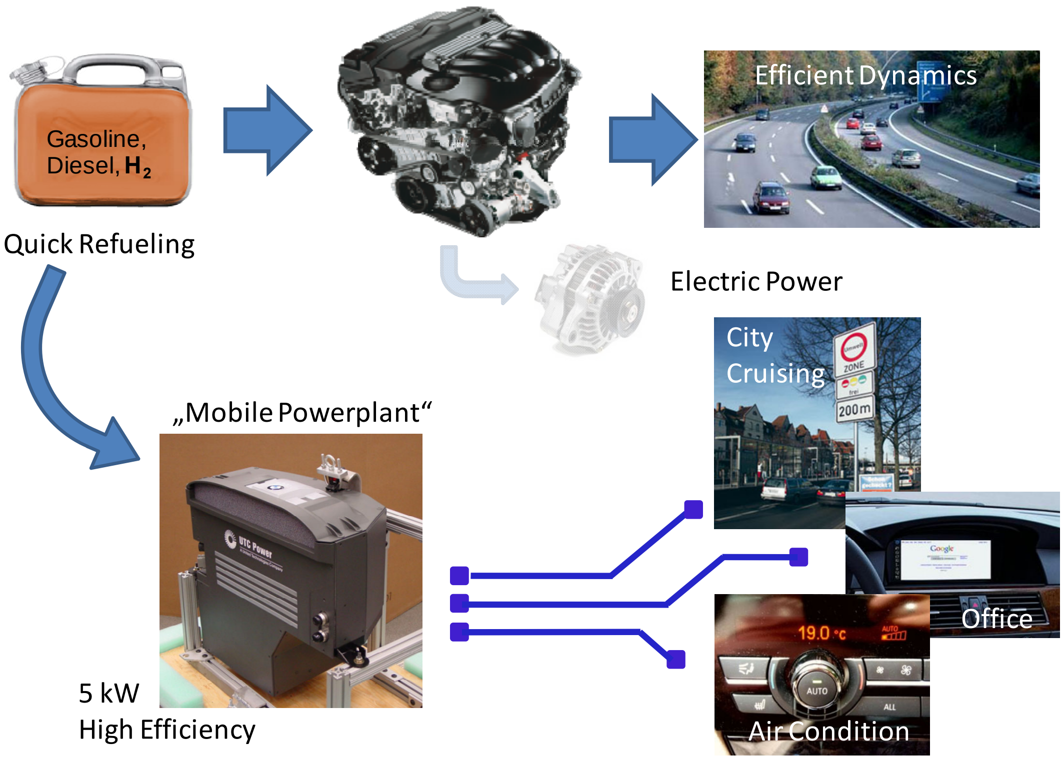


Figure 1: Energy management and new customer benefits.

Fuel cells offer with a direct conversion from fuel to electrical energy a highly efficient solution to ensure the demand of energy for electric vehicle components. Due to the implementation of this additional energy converter an independent supply with electricity in the car will be feasible. Figure 1 shows one future vehicle concept with two primary energy converters: internal combustion engine and a small fuel cell. The ICE is mainly used to drive the car in non urban areas, in which high power is needed. In urban areas, a small fuel cell can also cover besides the supply of the board-net, the needed energy for cruising at low speed.

This mobile fuel cell power plant is also capable to offer the customer additional benefits such as mobile office applications and air conditioning, even if the engine is not running. Using hydrogen as fuel, a zero emission vehicle in urban regions is reasonable by keeping the costs for the fuel cell as low as possible. With a power rating from 5 to 10 kW, the fuel cell can be optimized as an auxiliary power unit.

2 Technology

Designing an APU for cars, a system with lower volumetric and gravimetric power density compared to fuel cells supplying the drive train can be used. As a result, the main focus of this application is the highest efficiency of the whole system. In 13 years of development, an ultra-low pressure system promises the best solution for the application as a small fuel cell. Because the system operates at low pressure, a low power fan instead of a high power compressor can be used to provide air flow to the stack. The power required for all balance of plant parts is only one to two percent compared to the maximum power output. In Figure 2, the improvement of the system efficiency from GEN II (1999) to GEN IV (2010) is shown. All systems are rated at 5 kW output power.

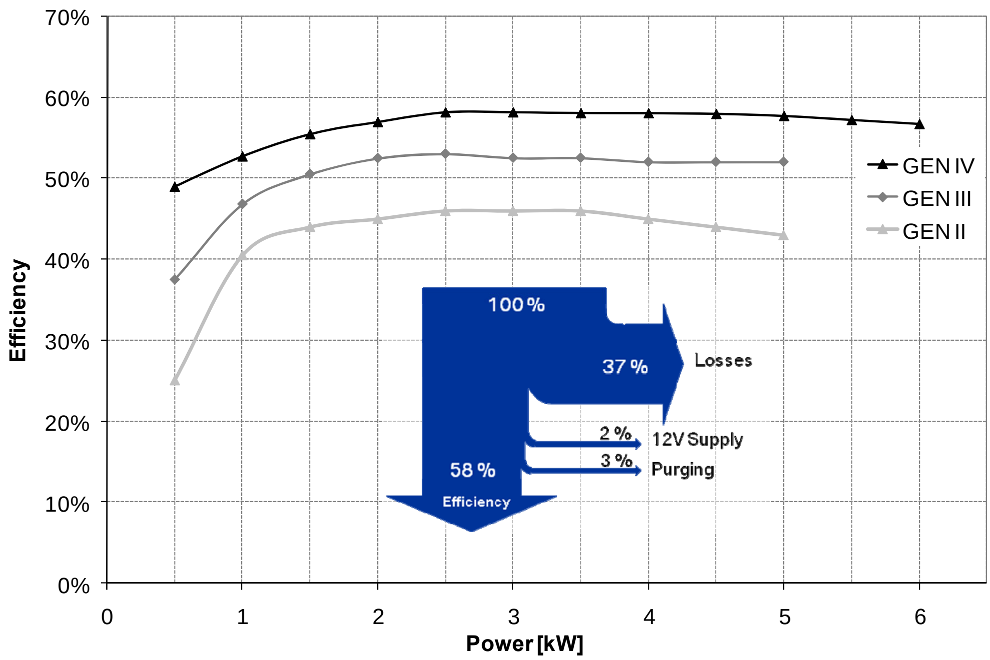
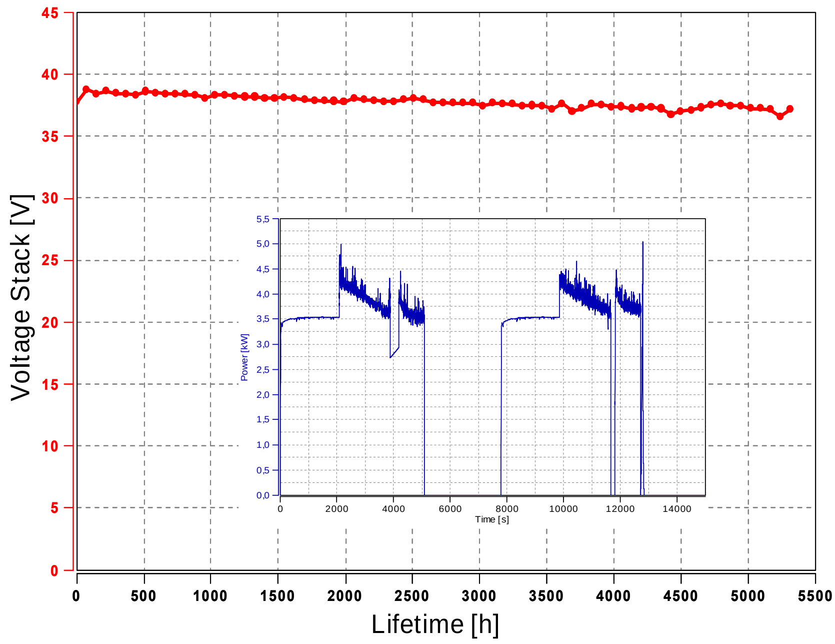


Figure 2: Efficiency of APU Generations II to IV.

Graphite porous bipolar plates are used to manage the water produced in the stack. Water diffusion through the bipolar plates enables the direct humidification of the reactants in the flow fields which ensures that the membrane is properly hydrated under all operating conditions. Additionally water removal from the cathode channels is enhanced. These measures result in an extended lifetime of the stack. Figure 3 shows the decrease of the stack voltage against the lifetime. Under test conditions that simulate use in a vehicle, the current GEN IV system reaches a lifetime of 5000 h in which a degradation of 5.5 µV/h per cell occurs. Also one important topic for the APU application is the dynamic response if the load changes rapidly. To replace the vehicle alternator with a battery, the fuel cell voltage must be above a certain limit at all times. Extreme testing with sudden changes from almost zero to full load is shown in figure 3. The response time is in this case is below 5 ms.

a)



b)

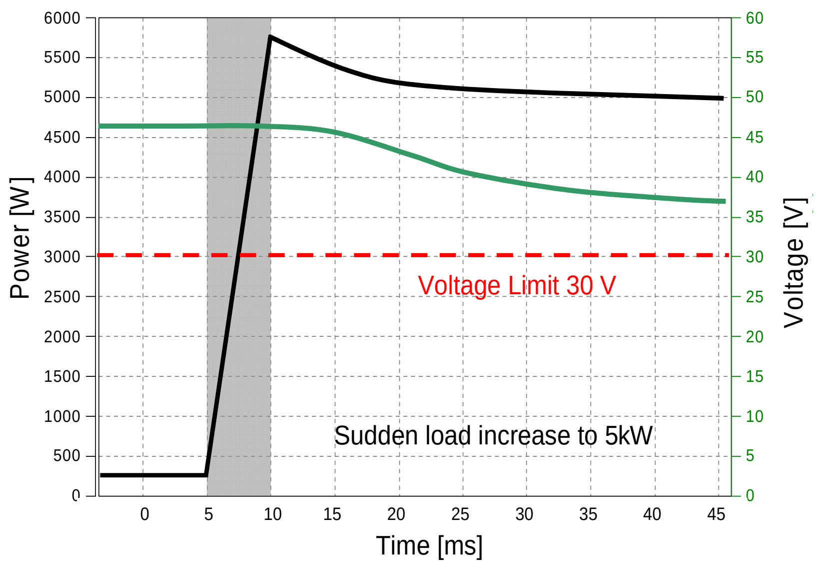


Figure 3: APU relevant test cycles a) Load profile b) Transient response.

With the help of water diffusion and evaporation of the water within the stack, an internal cooling system is also possible. This means no additional cooling circuit with a full flow cooling pump is necessary. A small pump, providing a slight vacuum pressure on the cooling water against the hydrostatic pressure is necessary. To reach a positive water balanced system at up to 60 °C, a condenser extracts the water from the cathode exhaust. If the system shutdowns, the water will flow naturally (with the help of gravity) to a reservoir. The complexity of the system is dramatically reduced. As a result, robustness and low cost are achievable.

3 Freeze Capability

The major challenge for mobile fuel cell applications is the cold start up at temperatures below 0 °C. In this case, the cooling water is completely frozen if the fuel cell is exposed to cold surrounding temperatures for more than one day.

The porous bipolar plates hold a small amount of water in the stack, which is sufficient to ensure the humidification of the reactants at the start initiation. This means no additional, external humidification is necessary. The system is able to deliver power to the vehicle 30 seconds after start-up. A certain amount of power is used internally to melt ice in the water reservoir at the bottom of the fuel cell system. This water is used for cooling and humidification when the system is heated up to normal operating temperatures.

In diagram 4, the voltage at different load levels during a period of 200 freeze start tests is shown. Only marginal changes in the fuel cell behavior after the tests indicate a very robust system under freeze conditions.

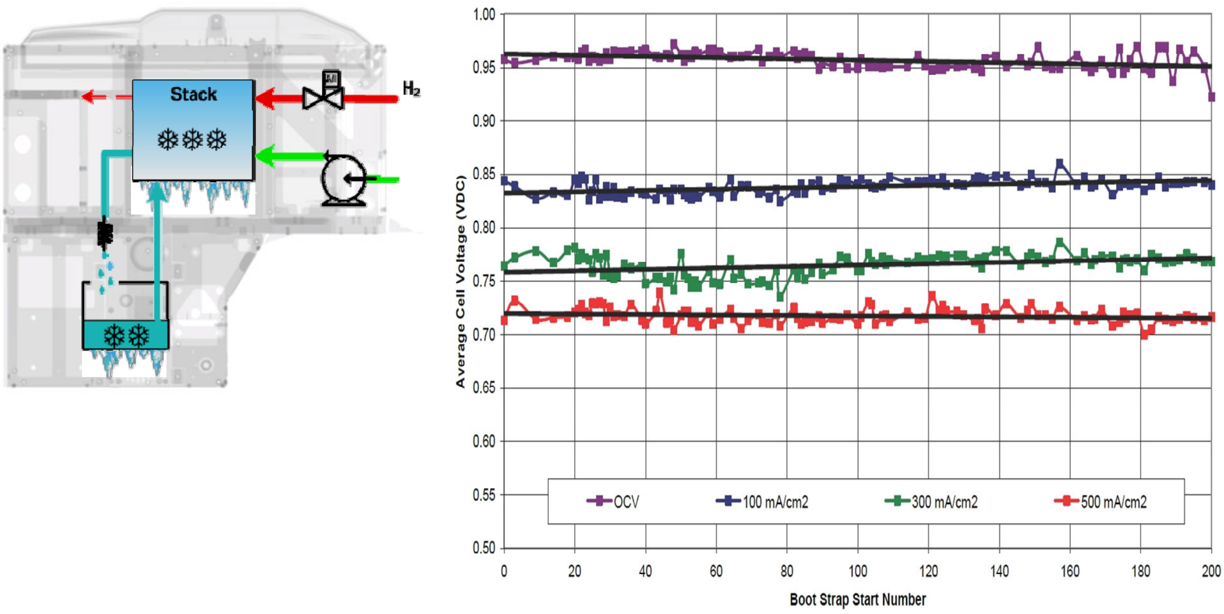


Figure 4: Scheme of the Fuel cell at freeze conditions and cell voltage during 200 starts.

Beside the lifetime investigation, startup tests with inclined systems are performed at the test stand. Testing the fuel cell with a maximum tilt angle of 17° in two directions (pitch and roll) should discover possible areas affected by ice blockage. These angles simulate extreme parking and freeze start positions. Figure 5 shows the frozen stack and the tilted freeze start with the climate chamber at the BMW test facility.

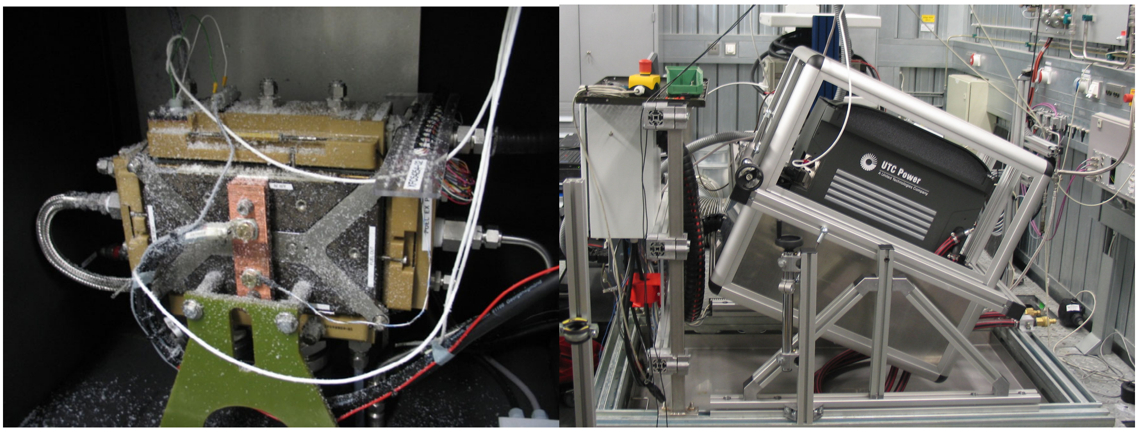


Figure 5: Freeze test of stack and system with vehicle relevant load profiles.

4 Fuel Cell Hybrid Car

The next step of the APU application in vehicles will be at BMW to supply power to the drive train at low speed. This concept allows driving without any emissions in urban and suburban areas. Based on analysis of the urban drive cycle, which is shown in Figure 6, only a power of approximately 3 kW is necessary to drive the vehicle during the whole cycle. With replacement of the alternator, in summary a power of 5 kW depending on the vehicle (e.g. weight, air resistance…) is required during the cycle. This average power and the supply of the 12 V board net can be handled with a very small fuel cell. Due to the low power output, an energy storage system is also needed to ensure acceleration and short driving periods at high speed (e.g. overtaking). With the use of the super capacitors, a recovery of the braking energy at deceleration is possible. This recuperation saves energy in the drive cycle and reduces fuel consumption.

The drive train of the 1-series car consists of one branch with a front wheel drive powered by the internal combustion engine. A second branch with a small fuel cell, super-capacitor and electric engine drives the rear axle. To charge the energy storage and for feeding the electrical engine, a DC/DC converter is necessary to shift the voltage from the fuel cell level to the drive voltage potential. Figure 7 shows the package of the car. With the shown arrangement of the components, the concept offers no significant customer disadvantages in case of space and payload.

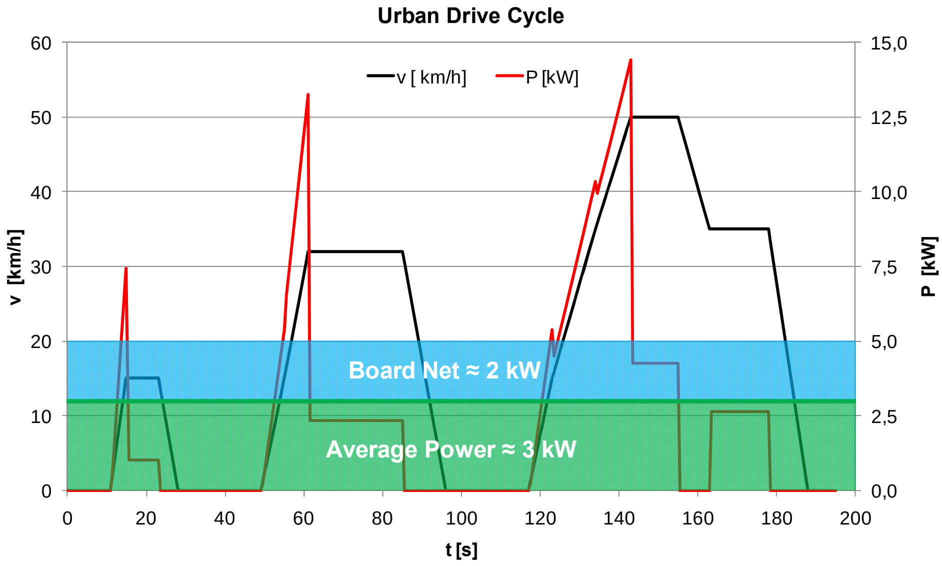


Figure 6: Urban Drive Cycle and average power.

The electric power train is designed to reach the highest efficiency in an urban drive cycle. Fuel consumption lower than 1 kg hydrogen per 100 km was measured at the dynamometer test stand with the vehicle undergoing the urban city cycle. Several city drives at warm and winter conditions confirm also these measurements. Driving at higher speed or at longer uphill distances, the internal combustion engine is switched on to ensure the demand of higher power. The fuel cell acts in this case as a pure APU and also improves the efficiency of the IC Engine by supplying the board net.

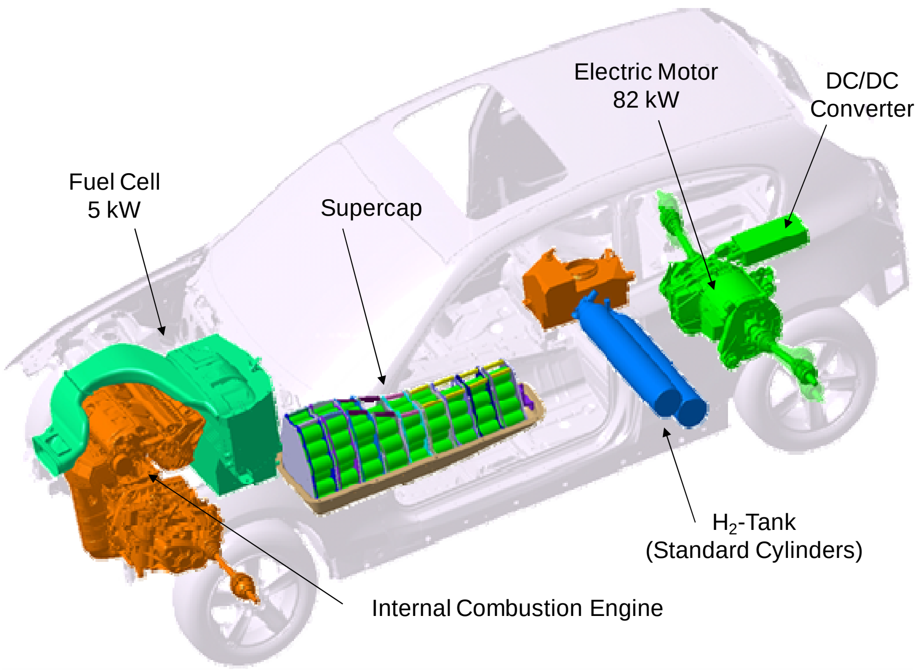


Figure 7: Package of the 1-series, fuel cell hybrid car.

According to this configuration, a vehicle concept is reasonable which ensures new customer benefits and allows driving without emissions in urban regions. During the introduction phase, the IC Engine can also be powered with gasoline or diesel. Hydrogen, supplied from the growing hydrogen infrastructure in cities can be used simultaneously with the two fuel vehicle concept. This technology has the potential to ensure the individual sustainable mobility in the future.

5 Summary

The developed APU system uses air and hydrogen at nearly ambient pressure and is designed for an electrical load of 5 kW. The high automotive requirements for lifetime and start up time at low temperatures are met without any significant degeneration of the system. With an immediate response from idle to full load, the APU offers an auspicious substitute to the electric generator and battery used today. Besides the higher efficiency compared to the alternator, the fuel cell can be operated independently from the internal combustion engine and therefore enables additional functionality for the customer e.g. air conditioning and office applications at standstill. In the car project, a zero emission vehicle was built up to demonstrate the feasibility to drive with only 5 kW APU power in urban areas. A maximum fuel consumption of 1 kg hydrogen per 100 km is feasible.

References

[1] J. Tachtler, T. Dietsch, G. Götz: "Fuel cell auxiliary power unit – Innovation for the electric supply of passenger cars?", SAE Technical Paper Series 2000-01- 0374, SAE 2000 World Congress, Detroit, 2000

[2] K. Pehr, S. Burckhardt, J. Koppi, T. Korn, P. Partsch: "Hydrogen– the fuel of the future – The BMW 750hL", ATZ, 2002

[3] A. Schüers, A. Abel, C. Fickel, M. Preis, R. Artmann: "12-Cylinder hydrogen engine in the BMW 750hL", MTZ, 2002

[4] M. Schneider, G. Götz, B. Fleming: "PEM fuel cell systems in automotive vehicles – the auxiliary electric power unit of the future", NHA conference, 2004

[5] S. Friedmann, C. Jones, R D Mesiti, M. André, P. Carminot, M. Audient, A Künzer, N. Kyriakis: „Hybrid Vehicle Technology: A sustainable development for efficient zero emission mobility?" 6th international EAEC conference an "Lightweight and small cars-the answer to future needs", Cernobbio, Italy 1997