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Feasibility study on fuel cell propulsion for urban city buses and delivery trucks

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Abstract

An investigation on the feasibility of fuel cell propulsion for urban buses and delivery trucks [1] was carried out by Ludwig-Bölkow-Systemtechnik GmbH between summer 1994 and spring 1995 and was financially supported by the Bavarian State Ministry of Economics, Transport and Technology [BStMWVT] as well as financially supported and sponsored with own contributions by the participating Bavarian industry (Daimler-Benz Aerospace AG [DASA], Linde AG, Magnet-Motor GmbH [MM], MAN Nutzfahrzeug AG, Neoplan, Siemens AG). A steering committee composed of representatives from the participating industry, the ministry [BStMWVT] as well as from Erlanger Stadtwerke AG [ESTW] and Solar- beginning of 1996 and shall lead to two bus demonstrators in early 1999 and possibly a delivery vehicle later.

The feasibility study dealt with the following issues: client / operator requirements, membrane fuel cell propulsion concept, electric drive concept, fuel supply and storage concept, possible vehicle concept, relevant rules and regulations, market requirements, environmental considerations and proposals for pilot demonstration activities.

The feasibility study came to the conclusion that the realization of the proposed fuel cell vehicle concepts within 2 to 3 years is technically feasible. Cost reduction potentials

Wasserstoff-Bayern GmbH [SWB] was installed which accompanied the feasibility study and the subsequent detailed specification phase, which was carried out between spring and late summer of 1995. The hardware realization has been started at the furthermore indicated that the technological concept will find a market under more stringent requirements for the reduction of vehicle-induced air pollution in urban areas.

1. Introduction

Traffic emissions have to be reduced significantly. This is not only true for especially sensitive areas such as health resorts, but also for highly polluted areas as are most conurbations. In these areas, solutions especially for public urban transport and the necessary commercial traffic have to be identified and developed. Vehicles with electric traction systems where the necessary electric current is produced by hydrogen driven fuel cells have to be considered as a promising solution.

The herewith presented project aims at theoretically and practically showing the technical feasibility and the economic viability of hydrogen driven fuel cell traction systems for urban buses and delivery vehicles. The ultimate goal is to promote clean vehicle propulsion concepts which produce no harmful local emissions whatsoever and which are potentially carbon dioxide free.

The theoretical feasibility of fuel cell traction systems for the aforementioned vehicle types has been shown in a feasibility study carried out by LBST between summer of 1994 and February 1995 and was financially supported by the Bavarian State Ministry of Economics, Transport and Technology [BStMWVT] as well as financially supported and sponsored with own contributions by the participating Bavarian industry: Daimler-Benz Aerospace AG [DASA], Linde AG, Magnet-Motor GmbH [MM], MAN Nutzfahrzeuge AG, Gottlob Auwärter GmbH & Co, Neoplan and Siemens AG. Further contributions were made by Erlanger Stadtwerke AG [ESTW] and Solar-Wasserstoff-Bayern GmbH [SWB].

The practical proof of concept will be offered by the realization of two bus demonstrators (MAN, Neoplan) and possibly one delivery vehicle demonstrator (MAN). The detailed specification of these vehicles was carried out between March and August 1995. In December 1995 a proposal prepared by the partners was worked out and sent to the Bavarian and Federal governments together with the request for a 50 % co-financing of the entire activity. The development of the buses has begun in January 1996 and is planned to last until early 1999. The possible construction of a delivery vehicle is envisaged but has not yet been decided upon.

2. Results of the feasibility study

Detailed technical considerations of membrane fuel cell propulsion concepts, electric drive concepts, fuel supply and storage concepts as well as possible vehicle concepts led to the conclusion that vehicles with hydrogen driven fuel cell propulsion are technically feasible. Given the world-wide fuel cell activities, this result was to be expected.

Furthermore, it was shown that even for first demonstrator vehicles only minor reductions of the passenger and/ or freight capacity have to be accepted. The higher weight of the vehicles compared to conventional diesel technology are due to both the fuel cell and the hydrogen storage system.

In detail, the following technical results were obtained:

- The PEM (Proton Exchange Membrane) fuel cell technology is being identified as the most suitable fuel cell technology for traction systems. Its current state of the art is being presented.
- A description of various electric traction systems leads to the respective definition of a

fuel cell electric system and a fuel cell electric system with magneto-dynamic flywheel storage (MDS) for break energy recuperation and peak load coverage. Wheel-mounted drive motors are an interesting alternative to central motors accommodated at the side under the seats, allowing for a much more flexible vehicle design, e.g. the realization of a 100 % low floor concept.

- The different possible fuel and reactant supply systems and their present state of the art are presented. It was shown that both the filling station technology and the on-board storage techniques are available. Nevertheless, present technical progress is significant and new designs will be available already for a first prototype vehicle within two to three years' time.
- The integration of all vehicle components into a vehicle concept shows that the present state of the art allows the design of prototype fuel cell vehicles. In a realistic operation (150 km to 300 km per day), only minor restrictions have to be accepted. Furthermore, standard city buses with hydrogen fuel have to be refuelled daily in contrast to the usual refuelling period of two days for diesel buses in Germany.

Investigations of the market requirements for fuel cell traction systems show that the technological concept will find a market under more stringent requirements for the reduction of vehicle-induced air pollution in urban areas. Fuel cell bus prices comparable to those of trolley buses in the short term and comparable to those of compressed natural gas (CNG) buses in the medium term seem realistic with respect to the expected development of fuel cell prices for small scale series production. These target prices together with competitive costs of renewably produced hydrogen will open a significant market segment for zero emission fuel cell vehicles, also with zero CO_2-emissions. This development can be strongly enhanced by progressive political boundary conditions and incentives for environmentally sound technologies as well as by assigning environmental criteria their proper market relevance.

3. Demonstration project

The project status presented here is of January 1996

Vehicle Design

For the practical demonstration of the feasibility of hydrogen driven fuel cell traction systems for urban buses and delivery vehicles two bus demonstrators are presently being designed. The possible development of a delivery vehicle has not yet been decided upon.
The buses will be low floor city buses with a passenger capacity of 100 persons, a length of 12 meters and a maximum total weight of 18 tonnes. They will be based on the MAN NL 222 diesel bus and the Neoplan N 4114 DE diesel electric bus, respectively (see *figures 1* to *3*).

The electric traction system of the MAN bus will consist of a standard central drive motor coupled to the rear axle via a mechanical reduction gear unit. The Neoplan bus on the other hand will be propelled by two wheel-mounted drive motors. For break energy recuperation a magneto-dynamic flywheel storage is integrated into the traction system, also covering the peak power demand of the Neoplan bus thus reducing the necessary fuel cell power. Consequently, the Neoplan bus will be equipped with a fuel cell system delivering half the power output of that of the MAN bus. The magneto-dynamic flywheel storage has an energy capacity of 2 kWh_e only, but a short term power capacity of an average of 150 kW_e, which underlines its power supply rather than energy storage function.
The fuel cell system for the Neoplan bus will deliver a maximum net electrical power of 60 - 90 kW_e to the drive motors, the exact maximum continuous power still being subject of further development. For the MAN bus the fuel cell system will deliver double this power output. These systems are designed for ambient temperatures of 4 °C to around 30 °C, maximum relative humidity of 60 % at 30 °C and ambient pressures of 0.09 to 0.11 MPa. The fuel cell systems must be protected from minus C degrees because of the use of de-ionised water in the interior of the cells. This temperature restriction of course only applies to outdoor stays of the bus in non-operational mode as the fuel cell sufficiently heats itself up during operation. For future vehicles in practical everyday use a remedy for this inconvenience will have to be found.

The fuel cell will be operated with air as reactant at an input pressure of 0.15 MPa, which will be delivered by an electrically driven compressor. The overall net efficiency of the fuel cell module (related to the lower heating value of hydrogen) will be just about 55 % at 100 % power output and will reach a maximum of about 63 % at about 20 % power output. The net efficiency (lhv) of the entire fuel cell system will be somewhat below 50 %.

The hydrogen for the two buses will be stored in compressed gaseous form (CGH_2). The on-board storage system will consist of 12 fully composite materials roof-top mounted storage vessels with a total geometric volume of 2.2 m^3 and a maximum operating pressure of 25 MPa.

Project costs

The costs of the project (including two vehicle demonstrators, the peripheral equipment and the test phase of half a year) will be roughly 20 million DM (approx. US$ 14 million), the most costly component being the fuel cell system.

Demonstration of the vehicles

After the realization and testing of the two buses, their demonstration with a public bus operator for a period of half a year is planned. The place of demonstration has not yet finally been selected. Nevertheless, the City of Erlangen, Bavaria, is a probable choice. Further operation of the bus demonstrators is yet to be defined. Several potential demonstration sites with the availability of hydrogen fuel are presently under preparation in Bavaria.

4. Outlook on commercialization perspectives conclusion

According to several international investigations, fuel cell propulsion technology is assigned a significant potential for improving energy efficiency [2, 3, 4, 5] as well as a drastic reduction potential of local and global emissions. Using renewable energy sources zero emission behaviour is achieved over the entire chain of energy supply and usage.

Taking into consideration the urgent need for air quality improvements in metropolitan areas all over the world on the one hand and on the other hand the need for CO_2-reductions in the light of an exponentially growing world-wide motorization (500 million motor vehicles today, probably reaching some 2.5 billion in the year 2040) fuel cell propulsion seems to have a bright perspective. Prerequisites are the reduction of the fuel cell propulsion unit costs to competitive levels within the next years as well as the provision of enough and economically priced renewable energy sources. Both goals are being pursued in first pilot projects and programmes which are under way [6, 7].

5. Literature References

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Vehicle	Standard city bus	Standard city bus	Delivery vehicle *(Realization not yet decided)*
Based on	MAN NL 222	Neoplan N 4114	MAN L2000
Length Max. total weight	12 m 18 t	12 m 18 t	8.9 m 7.5 t
Passenger / freight capacity	100 passengers	100 passengers	3 t
Electric drive concept	central motor	wheel-mounted drive motors	central motor
FC power (net)	120 — 180 kW_e	60 — 90 kW_e	90 — 120 kW_e
Buffer storage	none	MDS — magneto-dynamic storage (2 kWh_e, 150 kW_e)	none
Brake energy recuperation	no	yes	no
Simulated energy consumption[1]	231 kWh_{LHV}/100 km	163 kWh_{LHV}/100 km	133 kWh_{LHV}/100 km
H_2-storage	CGH_2	CGH_2	t.b.d.

[1] Drive cycle „Linie 66"; 50 passengers (bus), 2 t (delivery vehicle); higher weight due to fuel cell system and an LH_2 storage system considered.

Figure 1 Basic design data of the demonstrator vehicles.

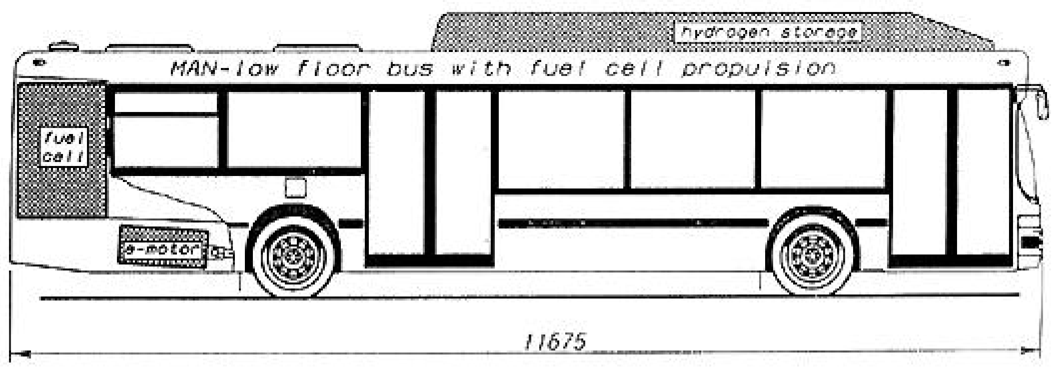

Figure 2 MAN prototype fuel cell bus based on NL 222.

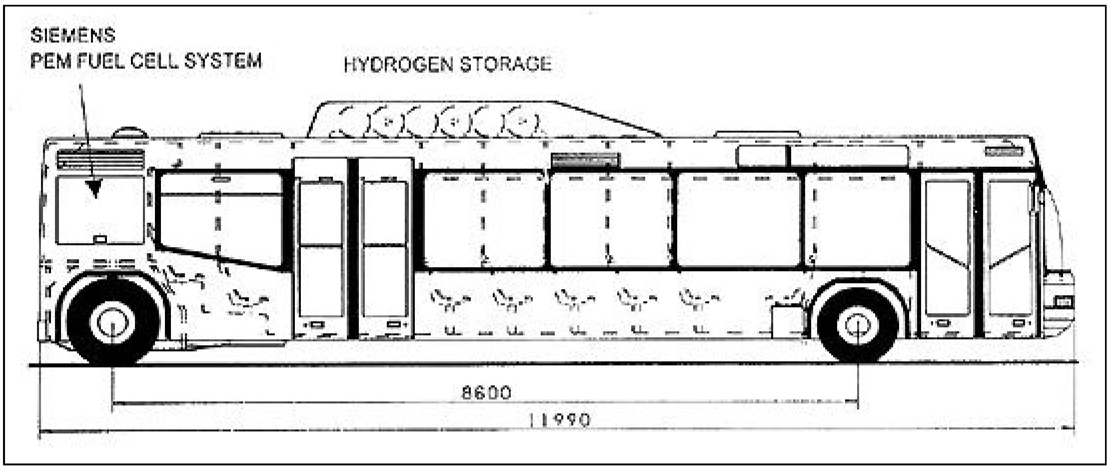

Figure 3 Neoplan prototype fuel cell bus based on N 4114