European Commission

New Solutions in Energy Utilisation

Seventh Technical Report (Final Report)

Phase II

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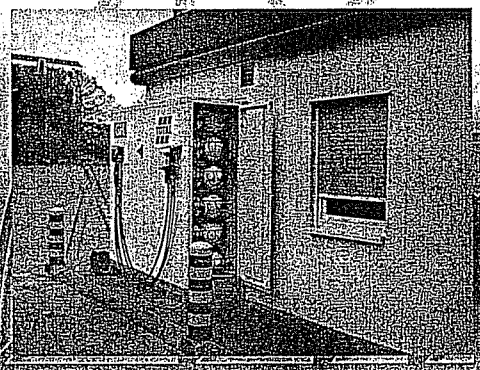

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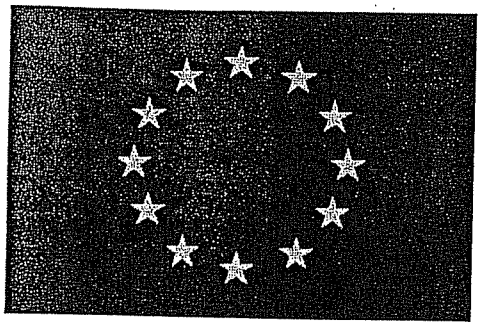
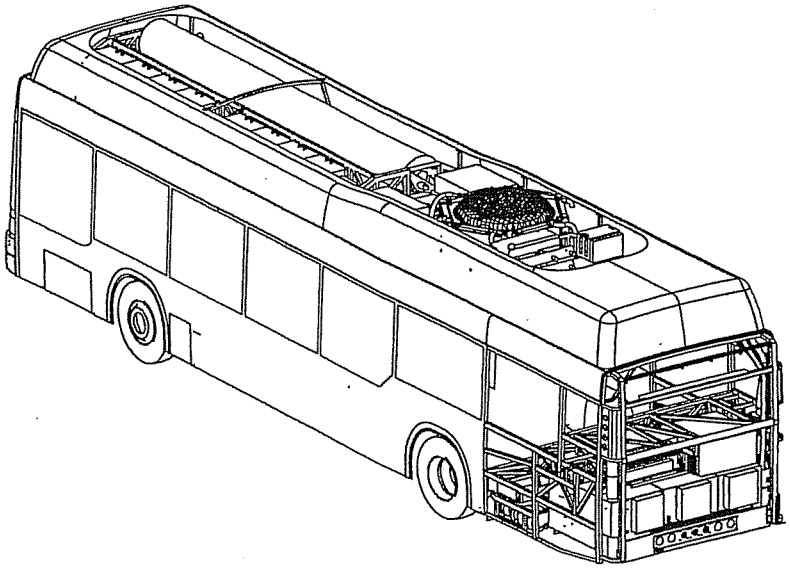
Directorate-General for Energy



Final Technical Report (01.03.2003 – 17.07.2003)

Fuel Cell Bus Berlin, Copenhagen, Lisbon II

CONTRACT N° NNE5-1999-00312



Edited by:

- Berlin Senate, Berlin, Germany
- BVG, Berlin, Germany
- MAN, Munich, Germany
- Air Liquide DTA, Sassenage, France
- Copenhagen Transport, Copenhagen, Denmark
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- Ar Liquido, Lisbon, Portugal
- MVV Consultants and Engineers GmbH, Berlin, Germany

SESAME DATA SHEET

COMMISSION OF THE EUROPEAN COMMUNITIES **Directorate-General for Energy and Transport** **B-1049 Brussels**	**Project Nr.:** NNE5-1999-00312	**Updated:** 01.09.2003
Title: **Fuel Cell Bus for Berlin, Copenhagen, Lisbon II**		**Decision:** Reference:
Principal Contractor: - Senate of Berlin, Germany **Associated Contractors:** - BVG, Germany - MAN, Germany - AIR LIQUIDE DTA, France - Copenhagen Transport, Denmark - IST, Portugal - CARRIS, Portugal - Ar Liquido, Portugal		**Site of Project:** Berlin, Copenhagen, Lisbon Project leader: Senatsverwaltung für Wirtschaft, Arbeit und Frauen Mr. Horst-Jürgen Rösgen Martin-Luther-Str. 105 D - 10825 Berlin Germany Tel.: +49-30-9013-7562 Fax: +49-30-9013-7568 E-mail: horst-juergen.roesgen@senwiarbfrau.verwalt-berlin.de
Sector: Transport		**Period of project:** 01.03.2000 – 17.07.2003 **Project duration:** 40,5

Type of phase:	Total Cost of project	Eligible Cost of project	EC Contribution	
	€	€	%	€
Design				
Manufacturing				
Installation				
Commissioning				
Monitoring				
Total:	**5,230,516**	**5,230,516**	**35%**	**1,830,680**

Keywords	Fuel Cell Bus, Hydrogen Filling Station, Hydrogen Infrastructure, Public Transport
Aim of project: (1000 characters max.)	The "Fuel Cell Bus for Berlin, Copenhagen, Lisbon II" project is the follow-up project to the "Fuel Cell Bus for Berlin, Copenhagen, Lisbon" project. Its aim was to demonstrate and further develop the first European fuel cell bus using liquefied hydrogen in an inner-city application and to implement a related infrastructure. Unfortunately, due to severe problems with the development of the fuel cell technology during phase I of the project, it was not possible to commence the demonstration phase of the fuel cell bus within this phase. Nevertheless, it was possible to gain important experiences on the state-of-the-art of European fuel cell technology and the resulting requirements for the electrical storage systems on board. The main parts of the second phase of the project were: • Development, construction and implementation of the electrical storage system to support the fuel cell system • Development, construction and implementation of a stationary hydrogen filling station • Demonstration of the bus in an inner-city environment and of the filling station infrastructure.
Project description: (3000 characters max.)	The second phase of this project consisted of: • Comparison and evaluation of different energy storage systems such as super capacitors, fly wheel and battery systems.

	• Installation and demonstration of the most suitable energy storage system in the Fuel Cell bus. • Demonstration and monitoring of the first liquid hydrogen filled Fuel Cell Bus in regular fleet operation in three European capital cities. • Investigation of brake energy recovery, use of different rear axle differential, investigation of power demand for different routes, etc. • Creation of a public stationary hydrogen filling infrastructure, including an emergency hydrogen production facility using a natural gas reformer. The hydrogen storage at the filling station has a capacity of 12,000 l (cryogen tank). • Development of a simulator. This was responsible for simulating operational conditions of the bus. It is capable of identifying the required route power based on the number of passengers, desired acceleration level, topography, etc. • Comprehensive measurement and monitoring programme showing the environmental benefits and costs. Due to the severe problems with the development of the fuel cell technology during phase I of the project, the consortium proposed to the European Commission on 3 June 2003 to start the demonstration using an MAN hydrogen internal combustion engine bus. This bus already participated in the inauguration of the filling station for the demonstration of the refuelling process. The bus could have begun operation immediately after after strengthening the gaseous refilling capacity of the compressors and related equipment at the filling station. The bus and the filling station could then have been demonstrated from September 2003 to February 2004 in Berlin. This would have allowed the BVG to gather urgently needed data on the operation of the hydrogen filling station. This bus implementation would have in so far been important, as the project was accompanied by massive press and public relations activities which successfully targeted the broad dissemination of hydrogen as one of Europe's fuels of the future. The vehicle which was suggested for implementation is already assembled. It is powered by a MAN H2866UH01 dedicated hydrogen combustion engine with a maximum output of 140 kW at 2,200 1/min and a maximum torque of 700 Nm at 1,000 1/min. The vehicle with a maximum weight of 18 t provides space for 94 passengers (37 seats, standing room for 57 passengers). With a letter dated 17 July 2003 the European Commission unfortuanately refused to accept this change to the original work programme of Phase II of the project. Herewith the implementation of a hydrogen powered bus was not possible in the framework of this project.
Results (3000 characters max.)	In the second phase of the project the following results were achieved: **Development, construction and implementation of the electrical storage system to support the fuel cell system**: In the first instance, the energy storage system was planned to support energy efficiency and economy of the project. The energy storage system should store brake energy making it available again for the following acceleration process. Detailed investigations on suitable technologies were undertaken. Due to the reduced performance of the fuel cell system, the selected concept had to be totally reconsidered. An energy system became necessary which is permanently available to support the performance of the fuel cell bus during acceleration. MAN developed both of these systems and prepared the fuel cell bus to incorporate the electrical storage system. Order and implementation of the system has been abandoned due to the technical difficulties in phase I of the project. **Development, construction and implementation of a stationary hydrogen filling station**: The stationary filling station has been constructed, commissioned and successfully implemented. The inauguration of the stationary filling station took place on 23.10.2002 and received excellent public attention and press coverage. **Demonstration of the bus in an inner-city environment and of the filling station infrastructure:** The demonstration of the innovative fuel cell propulsion system was planned to outline not only the benefits to be obtained from a zero emission fuel, but also the advantages of this type of bus from a design point of view and the performance of the energy storage system. During the commissioning of the fuel cell stacks however, Air Liquide detected an increased liquid hydrogen content in the exhaust gas of up to 10% during the bench tests. In particular,

	this high hydrogen purge would have required a complete re-design of the whole system to comply with safety standards. Furthermore, the applied fuel cell technology suffered under a performance reduction due to corrosion processes inside the system. When another leakage appeared while integrating the fuel cell system with the bus during the on the road testing, TÜV refused to provide certification for the demonstration with the participation of the public. The Consortium decided to abandon further tests with the fuel cell bus, but they did agree on an alternative suggestion with the main purpose being to make a hydrogen vehicle available to use at short notice and to demonstrate the hydrogen filling station at Usedomer Str. This would allow the gathering of important operation experiences from the hydrogen filling station and the handling of hydrogen in vehicle operation. This experience is urgently necessary for the implementation of other fuel cell projects in Berlin such as: • Fuel Cell Articulated Bus project, co-financed by the German Ministry of Economy • Clean Energy Partnership • CityCell project, NNE5-2001-00689 etc. MAN offered its hydrogen internal combustion engine bus to the project for demonstration purposes. This bus has already participated in the inauguration of the filling station for the demonstration of the refuelling process. The bus could have been put into operation immediately after strengthening of the gaseous refilling capacity of the compressors and related equipment at the filling station. The upgrade of the filling station would have need approximately four months. The bus and the filling station could have been demonstrated from September 2003 to February 2004 in Berlin. This change to the work programme was proposed to the European Commission on 3 June 2003. With a letter dated 17 July 2003 the European Commission unfortuanately refused to accept this change to the original work programme of Phase II of the project. Herewith the implementation of a hydrogen powered bus was not possible in the framework of this project.
References	• Model of the fuel cell bus for promotion at the permanent exhibition on innovative technologies "Innovationspark Berlin" organised by the Bewag in Berlin which started in June 2000 and at special events, e.g. from May 2000 until September 2000 at the building of the European Commission, DG TREN, Rue de la Mot in Brussels accompanied by a poster • "Tag der Brennstoffzelle (Fuel Cell Open Day)" in Munich on 08.05.00. During this meeting the previous model of the MAN fuel cell bus was presented for a test run. • Conference on "Prospects for Fuel Cells in a European Research Area", Tervuren - Brussels, Belgium – 29th and 30th May 2000, organised by the European Commission. For this event, in addition to the oral presentation, posters and two articles were prepared. • World Bus & Clean Fuel Summit in Los Angeles on 31.05.00 • CARRIS prepared a presentation of the Fuel Cell Bus project • "Hydroforum" in Munich on 13.09.00 • Articles on the project were published on the Internet • „VDV Tagung Wasserstofftechnologie"(Association of German Public Transport Companies: Conference on Hydrogen Technologies) at the VAG Nuremberg, 06.12.00 • Symposium "Zukünftige Elektroantriebe für Omnibusse" (Future electric drives for buses) in Darmstadt, on 19.01.2001 • UITP meeting in Maastricht, on 06.02.01 • Vienna Energy Day, on 5.12.2000 • "fuel cells bulletin", Issue 12/2000 • Seminar on "Motor Combustion" at the House of Technology, on 12./13.3.2001 • "Gás Veicular" conference in Lisbon with a lecture on "Pilhas de Combustivel Projecto em desenvolvimento subsidiado pelo Programa Thermie", on 11-12, October 2000 • "Protap - Pilhas de Combustivel" conference in Lisbon with a lecture on "Autocarros can Porpulsão a pilhas de combustivel", on 20 November 2000 • "Protap – Veiculos Verdes" conference in Lisbon with a lecture on "Novos desafios impostos pela aproximação ao conceito do veiculo verde", on 25 January 2001 • "Innovation dans les Transports Public Sur Route" conference in Maastricht, on 7-9 February 2001 • Hanover Industrial Fair 2001 • "Bavarian Regenerative Fair" in Augsburg

- "Clean Air VI - sixth international conference on Technologies and Combustion fo Clean Environment", Porto, on 9-12 July, 2001
- "Bus Technik, heute und morgen: Fuel cell technology, Hanover"
- 54th UITP World Congress in London (UK), on 20-25, May 2001
- APEMETA Eficiência Energética e Energias Renováveis in Lisbon and Oporto, on 2 June
- *"Was there no technological development in the last 20 years ?"* within the framework the conference 'Technologies and Combustion for a Clean Environment- Clean Air', o 9-12, July 2001
- "Clean Air VI - sixth international conference on Technologies and Combustion for Clean Environment", Porto, on 9-12 July, 2001
- "7th National Conference on Environmental Quality", Aveiro, April 2001
- "Hydrogen infrastructure development – how to gain a sustainable approach?" at Total ir Paris, 15.06.2001
- CARRIS prepared a leaflet on the project
- MAN presented the project at the conference "BZ im Automobil (Fuel Cell Applications in Vehicles)" in Frankfurt September 2001
- Electric Vehicle Symposium EVS 18 in Berlin, October 2001
- Prosper Congress "Hybrid Technology in Public Transport – Advanced transport technologies" in Karlsruhe, on 19.09.2001
- Bus Exhibition and Conference on "Marketing Environmental-Friendly Public Transport" organised by "Transporti Tutti" in Verona, on 15 – 16.11.2001
- VDV meeting on "Innovative Propulsion Systems" in Nuremberg, on 06.12.2001
- Voyager Conference on "Public Transport Infrastructure and Rolling Stock" in Brussels, on 22.-23.01.2002
- Carris interview on a state television programme dealing with innovation issues (2010 at RTP). The central topic during that interview was the fuel cell bus.
- OPET MERCOSUR road show with a presentation "Transportes -sua contribuicao para um desenvolvimento sustentavel" in SAG PAULO (Brazil), on 21/22 November 2001
- Personal interview to the 2010 RTP 2 TV programme in Lisbon, on 18 October 2001
- Inauguration of the new hydrogen laboratory at the German Bundesanstalt für Materialforschung und –prüfung (State Organisation for Material Research and Testing) on 18.10.2001 in Berlin
- National Conference on Environmental Quality, 18-20 April 2001, Aveiro, Portugal (paper entitled "Autocarro a pilha de combustível (Berlin, Copenhaga, Lisboa)")
- Sixth International Conference on Technologies and Combustion for a Clean Environment – Clean Air, 9-12 July 2001, Oporto, Portugal (paper entitled "Fuel cell bus Berlin, Copenhagen and Lisbon: A sustainable and environmental technology for the urban passenger transportation sector")
- Transport and Air Pollution: 10th International Scientific Symposium, 17-19 September 2001, Boulder, CO, USA (paper entitled "The Fuel Cell Bus Berlin, Copenhagen and Lisbon: a sustainable and environmental technology for the urban passenger transportation sector")
- Urban Transport and the Environment 2002", Eighth International Conference on Urban Transport and The Environment in the 21st Century, 13 – 15 March 2002, Seville (paper entitled "Fuel cell bus Berlin, Copenhagen and Lisbon: a sustainable and environmental technology for the urban passenger transportation sector")
- Urban Transport and the Environment 2002", Eighth International Conference on Urban Transport and The Environment in the 21st Century, 13 – 15 March 2002, Seville (paper entitled "Analysis of Environmental Impact of Urban Buses: Application to a Case Study in Lisbon")
- Workshop "Alternative Energy on Road Transport", Lisbon, January 29, 2002
- Workshop "Future Solutions on Road Transport", Almada, May 25, 2002
- 7th International Conference on Modeling and Simulation of Electric Machines, Converters and Systems, Montreal, August 18-21, 2002 (paper entitled "Hybrid Electric Buses: Dimensioning the Intermediate Electric Storage Stage")
- The project operates its own home page under http://euweb.de/fuel-cell-bus.

Potential users (1000 characters max.)	The potential users are public transport companies who are looking for environmentally clean transport solutions.
Company description (250 characters max.)	The "Senatsverwaltung für Wirtschaft, Arbeit und Frauen" is a local public authority with 600 employees. It co-ordinates all activities in public transport and supervises the public transport company of Berlin (BVG)
Size of company (number of employees)	600 employees
Manufacturers (1000 characters max.)	• **Fuel cell bus**: MAN low-floor vehicle type NL223 • **Fuel cell**: Nuvera formerly deNORA, net power is 75 $kW_{max,}$ integration: Air Liquide • The **electric power system** including power electronics: Siemens Transportation Systems / Erlangen. Likewise, **voltage increase devices** for adjusting the voltage of the fuel cell modules which is too low have been designed and manufactured by Siemens. • **Components for the secondary cooling system**: Längerer & Reich. The power for the ventilators comes from the modular system designed by Siemens TS • **Filling infrastructure**: Furthermore, Linde also supplies both the mobile and stationary filling stations (the mobile filling station is part of phase I of this project). This ensures complete compatibility of the total liquid hydrogen supply from delivery to application in the vehicle. • **Electrical energy storer**: EPCOS was planned to be the supplier for the electrical energy storer. The EPCOS system uses supercondensators for brake energy recovery. As an alternative, an additional supercondensator system manufactured by a Swiss company and a new type of storage concept manufactured by Electrastor was taken into consideration. Due to the reduction in performance of the fuel cell system, it became necessary to fall back in the short term on another storage concept. Therefore, the integration of a system with high temperature batteries produced by the company MES-DEA was taken into consideration. In parallel to this test, bench trials with a new type of storage system manufactured by the company Electrastor were undertaken.
Estimated energy production saving in KW_{th} h and/or KW_{el}h or TOE*	N.N.
Estimated payback:	N.N.
Status:	Completed
State of progress (1,000 characters):	see above under Results
Published literature:	see under References

* 1 MW_{th} .h = 0.086 TOE (or TEP), 1 MW_e .h = 0.258 TOE (or TEP)

Contents List

Summary

The "Fuel Cell Bus for Berlin, Copenhagen, Lisbon II" project has been the follow-up project to the "Fuel Cell Bus for Berlin, Copenhagen, Lisbon" project. It was aimed at demonstrating and further developing the first European fuel cell bus using liquefied hydrogen in an inner-city application as well as at the implementation of a related infrastructure.

The main components of the project comprised:

- Comparison and evaluation of different energy storage systems such as super capacitors, fly wheel and battery systems.
- Installation and demonstration of the most suitable energy storage system in the Fuel Cell bus.
- Demonstration and monitoring of the first liquid hydrogen filled Fuel Cell Bus in regular fleet operation in three European capital cities.
- Investigation of brake energy recovery, use of different rear axle differentials, investigation of power demand for different routes, etc.
- Creation of a public stationary hydrogen filling infrastructure, including an emergency hydrogen production facility using a natural gas electrolyser. The hydrogen storage at the filling station has a capacity of 12,000 l.
- Development of a simulator being responsible for simulating operational conditions of the bus and being capable of identifying the required route power, based on the number of passengers, desired acceleration level, topography, etc.
- Comprehensive measurement and monitoring programme showing environmental benefits and costs.

The project aimed at showing the benefits of different energy storage systems and offered solutions for the installation of a hydrogen refilling infrastructure. It provided guidance for manufacturers and researchers on further needs for action regarding fine-tuning of technology and the decision for a clean fuel for tomorrow and how this can be applied.

Due to the fact, that the fuel cell bus could not be implemented in Phase I of the project, the demonstration component of the project had to be cancelled.

1 Project details

Project Number	**NNE5-1999-00312**
Title of Project	**Fuel Cell Bus Berlin, Copenhagen, Lisbon II**

Technical Report (N° 7)

Period covered: from 01.03.2003 to 17.07.2003
Date of report: 01.09.2003
SESAME-Sheet-enclosed: yes

	1st Contractor	**2nd Contractor**
Name of the Company	Senatsverwaltung für Wirtschaft, Arbeit und Frauen	Berliner Verkehrsbetriebe
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	3rd Contractor	**4th Contractor**
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Report prepared by	Name of company	MVV Consultants and Engineers GmbH
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Period covered: from 01.03.2003 to 17.07.2003; Date of report: 01.09.2003

Report approved by Senatsverwaltung für Wirtschaft, Arbeit und Frauen, project co-ordinator, Mr. Horst-Jürgen Rösgen.

Senatsverwaltung für
Wirtschaft, Arbeit und Frauen
Martin-Luther-Str. 105
Postanschrift | Hausanschrift
10820 Berlin | 10825 Berlin

Berlin, 01.09.2003

Technical Report (N° 7)

Contract Number **NNE5-1999-00312**
Title of Project **Fuel Cell Bus Berlin, Copenhagen, Lisbon II**

	5th Contractor	**6th Contractor**
Name of the Company	HT Copenhagen	Companhia de CARRIS de Ferro de Lisboa, S.A.
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	7th Contractor	**8th Contractor**
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2 Aim and general description

2.1 Aim of project

The "Fuel Cell Bus for Berlin, Copenhagen, Lisbon II" project has been the follow-up project to the "Fuel Cell Bus for Berlin, Copenhagen, Lisbon" project. It was aimed at demonstrating and further developing the first European fuel cell bus using liquefied hydrogen in an inner-city application as well as at the implementation of a related infrastructure.

Unfortunately, due to severe problems with the development of the fuel cell technology during phase I of the project, it was not possible to commence the demonstration phase of the fuel cell bus within this phase. Nevertheless, it was possible to gain important experiences on the state-of-the-art of European fuel cell technology and the resulting requirements for the electrical storage systems on board.

The main parts of the second phase of the project were:

- Development, construction and implementation of the electrical storage system to support the fuel cell system
- Development, construction and implementation of a stationary hydrogen filling station
- Demonstration of the bus in an inner-city environment and of the filling station infrastructure.

2.2 Description of projects and sites

This project's target was the completion of the demonstration approach of the first European fuel cell bus using liquefied hydrogen in an inner city application.

The second part of the project aimed at showing the benefits of different energy storage systems and offered solutions for the installation of a hydrogen refilling infrastructure. The project provided guidance for manufacturers and researchers on further needs for action regarding fine-tuning of technology and the decision for a clean fuel for tomorrow and how this can be applied.

In the first phase, the project consisted of the build-up of one fuel cell bus. Furthermore, a mobile filling station was developed and successfully tested. The demonstration of the fuel cell bus in inner urban application, namely in the cities of Berlin, Copenhagen and Lisbon had to be cancelled due to continuous technical problems in the technology development. The bus operators investigated the operational preconditions for the fuel cell bus technology according to the particular technical requirements of the technology.

The Berlin Bus company selected the 109 bus route between the airport and the city centre. The bus was planned to be based at the BVG depot on Usedomer Straße. This depot is also the location of the BVG's stationary filling station and Hydrogen Competence Centre, please refer to section 2.3.3. The mobile filling station would also have been located in the Usedomer Straße depot.

The bus would have undergone test runs in Lisbon. The route selected for Lisbon was adopted for the operation of the fuel cell bus. After the strong reduction in performance of the fuel cell power module became obvious, Carris selected a different route. The bus should also have undergone test runs in Copenhagen for one month under the operation of HT.

Of special interest during the identification of these routes for test runs was how factors such as climate and geography (e.g. flat/hilly terrain) can influence the fuel cell bus. In addition, the

project investigated the advantages of using fuel cells in buses compared to the use of conventional fuels.

An operation plan was set up and implemented in each city, please refer to the final report of phase I. The full integration of the fuel cell bus within the respective bus fleets was also planned during the demonstration period.

It was planned to analyse the performance of the test runs in relation to inner city conditions. Economic data such as vehicle reliability, technology, operation and fuelling should have been gathered as part of a process to establish the market viability of this technology. The project has developed the methodology and the technical interfaces to carry out a comprehensive measurement programme which could clearly show the environmental benefits to be gained from the introduction of a technology which provides a 100% reduction in emissions, please refer to the final report of phase I.

The project has also investigated the advantages for passenger comfort resulting from the innovative design which has been made possible due to the application of fuel cell technology and the use of an electric drive. The fact that the technology permits a low floor bus design throughout the length of the bus enhances passenger and user acceptance. Fig. 2-1 gives a summary of phase I of the project.

Vehicle Type Length, weight (max.) Basic bus Propulsion system LH_2- storage Electric storage system (phase II)	**MAN Nutzfahrzeuge AG** Low-floor NL 263 bus 12 m, 18 t NL A21, diesel-electric Central drive unit (Siemens): 2 x 75 kW, summation gearbox Linde: 600l LH_2, -253°C; 60kW, 25kWh; battery/super capacitors (tbd)
Fuel cell system Fuel cell stacks power output (net)	**Air Liquide (France)** Nuvera (formerly De Nora, Italy) 75 kW_{net} (120 kW_{net} originally planned)
Bus operators	**BVG/Berlin** Rent of the basic bus (type diesel-electric) Mobile hydrogen filling station Delivery of hydrogen Route analysis and selection of route Bus operation plan **CARRIS (Portugal)** Route analysis and selection of route Mobile hydrogen filling station Bus operation plan Ar Liquido Portugal: Hydrogen supply **HT (Denmark)** Mobile hydrogen filling station Investigation of safety aspects
Simulation FC-system, telematics	**IST (Portugal)**
Co-ordination of project	**Berlin Senate**

	MVV Consultants and Engineers GmbH
Financial support (40%)	**EC DG TREN, THERMIE A, Energie**

Fig. 2-1: Summary of the project

The second phase of this project consisted of:

- Comparison and evaluation of different energy storage systems such as super capacitors, fly wheel and battery systems.
- Installation and demonstration of the most suitable energy storage system in the Fuel Cell bus.
- Demonstration and monitoring of the first liquid hydrogen filled Fuel Cell Bus in regular fleet operation in three European capital cities.
- Investigation of brake energy recovery, use of different rear axle differentials, investigation of power demand for different routes, etc.
- Creation of a public stationary hydrogen filling infrastructure, including an emergency hydrogen production facility using a natural gas electrolyser. The hydrogen storage at the filling station has a capacity of 12,000 l (cryogen tank).
- Development of a simulator being responsible for simulating operational conditions of the bus and being capable of identifying the required route power, based on the number of passengers, desired acceleration level, topography, etc.
- Comprehensive measurement and monitoring programme showing environmental benefits and costs.

Due to the fact, that the fuel cell bus could not be implemented in Phase I of the project, it was suggested to the European Commission to start the demonstration using an MAN hydrogen internal combustion engine bus instead of the fuel cell bus. This bus already participated in the inauguration of the filling station for the demonstration of the refuelling process. The bus could have been put into operation immediately after strengthening of the gaseous refilling capacity of the compressors and related equipment at the filling station. The upgrade of the filling station would have needed approximately four months. The bus and the filling station could have been demonstrated from September 2003 to February 2004 in Berlin.

The testing of the bus and the filling station would have been carried out by the BVG for six months in Berlin on the route between Tegel airport and the city centre.

This change to the work programme was proposed to the European Commission on 3 June 2003. With a letter dated 17 July 2003 the European Commission unfortunately refused to accept this change to the original work programme of Phase II of the project. Herewith the implementation and demonstration of a hydrogen powered bus was not possible in the framework of this project.

2.3 Description of the installation

From a technical point of view this project was composed of an extension to the innovative fuel cell bus project, the demonstration and evaluation of the fuel cell propulsion system, the extension of the bus with one of three optional electrical storage systems (battery, fly wheel and super cabs) and the erection of a stationary hydrogen filling station.

The bus should have been powered by a Fuel Cell Propulsion System, i.e. a static device used to generate electric power. It converts the chemical energy of a fuel and oxidant directly into electricity without combustion. Hydrogen fuel and air react at low temperature (80°C) thus

producing electric power and pure water only as a by-product. Its energy efficiency is high, typically between 50 and 60% over a wide range of loads (50-100%). The absence of moving parts reduces to a minimum maintenance, manpower requirements and down-time. The low operating temperature allows for a fast start-up.

The intrinsic advantage of a fuel cell over a conventional internal combustion engine is clear. The engine produces energy through the intermediate step of combustion. The use of combustion limits efficiency to 20-25% and produces waste heat and noise; the high temperature of combustion generates polluting by-products such as SO_x, NO_x and particulates in addition to hydrocarbons.

The fuel cell has many advantages over the most advanced batteries currently available, providing a higher power density and power volume (e.g. to 25kW/kg or 0.3kW/l) and solving problems of space constraints. It does not require re-charging since it operates as long as fuel is available and it has a much longer operating life compared to other batteries available. It employs no corrosive liquid electrolytes and has no moving parts. Its components can, therefore, be easily recycled at the end of its operating life, thus avoiding the environmental problems associated with battery disposal. The fuel cell has much greater flexibility with regard to the site of installation.

These extremely favourable characteristics of the fuel cell technology allow applications where intermittent operation is required and where safety and reliability must be enhanced. These factors make it an ideal technology for use in all types of road vehicles, especially heavy trucks and buses.

Fuel cell technology operated on liquefied hydrogen is well below the EC norms "Euro I" and "Euro II". Emissions are even lower than the "Euro III" norm which was introduced in 1998/9 ($CO/HC/NO_x/PM = 2.0/0.6/5.0/0.1$ g/kWh).

The technology to be implemented under phase I of the project consisted of:

The fuel cell system: The fuel cell technology was designed by the Italian company Nuvera, formerly named DE NORA s.p.a. Nuvera is sub-contractor to Air Liquide in the project.

The Nuvera fuel stacks have been integrated by the French company, Air Liquide DTA. The original design comprised a power module with a net power of 120 kW_{max}. The 120 kW_{net} power module consists of 3 x 40 kW Fuel Cell Module (FCM) assembled on a common frame. The elementary 40 kW FCM was developed as a standard module with 110 cells per stack. However, due to necessary internal modifications, the pressure drop was increased and the cooling water flow in the stacks was reduced, resulting in a decreased power output. The new net power obtainable from the power module was measured on Air Liquide's test bench as 75 kW at design cooling water temperature. Each system contains the following main integrated items:

- Air compressor, directly connected to the stack
- Fuel cell stack
- Water management and recovery system on both parts (anodic and cathodic side)
- Hydrogen feeding and recycling system
- Primary de-mineralised water cooling loop including water/water heat exchangers
- Micro-programmable logic controllers (control-command) which communicate individually to the main bus controller at CAN bus.

The heat produced is dispelled by a common freeze-proof secondary loop, which contains a fan and an air heat exchanger. The power modules are placed in specific locations at the rear of the vehicle.

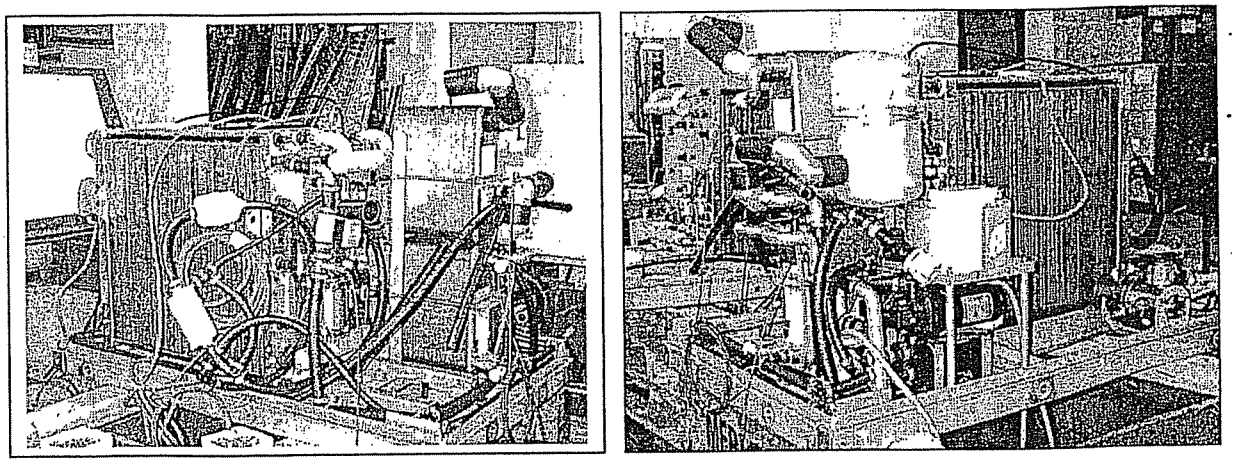


Fig. 2-2: Fuel cell system (during montage)

The power module is fed by hydrogen at the required flow pressure and temperature and delivers non-converted current, the specification of which results from the stack assembly. Energy for the compressor and the power module auxiliary is operated under generally steady conditions, controlled locally within the power module.

Due to technical problems arising during the commissioning of the fuel cell module in the bus, TÜV refused to provide certification for the demonstration with the participation of the public.

The fuel cell bus: The basic vehicle used is a new generation MAN low-floor bus with its interior fitted in line with the requirements of the Berlin public transport company, "Berliner Verkehrsbetriebe, BVG". It is an NL263 series low-floor 12m dual axle city bus with an additional legal permissible weight of 18 tonnes. For route operation in Berlin, a rear axle load of 11.5 tonnes is given. The bus has a capacity of about 70 to 75 persons. Approximately 40 seats are available. The interior of the bus has been elaborated according to the specifications of the Berlin Transport Company (seating, handrails). The outside varnish corresponds to the MAN hydrogen design.

The fuel cell device, the electric power including the power electronics as well as the additional vehicle components and heating are housed at the rear of the bus. All remaining power components, e.g. air-conditioning and liquid hydrogen storage have been mounted on the roof of the bus. The complete fuel cell unit from Air Liquide is housed in the rear of the bus, pre-assembled on a special frame. The power converters for the fuel cell drive and the voltage adjustment have been assembled and wired via the fuel cell modules on a free-standing platform fixed inside the vehicle.

The on-board liquid hydrogen tank manufactured by Linde has a capacity of 600 litres of liquid hydrogen. Both the on-board liquid hydrogen tank including the LH_2 periphery and the "fill-in-space" for the electrical energy storer have been installed on a special rack designed by MAN which has been assembled towards the front of the bus roof section.

The vehicle drive consists of two three-phase asynchronous motors manufactured by Siemens, each with a power of 75 kW which are linked to the series rear axle via a mechanical summing gear/transmission. A central electric drive is used to generate the auxiliary energy

required by the vehicle for the compressed air and power steering. This has been housed in the lower floor area on the left hand side directly in front of the fuel cell modules.

Fig. 2-3 shows the complete bus including the components of the tanks and the cooling system.

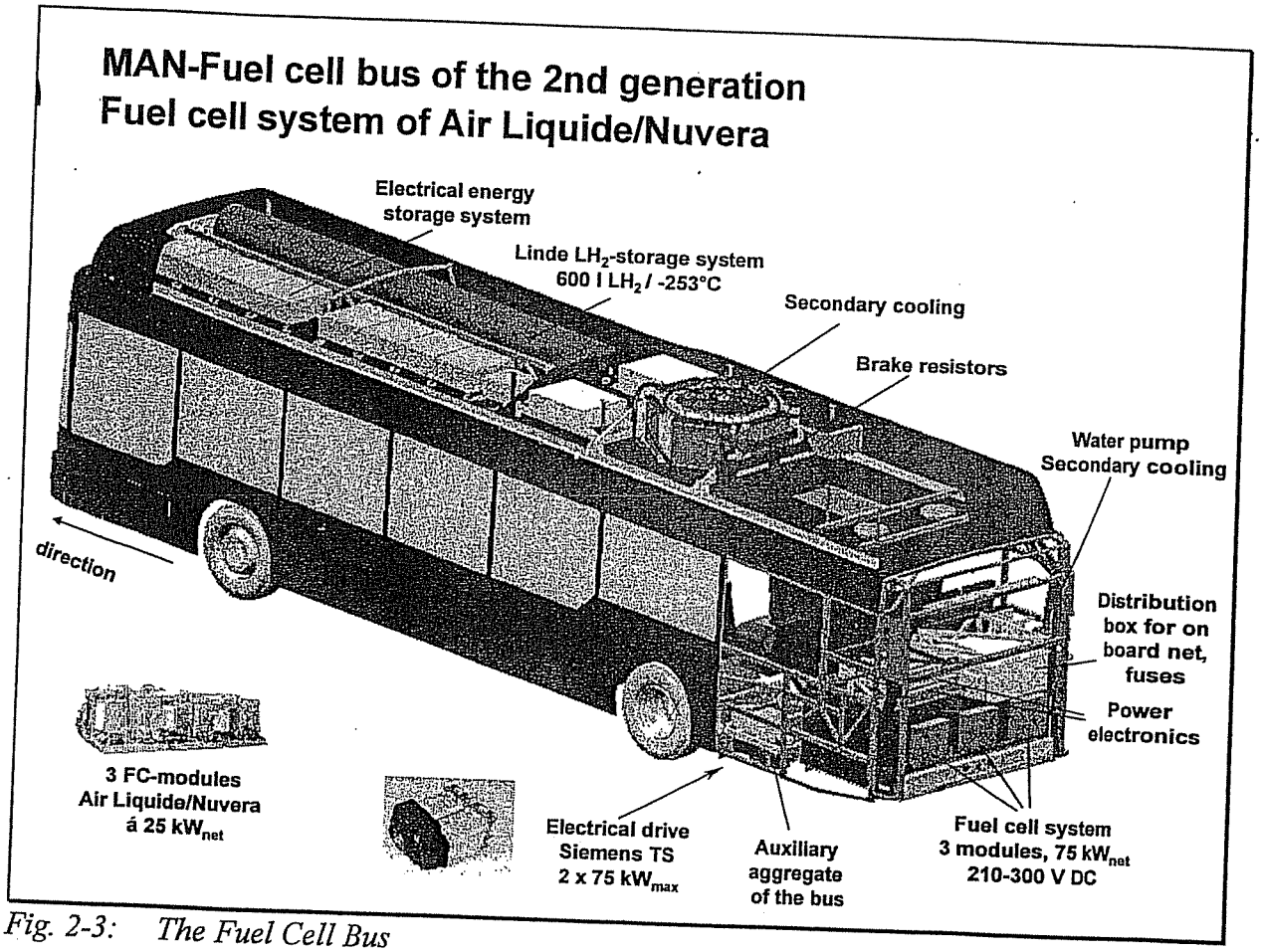


Fig. 2-3: The Fuel Cell Bus

2.3.1 The energy storage system

Within the second phase of the project the bus should have been equipped with an electrical storage system which was originally intended for the provision of peak demand and for an increase of energy efficiency through the recovery of brake energy. During operation, an electrical storage system in the braking system was planned to recover energy dynamically from the engine operation.

Particularly suitable options for this are fly wheels, super capacitors and the latest type of battery storage.

All the different options and the control system for energy management were investigated within the scope of the project for their suitability. For the evaluation of the different electrical storage systems, different characteristics of the energy storage systems were compared. These are, for example:

- Relation of energy content to charged or discharged performance of the storage. This relation describes the time necessary to discharge or charge the storage system.
- Frequency of charges and discharges
- Availability on the market

- Costs.

Typical technical characteristics for different energy storage systems are shown in Fig. 2-4. In addition, the use of a flywheel energy storer through the non-frictional storage of a rotating mass to enable the greatest possible loss-free storage of energy was investigated. The loss-free, self-stabilising storage of the rotating parts is possible through a high temperature super conductor. The principal effect of this type of storage is to fix a magnetic flow within the properties of the super conductor materials. If it comes into contact with a permanent magnet with a symmetrical rotational inhomogeneous field, then a stabilising reserve power is registered in all directions. This technology makes it possible to fuse the rotor and storer of a permanent magnetic drive with one another. This renders maintenance mechanics unnecessary. The storer runs on a contact-free and friction-free basis. Fig. 2-5 and Fig. 2-6 show the main layout.

Storage technology	Energy density [Wh/kg]	Performance density [W/kg]	Energy / Per-formance [sec]	Number of cycles, life time	Efficiency [%]
Fly wheel	5-50	180-1,800	100	10^6	90-95
Battery	30-200	100-700	>1,000	1,000	80-85
Capacitor	2-5	7,000-18,000	<1	$>10^6$	>95

Fig. 2-4: Comparison of different electrical energy storage systems[1]

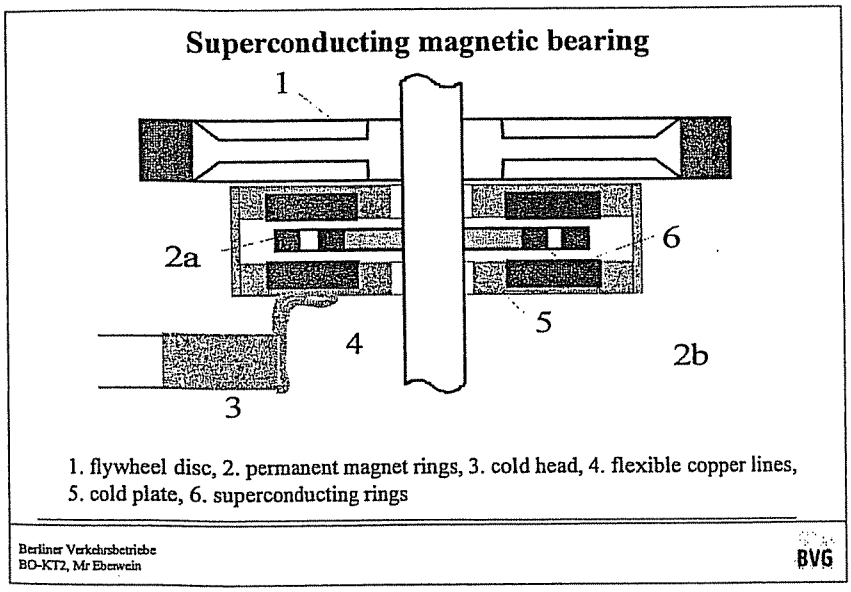


Fig. 2-5: Superconducting magnetic bearing

1 Burg, Peter von: Moderne Schwungmassenspeicher – eine alte Technik in neuem Aufschwung, Zürich

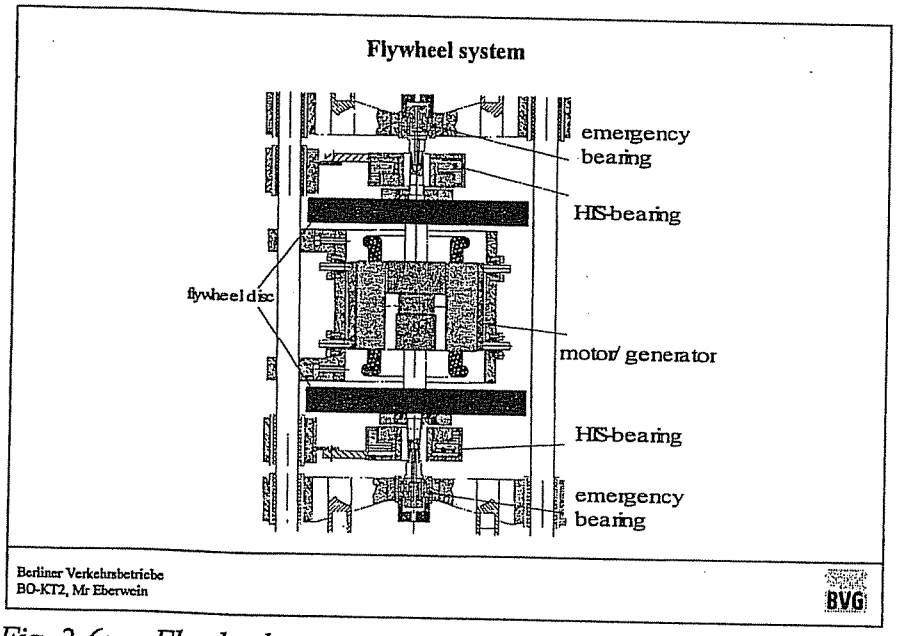


Fig. 2-6: Flywheel system

Due to the high performance density, high efficiency and availability on the market at a reasonable cost, it had been decided to use a supercapacitor for the recovery of brake energy and to increase the overall efficiency of the fuel cell bus system.

However, due to a reduction in the performance of the fuel cell system from 120 kW_{net} to 75 kW_{net} another solution had to be found.

This investigation was carried out by MAN and the results are summarised in Fig. 2-7. A decision to use a Zebra-battery has been made.

• Ultracaps	Too low energy content
• Zebra-battery	Suitable, limited lifecycle (approx. 1-2 years)
• NiMH battery	Suitable, very high costs, time delay
• Lead battery	Non suitable (cycles), too slow chargeability; time delay
• Li- Ion	New system, very high costs, time delay
• New concepts	New concept, to be checked, not suitable for short term installation

Fig. 2-7: Summary of results on a suitable energy concept

2.3.2 Liquefied hydrogen as a fuel

Hydrogen is one of the most widely available chemical elements in the world. However, it is predominantly found in a combined form which prevents it from being used directly as a fuel. Nonetheless, hydrogen can be produced from water through electrolysis, for example, using renewable electricity, by reforming from natural gas or by gasification of biomass and cleaning of the gas obtained. The availability of hydrogen through these methods is virtually inexhaustible. The fuel cell reverses the process of electrolysis. The release of electrical energy produces actual water from hydrogen and oxygen.

When hydrogen is produced from renewable energy sources, the operation of the fuel cell bus can have a substantial impact on the reduction of greenhouse gases.

In this project the fuel cell technology uses liquefied hydrogen. This is at the specific request of the bus operators who require a daily capacity of at least four hundred kilometres per tank

filling under normal urban application. Optimal hydrogen storage is therefore necessary to fulfil this demand. Where optimal storage capacity is concerned, as with other gases, it is necessary for hydrogen to be in a liquid form. When comparing the systems, liquid hydrogen storage systems are more efficient as far as volume and weight are concerned. Please refer to Fig. 2-8 for a direct comparison of the characteristics of liquefied and gaseous hydrogen.

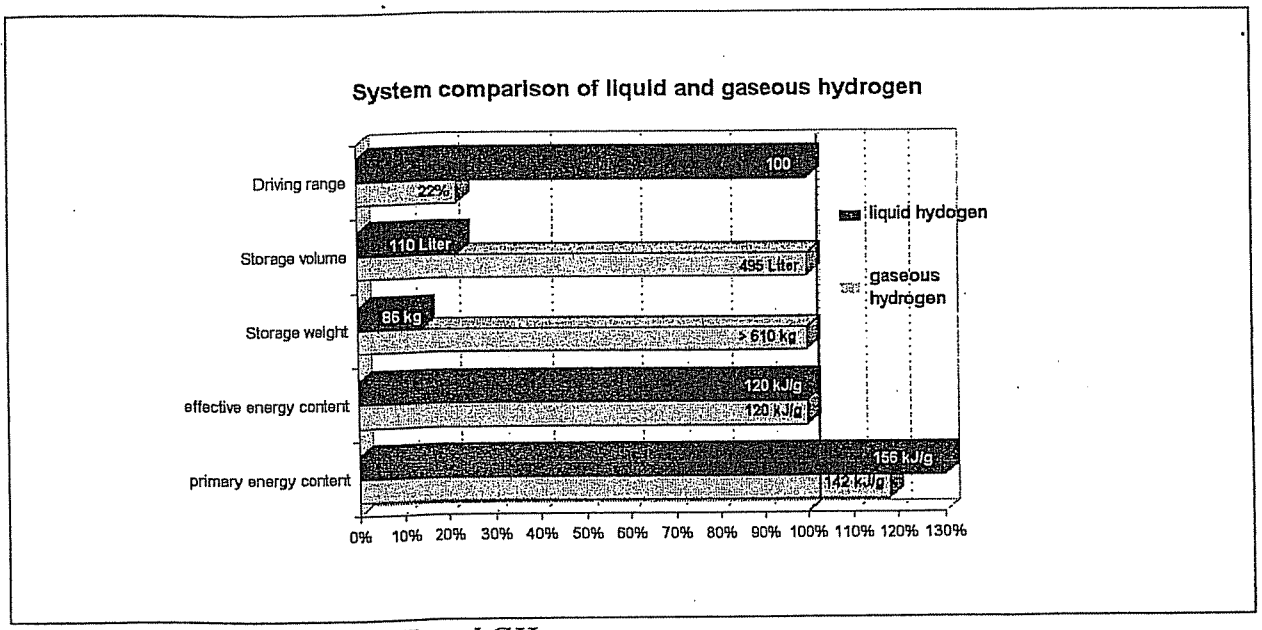


Fig. 2-8: Comparison of LH_2 and GH_2

2.3.3 Stationary hydrogen filling station

The project included the construction and operation of a public hydrogen filling infrastructure. The hydrogen storage at the filling station has a capacity of 12,000 l (cryogen tank). However, the ideal situation would be for hydrogen to be recovered from renewable energy sources. Produced through renewable energy sources, hydrogen provides the cleanest solution for the emission-free transportation of people and goods.

The stationary filling station is located at the BVG's bus depot on Usedomer Straße.

The LH_2 filling equipment has been installed in a container on a concrete base. The filling connection points are clearly marked as safety areas and have a radius of 5m. Within these safety areas no inflammable sources, no additional installations and no traffic or unauthorised personnel are permitted. The installations are also protected against unintentional knocks.

The LH_2 filling equipment primarily consists of:

- The filling connection points
- Two nitrogen bottles for the preparation of the pneumatic auxiliary energy
- An inerterisation unit running on helium with vacuum pumps
- A liquid hydrogen pumping system for filling the vehicle
- The necessary fittings, hoses, pipelines and safety equipment
- 12,000 litres hydrogen cryogenic storage.

For the fuelling process, no external auxiliary energy is required with the exception of an alternating current. The alternating current is taken from an alternating current power point which is located outside the safety area.

In addition to the normal fuelling process, the following operations are possible:

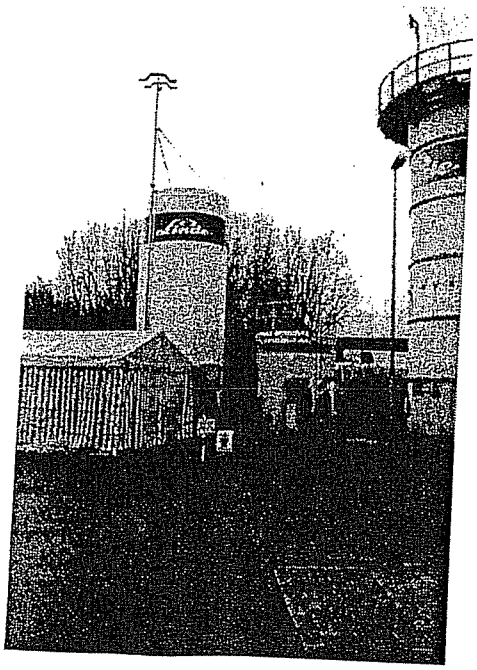


Fig. 2-9: Stationary filling station during the commissioning at Linde

- First time fuelling (evacuating, rinsing and cold start operation of the tank) and
- Removal from operation (emptying the tank of LH_2 and making the system inert).

The fuelling process as well as the above-mentioned operations are regulated on a fully automatic pneumatic basis. The pneumatic regulation of the fuelling process is fixed in such a way that only the correct installation of the fuelling connections will permit the fuelling process to function. The fuelling hoses are vacuum super insulated transfer pipes.

One of the most advanced parts of the liquid hydrogen station is the LH_2-transfer pump for filling the vehicle.

The complete three cylinder pump consists of three main parts: a vacuum isolated storage container; the pumps themselves which are individually pushed into the storer and the wobble plate drive.

The capacity of the pump is approx. 3,000 l/h, the pressure difference between the suction side and the pressure side is approx. three bar. In this way super-cooling of the boiling hydrogen is achieved.

A securely integrated pressure casing built into the liquid storage is located in the storer in order to fix the three pumps and through which the pressure sides of the three pumps are connected to each other.

The considerably smoothed transfer of the conveyance liquid from the pressure casing occurs as a result of pulsating cushions over a similarly integrated measuring stretch.

Due to individual installation and drawback pumps, the size of the relevant cross sections on the pumps for heat transfer as well as the storage tanks can be kept to a minimum

To maintain a constant liquid level in the storage tanks, an optoelectronic sensor should be fixed to the connecting flange. This describes the liquid level in the storer. Special valve technology allows the defined liquid level to be maintained in the storer. For this purpose either the liquid intake or the gas draw-off of the storer is opened.

Fig. 2-10: Fittings of the stationary filling stations

The drawback piston (pressure lift) in the pump immersed in the storer liquid is placed in the initial position by a spring against the lift pressure.

During the process, a gap is created between the piston body, attached to the upper piston rod and a specially designed and fixed piston ring, in order that fluid from the previous lift cycle can be moved to the pressure side of the piston.

During the lift reversing, the conveyance liquid is pressed into the common pressure casing via the membrane outlet valve.

At the moment of lift reversing, the bottom valve on the lower end of the cylinder is immediately opened. The storer liquid can flow loss-free into the space vacated by the piston. Shortly before the upper dead centre, because of the reduced diameter of the piston rod, the friction between the latter and the bottom valve is removed and the bottom valve closes due its own weight. As a result of this action, it is also possible to pump liquids with little heat from vaporisation, such as liquid hydrogen at boiling status.

The three pumps embedded in the storers are actuated by drawbars via a wobble plate drive attached to the blind flange above the lamp.

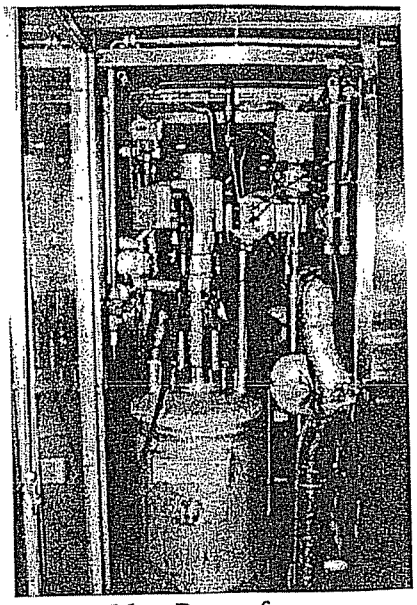


Fig. 2-11: Pump for cryogen liquids

The transformation of the rotation of the geared motor into a lifting movement occurs as a result of the combination of the wobble plate with the eccentric shaft attached to the geared motor. In order to achieve the drawbar movement necessary for the rectilineal pump actuation, the gyrating movement of the drawbars is levelled out by the crossheads.

2.4 Description of the performance of the monitoring and measuring system

IST has been responsible for the monitoring and assessment of energy efficiency, environment and economics. The objectives of the monitoring and assessment of the fuel cell bus have been to analysis energy efficiency, the environmental and economic aspects of a fuel cell bus, long-term experience, especially necessary maintenance and user acceptance (passengers and drivers). In addition to implementing measurements and monitoring of the fuel cell bus, a simulator was developed which is capable of predicting the power and fuel consumption required by the fuel cell bus to execute a specific route. Throughout the lifetime of the project, the following acitivities were performed.

The IST team developed a code named EcoGest and applied it to the project. The model calculates the power required for different working conditions as a function of travelling position for a variety of variables, such as route selected, topography, bus weight (number of passengers, quantity of fuel in the tanks), outside temperature, i.e. use of air conditioning, acceleration required to achieve the estimated performances and use of regenerative breaking. This computer software provides end users as well as fuel cell bus developers with an additional tool capable of identifying their needs in terms of power, autonomy of the fuel cell bus and selection of the most appropriate operation conditions.

A bus control system that uses the GSM/SMS network was developed in order to establish real time communication between a control station computer and the fuel cell bus. The system includes a cellular phone installed in the fuel cell bus which is responsible for collecting data from an Input /Output box in which different sensors can be plugged. The sensors can transmit either digital or analogue signals and are prepared for locating the bus position (through GPS).

An additional cellular phone directly installed in a PC at the control station captures data transmitted through GSM/SMS via the cellular phone.

The control station is capable of sending both verbal or written messages to the Fuel Cell Bus if desired by the manager.

The central station software was developed/adapted in order to properly collect, treat and manage the measured data. The central station is able to perform the following tasks:

- Identify on a real time basis the actual position of the fuel cell bus on a city map shown on the PC screen,
- Present the evolution of the data gathered as a function of the bus position (or time),
- Send alerts when pre-defined limits of any monitored equipment are exceeded. These alerts can be in the form of a signal on the screen of the central station PC, or a written or verbal message sent to the most appropriate address (e.g. the cellular phone of the bus driver, the fleet manager or the fire department).

In addition to the collection of measurement data and the monitoring of the fuel cell bus, a simulator was developed, based on the Ecogest model. It is capable of predicting the power and fuel consumption required by the fuel cell bus to execute a specific route.

IST and Carris began to run an experimental programme, the main goal of which was to characterise the dynamic and fuel consumption performance of the CARRIS fleet. While the performance of the fleet was investigated numerically, experimental data concerning specific engine fuel consumption, torque and power (versus engine speed), bus fuel consumption and typical driving behaviours were required.

Therefore, IST researchers at CARRIS have been measuring the following:

- Engine specific fuel consumption, torque and power (versus engine speed) on the CARRIS dynamometer (Zoellner)
- Dynamic characteristics (speed, acceleration and spatial position along time) of the CARRIS buses for pre-defined routes.

These data were introduced into the ECOGEST software (developed by IST). ECOGEST is now able to simulate different operating conditions and to identify the performance and environmental impact of a CARRIS bus with regard to the type of engine, bus capacity, route, etc. A comparison between ECOGEST results for fuel consumption, obtained using some inputs from real measurements of the dynamics of the bus, and the values from CARRIS showed differences of less than 15%, while additional components had not been considered (namely air conditioning).

Two researchers from the electrical engineering department modified ECOGEST in order to simulate the performance of a fuel cell bus in future.

The programme is now able to simulate the performance of a series hybrid vehicle. The main inputs to the programme are:

- Route topography
- Velocity desired for the vehicle (reference speed)
- Number of passengers inside the vehicle
- Vehicle characteristics (frontal area, weight, tire dimensions, etc.)
- Power of auxiliary systems
- Efficiency of the assemblage engine, electronic converter.

The main outputs of the programme are:

- Energetic consumption
- Maximum power of the electronic converter during the simulation

- Power of the generator group – Minimum power for the generator group
- Necessary energy for the simulated trip
- Energy supplied by the generator group
- Energy consumed by the batteries – accounting for energy recuperation
- Mean velocity
- Total distance travelled.

Fig. 2-12: Oreos 55H bus

Since the MAN Fuel Cell Bus was not available, and due to the limited time available for the researchers involved, the programme was validated with experimental results obtained from an Oreos 55H bus. Oreos 55H is a series hybrid electrical bus fed by a GPL engine and set in motion by a 25 kW alternator and batteries. The main characteristics of the bus are presented in Fig. 2-13.

Bus	Weight Maximum weight Length Height width	9350 kg 13000 kg 7.715 m 2.22 m 3.03 m
Tire	Width Wheel diameter Height	285 mm 19.5 polegadas 70%
Propulsion engine (trifasic induction engine)	Maximum power Nominal power Maximum speed Maximum torque	120 kW 75 kW 5200 rpm 500 Nm / 0-2000 rpm
Alternator	Power	25 kW
Batteries	Total tension Capacity Number	522 V 140 Ah 87 blocks of 6 V
Consumption	1 kWh/km	

Fig. 2-13: Characteristics of the bus

The results obtained showed that the programme is able to simulate this kind of propulsion systems.

In order to quantify the emissions of standard urban buses for future comparison with zero emission fuel cell buses as well as with emissions from additional automobile traffic, a study of the environmental impact of urban buses in a real inner city situation was performed (results were presented at an international conference). The study focused on several routes of CARRIS, one of the companies responsible for exploring the bus routes within the central area of Lisbon. Based on CARRIS's urban bus fleet, the topography of selected routes, the vehicles average speed and transported passengers, the CORINAIR methodology (developed by the European Environment Agency – EEA) was used to predict fuel consumption and CO_2, CO, NO_x, HCs and particle emissions from these urban buses. Experimental measurements of

the bus's dynamic performance and fuel consumption where performed in order to apply the CORINAIR methodology.

In addition, Ecogest was applied to estimate instantaneous fuel consumption as well as instantaneous and average CO_2 exhaust emissions. This study was carried out in order to evaluate the precision of the CORINAIR methodology with regard to the situations studied which were characterised by low average bus speed and large speed variations along the route. Following this task, alternative studies on the influence of several parameters, such as driving behaviour, route topography and type of vehicle related to dynamic and environmental characteristics, were performed. Finally, with the purpose of predicting the influence of the CARRIS fleet on global emissions (as gramme per kilometre and gramme per kilometre per passenger), in comparison with the remaining road traffic as a whole, the same methodology was adopted to calculate the emissions caused by private owned vehicles (along the same routes).

3 Construction, installation and commissioning

3.1 The stationary filling station in Berlin

During the first year of project duration, the construction licence for the stationary filling station was requested from the respective Berlin authorities. In addition, the BVG requested national funds from the German Ministry for Economy for a further extension of the stationary filling station.

During the second year, the construction licence for the stationary filling station was granted by the respective Berlin authorities and BVG began the preparation of the construction site. The concrete area where the tank is placed was built and bollards were installed to protect the filling station against a potential collision with the bus, the hydrogen trailer or other vehicles. Explosion-proof measures have been carried out in the area, including the demolition of lamps and the sealing of the ground and all drains.

On 24.01.2002, BVG visited Linde to inspect the progress of the assembly of the stationary filling station. The stationary filling station was ready for construction at the BVG depot on Usedomer Straße in Berlin.

The works on the further extension of the stationary filling station, co-financed by the German Ministry for Economy, began. These included, in particular, the design and development of a container solution for the housing of the decentralised hydrogen supply components, in particular the electrolyser with prior water treatment for feeding the electrolyser, the compressor unit, the storage unit for the produced gaseous hydrogen and the filling technology. The gaseous hydrogen can be partly liquefied in the cryogen tank and could be used to cover the hydrogen losses caused by evaporation in the cryogen tank.

During the third year, the construction activities at the liquid hydrogen filling station were finalised.

Furthermore, BVG signed a co-operation agreement with Total for the operation of the liquid hydrogen filling station and co-operation in further joint research projects.

This co-operation includes the joint implementation and operation of a Hydrogen Competence Centre between BVG, Total, Linde and MAN. For the operation of the Hydrogen Competence Centre, an information container was constructed which houses an entrance area for the filling

station, a meeting room with space for 20 people and the gaseous hydrogen production facilities (not financed under the Fuel Cell Bus Berlin, Lisbon, Copenhagen project).

The gaseous hydrogen production facilities were developed, implemented and financed under the "Fuel Cell Articulated Bus Project for Berlin", which is funded by the German Federal Ministry of Economics and Labour and Total. Fig. 6-1 shows pictures from the construction works at the stationary filling station.

The gaseous hydrogen production facilities include the following process parts:

- GH_2-production through electrolysis
- GH_2-storage in a two-bank-bottle storage
- GH_2-storage of the evaporation losses of the LH_2-storage system
- Filling nozzles for GH_2 for filling of vehicles from the storage system, please refer to Fig. 6-2 for a picture of the gaseous dispenser
- GH_2-production through reformation.

The gaseous hydrogen filling station supplements the liquid hydrogen filling station. The hydrogen which evaporates from the 12,000 litre cryogen tank is stored. A pipe has been installed between the LH_2-storage tank and a second pressure tank in the electrolyser's room, the so-called "Pumping Tank B" ("Pumping Tank A" is filled by the electrolyser). It is possible to select manually which tank is emptied by the compressor into the two-bank-bottle-storage.

The hydrogen filling station of the Berlin Transport Company, BVG, was inaugurated on 23.10.2003.

For the complete operational area of the gaseous and liquid hydrogen filling station, Total and BVG carried out a detailed safety study which is aimed at controlling all work processes. Therefore, a Loss Control Management has been implemented.

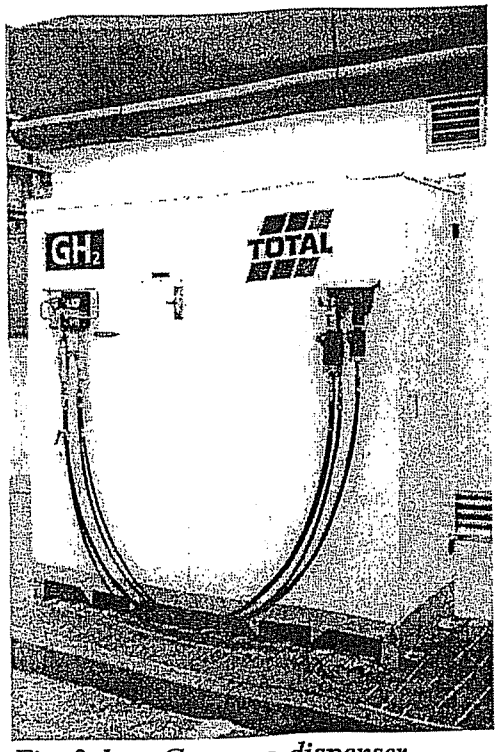


Fig. 3-1: Gaseous dispenser

The programme to improve the safety is called International Small Site Safety Rating System (ISSSRS). It has been developed for small businesses to implement an inventory of all safety relevant information. It contains interviews with the management and the employees, an analysis of the operating instructions and an inspection of all the premises.

3.2 The energy storage system

During the first six month, MAN analysed the available electric storage systems and selected super capacitors as the most suitable electrical storage system for the provision of peak energy demand and for an increase of energy efficiency through the recovery of brake energy. The structure of the bus had been prepared to house the supercapacitors.

In November 2001, the Consortium was informed by Air Liquide that the performance of the fuel cell system would be reduced from 120 kW_{net} to 75 kW_{net} due to problems with the Air Liquide/Nuvera fuel cell system. This reduced power would not allow for a safe operation in

daily traffic using only the power provided by the fuel cell and therefore, MAN investigated possibilities of solving this problem.

The result of this investigation was a suggestion to install further energy storage on the bus which would be able to store energy for a longer time than the originally considered supercapacitors. This energy storage system should be a ZEBRA battery. Integrating the ZEBRA-battery system would allow bus operation with a FC system, which supplies only 75 kW. The ZEBRA-system allows standalone driving without any FC-power for approx. 25 minutes. Maximum battery power is 120 kW. Thus, higher peak demands in traffic can also be covered for certain time periods. If the operation mode could be kept "soft" (decision of route/number of passengers, routes with "low gradients"), bus operation would even be possible only by battery.

MAN presented the results of the investigation into a new energy storage system during a meeting with the Berlin Transport company and the project co-ordinator in Munich on 24.01.2002. In addition, the results were presented to the European Commission on 04.02.2002.

The installation of the ZEBRA system is 95,000 Euro more expensive than the supercapacitor solution. Before ordering and installing the system, the question of cost coverage needed to be clarified. This was agreed during a consortium meeting in Brussels.

Within the fifth and sixth reporting period preparations were made at MAN to install the electrical energy storage on the support rack next to the liquid hydrogen storage. For this reason, new investigations were carried out, please refer to section 2.3.1.

Carris analysed the problems related to power availability and safety of the fuel cells. Several discussions on this topic were developed and a discussion on the results of a survey on available alternative systems was held. The preliminary testing activities were defined and scheduled and the inauguration plan for the hydrogen filling station was discussed.

3.3 Suppliers of equipment and services

The following suppliers were involved in the project:

- **Fuel cell bus**: MAN low-floor vehicle type NL223
- **Fuel cell**: Nuvera formerly deNORA, net power is 75 kW_{max}
- The **electric power system** including power electronics was supplied to MAN by Siemens Transportation Systems / Erlangen. Likewise, voltage increase devices for adjusting the voltage of the fuel cell modules which is too low were designed and manufactured by Siemens.
- **Liquid hydrogen storage system**: The liquid hydrogen storage system manufactured by Linde was constructed in its entirety and certified by TÜV Süddeutschland. The system includes a tank with a capacity for 600 litres of LH_2 and fittings on the side. The periphery of the liquid hydrogen device as well as the couplings with the vehicle and tank were likewise designed by Linde.
- **Filling infrastructure**: Linde also supplied both the mobile and stationary filling stations (the mobile filling station was part of phase I of this project). This ensured complete compatibility of the total liquid hydrogen supply from delivery to application in the vehicle.
- **Components for the secondary cooling system**: The components for the secondary cooling system were supplied by Längerer & Reich. The power for the ventilators comes from the modular system designed by Siemens TS for the vehicle power.

- **Electrical energy storer**: EPCOS was planned to be the supplier for the electrical energy storer. The EPCOS system uses supercondensators for brake energy recovery. As an alternative, an additional supercondensator system manufactured by a Swiss company and a new type of storage concept manufactured by Electrastor was taken into consideration. Due to the reduction in performance of the fuel cell system, it became necessary to fall back in the short term on another storage concept. Therefore, the integration of a system with high temperature batteries produced by the company MES-DEA was taken into consideration. In parallel to this test, bench trials with a new type of storage system manufactured by the company Electrastor were undertaken.

3.4 Project management

The structure of the project is shown in Fig. 3-2. BVG, HT and CARRIS have been the involved bus operators in Berlin, Copenhagen and Lisbon, respectively. MAN has constructed the fuel cell bus and has integrated the fuel cell drive. The fuel cell system was developed and integrated by Air Liquide. Air Liquide, Portugal has been supporting the creation of the infrastructure in Lisbon. The Lisbon project was monitored by IST. Linde developed the mobile and the stationary filling station. For the development and implementation of the stationary filling station, Linde acted as a partner in the project.

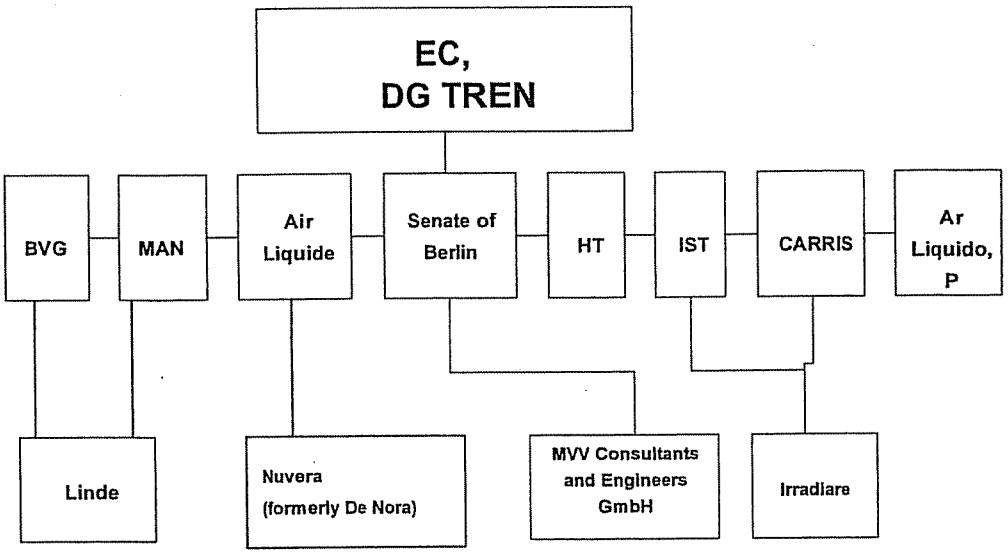


Fig. 3-2: Management structure of the project Fuel Cell Bus Berlin, Copenhagen, Lisbon

No official Kick-off meeting took place for the project as it is seen as the second phase of the Fuel Cell Bus Berlin, Lisbon, Copenhagen project. The Kick-off meeting of this project took place on 11 and 12 May 1999 in Berlin. The first consortium meeting for the second phase of the project took place in the framework of the third consortium meeting of phase I. This meeting took place in Sassenage on the premises of Air Liquide on 10.04.00. The second consortium meeting took place in Berlin on 16.11.00. The third consortium meeting took place on 20.07.2001. The fourth consortium meeting took place on 17.10.2001. On 15.05.2002 a technical meeting took place in Berlin to discuss the urgent technical problems which occurred in the fuel cell module, please refer to phase I. The fifth consortium meeting took place on 30.05.2002 in Brussels.

During the meetings, the consortium discussed the status of the project, the problems which had occurred and put emphasis on finding new solutions to cope with the technical problems

and to adopt the time planning. In addition to the consortium meetings, several bilateral meetings have taken place.

MAN presented the results of the investigation into a new energy storage system during a meeting with the Berlin Transport Company and the project co-ordinator in Munich on 24.01.2002. In addition, the results of the project were presented to the European Commission on 04.02.2002.

3.5 Problems, solutions, successes

In the second phase of the project the following results were achieved:

Development, construction and implementation of the electrical storage system to support the fuel cell system: In the first instance, the energy storage system was planned to support energy efficiency and economy of the project. The energy storage system should store brake energy and make this energy available again for the following acceleration process. Detailed investigations on suitable technologies have been analysed, please refer to section 3.2.

Due to the reduced performance of the fuel cell system, the selected concept had to be completely reconsidered. An energy system became necessary which is now permanently available to support the performance of the fuel cell bus during acceleration, please refer to section 3.2.

MAN developed both of these systems and prepared the fuel cell bus to incorporate the electrical storage system, please refer to sections 2.3.1 and 3.2. Order and implementation of the system was abandoned due to the technical difficulties encountered in phase I of the project.

Development, construction and implementation of a stationary hydrogen filling station: The stationary filling station has been constructed, commissioned and successfully implemented. The inauguration of the stationary filling station took place on 23.10.2002 and received excellent public attention and press coverage, please refer to sections 2.3.3, 3.1 and 5.1.

Demonstration of the bus in an inner-city environment and of the filling station infrastructure: The demonstration of the innovative fuel cell propulsion system was planned to outline not only the benefits to be obtained from a zero emission fuel, but also the advantages of this type of bus from a design point of view and the performance of the energy storage system.

During the commissioning of the fuel cell stacks, however, Air Liquide detected an increased liquid hydrogen content in the exhaust gas of up to 10% during the bench tests. In particular, this high hydrogen purge would have required a complete re-design of the whole system to comply with safety standards. Furthermore, the applied fuel cell technology suffered from a performance reduction due to corrosion inside the system. When another leakage appeared while integrating the fuel cell system with the bus during the on the road testing, TÜV refused to provide certification for the demonstration with the participation of the public.

The Consortium decided to abandon further tests with the fuel cell bus, but they did agree on an alternative suggestion with the main purpose being to make a hydrogen vehicle available to use at short notice and to demonstrate the hydrogen filling station at Usedomer Str. This would have allowed the gathering of important operation experiences and data from the hydrogen filling station and the handling of hydrogen in vehicle operation. This experience

would have been urgently necessary for the implementation of other fuel cell projects in Berlin such as:

- the Fuel Cell Articulated Bus project, co-financed by the German Ministry of Economy
- the Clean Energy Partnership
- the CityCell project, NNE5-2001-00689 etc.

MAN offered its hydrogen internal combustion engine bus to the project for demonstration purposes. This bus has already participated in the inauguration of the filling station for the demonstration of the refuelling process. The bus could have been put into operation immediately after strengthening of the gaseous refilling capacity of the compressors and related equipment at the filling station. The upgrade of the filling station would have need approximately four months. The bus and the filling station could have been demonstrated from September 2003 to February 2004 in Berlin.

This change to the work programme was proposed to the European Commission on 3 June 2003. With a letter dated 17 July 2003 the European Commission unfortunately refused to except this change to the original work programme of Phase II of the project. Herewith the implementation of a hydrogen powered bus was not possible in the framework of this project.

3.6 Modifications and over-runs

During Phase I of the project several technical problems occurred in the fuel cell module development. This resulted not only in the reduction of fuel cell module performance. Due to the detection of hydrogen leakages the commissioning of the bus for public transport operation had to be stopped. The necessary changes in the technology to reach the required safety standards would not have been suitable due to the expected further reduction in the fuel cell module performance.

The fuel cell bus could, therefore, not be realised during Phase I of the project which effected in particular the demonstration component of Phase II of the project. While the hydrogen filling station at Usedomer Straße was demonstrated during the inauguration on 23.10.2002, the demonstration of the bus in Berlin, Lisbon and Copenhagen had to be abandoned.

3.7 Time schedule

Workpackage descriptions	Duration / Critical Path																																			
	1st year												2nd year												3rd year											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Workpackage 1: Project design																																				
Task 1.1: Design of filling station and request for authorisation																																				
Task 1.2: Design of energy storage																																				
Task 1.3: Manufacturing and bench testing of energy storage																																				
Workpackage 2: Implementation of technology																																				
Task 2.1: Construction of filling station																																				
Task 2.2: Commissioning of filling station																																				
Task 2.3: Implementation and integration of energy storage																																				
Task 2.4: Testing Phase of the fuel cell bus																																				
Workpackage 3: Operation and demonstration																																				
Task 3.1: Demonstration in city 1																																				
Task 3.2: Demonstration in city 2																																				
Task 3.3: Demonstration in city 3																																				
Task 3.4: Operation of stationary filling station																																				
Workpackage 4: Monitoring and assessment of energy efficiency, environment and economics																																				
Task 4.1: Monitoring and assessment of fuel cell bus																																				
Task 4.2: Monitoring and assessment of filling station																																				
Workpackage 5: Dissemination of results																																				
Task 5.1: Dissemination of results																																				
Workpackage 6: Project management																																				
Task 6.1: Overall project management																																				
Task 6.2: Local project management																																				

Workpackage descriptions	Duration / Critical Path																																							
	1st year												2nd year												3rd year												4th year				
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
Workpackage 1: Project design																																									
Task 1.1: Design of filling station and request for authorisation	■	■	■	■	■	■	■	■																																	
Task 1.2: Design of energy storage				■	■	■	■	■	■	■	■	■																													
Task 1.3: Manufacturing and bench testing of energy storage													■	■	■	■																									
Workpackage 2: Implementation of technology																																									
Task 2.1: Construction of filling station																			■	■	■	■	■	■	■	■	■	■	■	■											
Task 2.2: Commissioning of filling station																								■	■	■	■	■	■	■	■										
Task 2.3: Implementation and integration of energy storage																									■	■															
Task 2.4: Testing Phase of the fuel cell bus																																									
Workpackage 3: Operation and demonstration																																									
Task 3.1: Demonstration in city 1																																									
Task 3.2: Demonstration in city 2																																									
Task 3.3: Demonstration in city 3																																									
Task 3.4: Operation of stationary filling station																																■	■	■	■	■	■	■	■	■	■
Workpackage 4: Monitoring and assessment of energy efficiency, environment and economics																																									
Task 4.1: Monitoring and assessment of fuel cell bus														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Task 4.2: Monitoring and assessment of filling station																																■	■	■	■	■	■	■	■	■	■
Workpackage 5: Dissemination of results																																									
Task 5.1: Dissemination of results			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Workpackage 6: Project management																																									
Task 6.1: Overall project management	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Task 6.2: Local project management	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

3.8 Costs

WP No	Work package title	Cost (Euro) - planned -	Costs (Euro) - effective -
1	**Project design**	**986,781**	
1.1	Design of filling station	257,798	
1.2	Design of energy storage	284,548	
1.3	Manufacturing and bench testing of energy storage	444,435	
2	**Implementation of technology**	**1,749,472**	
2.1	Construction of filling station	1,387,610	
2.2	Commissioning of filling station	41,595	
2.3	Implementation and integration of energy storage	120,090	
2.4	Testing Phase of the fuel cell bus	200,176	
3	**Operation and demonstration**	**579,870**	
3.1	Demonstration in city 1	191,795	
3.2	Demonstration in city 2	85,000	
3.3	Demonstration in city 3	125,025	
3.4	Operation of filling station	178,050	
4	**Monitoring and assessment of energy efficiency, environment and economics**	**1,147,942**	
4.1	Monitoring and assessment of fuel cell bus	1,032,942	
4.2	Monitoring and assessment of filling station	115,000	
5	**Dissemination of results**	**215,636**	
5.1	Dissemination of results	215,636	
6	**Project management**	**550,816**	
6.1	Overall project management	249,320	
6.2	Local project management	301,496	
	TOTAL	**5,230,517**	**2,963,019**

4 Operation and results

4.1 Operating history

4.1.1 The stationary filling station in Berlin

The hydrogen filling station of the Berlin Transport Company, BVG, was inaugurated on 23.10.2003. Please refer to section 5.1 for a detailed description of the dissemination activities carried out in the framework of the inauguration. Please refer to section 2.3.3 for a detailed technical description of the technology implemented.

During the inauguration of the filling stations, two vehicles were presented, the internal combustion engine hydrogen bus from MAN for the gaseous hydrogen refilling demonstration and a fuel cell powered Opel Saphira for the liquid refilling demonstration.

For the complete operational area of the gaseous and liquid hydrogen filling station, Total and BVG have carried out a detailed safety study which is aimed at controlling all work processes. Therefore, a Loss Control Management has been implemented.

The programme to improve the safety is called International Small Site Safety Rating System (ISSSRS). It has been developed for small businesses to implement an inventory of all safety relevant information. It contains interviews with the management and the employees, an analysis of the operating instructions and an inspection of all the premises.

4.2 Performance

As the European Commission refused to accept the requested changes to the original work programme of Phase II of the project by allowing the implementation of a bus on hydrogen combustion engine instead of the originally planned fuel cell bus, the demonstration of the infrastructure was so far not possible.

BVG is involved in the following projects which are either under implementation or in the pipeline:

- Fuel Cell Articulated Bus project, co-financed by the German Ministry of Economy
- Clean Energy Partnership Berlin
- CityCell project, NNE5-2001-00689 etc.

In the framework of these projects BVG will implement fuel cell buses as well as buses running on hydrogen combustion engines. The first bus to be implemented will be in operation in autumn 2003.

The performance of the installation in normal daily operation can, therefore, at present not be estimated. Detailed data will be available after the start of the normal operation.

4.3 Operating costs

As described in Ch. 4.2 the start of normal operation of the installation was so far not possible due to the fact that the European Commission refused to accept the requested changes to the original work programme of Phase II of the project.

As BVG is involved in the following projects

- Fuel Cell Articulated Bus project, co-financed by the German Ministry of Economy,
- Clean Energy Partnership Berlin,
- CityCell project, NNE5-2001-00689 etc.,

fuel cell buses as well as buses running on hydrogen combustion engines will be implemented and in operation only after autumn 2003.

The operating costs can, therefore, at present not be calculated. Detailed data will be available after the start of the normal operation.

4.4 Future of the installation

Already in the first year of project lifetime, BVG started negotiations with several partners for co-operation to guarantee an efficient use of the stationary filling station, to attract further applications of mobile fuel cells and to further develop the infrastructure. National funds for a further extension of the stationary filling station from the German Ministry for Economy were granted. This included:

- A summary study of the available technologies for the production of hydrogen from natural gas and an analysis of the different reforming steps. The different processes available will be analysed for their suitability to fuel cell bus fleets.
- Identification and implementation of a pilot project for the local production and subsequent liquefying of hydrogen. The hydrogen production rate will be approximately 200 L/h (gaseous) i.e. equal to 10 L/d (liquid).

It has been decided to develop the Usedomer Str. location as a Fuel Cell Technology and Innovation Centre. Detailed usage and partnership concepts have been considered.

In the second year, BVG continued its negotiations with several partners for co-operation on the use of the stationary filling station. This included BMW. BMW intend to provide some hydrogen BMWs for the VIP car pool of the German government. In addition, the German automobile, mineral oil and gas industry supported by the German Ministry of Transport, Construction and Housing is preparing a large fuel cell vehicle demonstration project in Berlin which is named "Clean Energy Partnership". The BVG's stationary filling station will be used within this project and the garages of the depot will be further enlarged for the use of hydrogen-filled vehicles.

5 Publicity, commercialisation and other developments

5.1 Publicity and publications

The project was jointly disseminated with the results of phase I:

- BVG ordered a model of the fuel cell bus for the promotion of the project. The project is presented during a permanent exhibition on innovative technologies "Innovationspark Berlin" organised by the Bewag in Berlin which started in June 2000. The "Fuel Cell Innovation Park" exhibition presents background information on Berlin fuel cell projects. An outdoor exhibition gives a view of today's energy supply system and presents a vision of tomorrow's energy supply. An additional specialists' exhibition with real systems and products presents practical information on fuel cells. The "Fuel Cell Bus Project Berlin, Lisbon, Copenhagen" exhibits a model of the fuel cell bus and a poster, please refer to Fig. 5-1 for a photo of the fuel cell bus model.
- The fuel cell bus model was also exhibited from May 2000 to September 2000 at the European Commission, DG TREN, Rue de la Mot, in Brussels accompanied by a poster.

- Dr Schaller of MAN presented the project during the "Tag der Brennstoffzelle (Fuel Cell Open Day)" in Munich on 08.05.00. During this meeting the previous model of the MAN fuel cell bus was presented for a test run.
- Ms Lemke represented the "Fuel Cell Bus Project Berlin, Lisbon, Copenhagen" during the Conference on "Prospects for Fuel Cells in a European Research Area", Tervuren - Brussels, Belgium – 29th and 30th May 2000, organised by the European Commission. For this event, in addition to the oral presentation, posters and two articles were prepared.
- Mr Eberwein presented the Fuel Cell Bus Project Berlin, Copenhagen, Lisbon project at the World Bus & Clean Fuel Summit in Los Angeles on 31.05.00.
- CARRIS prepared a presentation of the Fuel Cell Bus project.

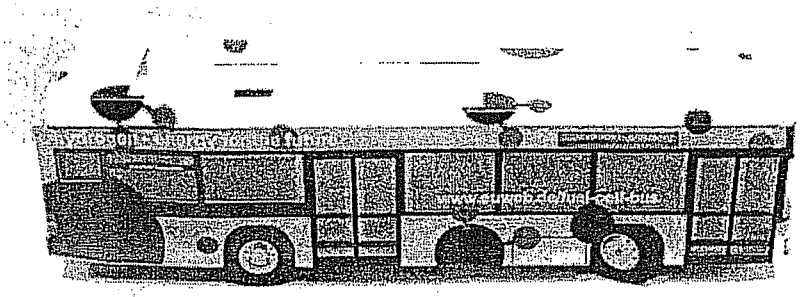


Fig. 5-1: Photo of the fuel cell bus model

- Dr Schaller of MAN presented the project during the "Hydroforum" in Munich on 13.09.00.
- Articles on the project were published on the Internet.
- On 06.12.00, Mr Eberwein from the BVG presented the project at the „VDV Tagung Wasserstofftechnologie"(Association of German Public Transport Companies: Conference on Hydrogen Technologies) at the VAG Nuremberg.
- On 19.01.2001, Mr Eberwein from the BVG presented the project at the Symposium "Zukünftige Elektroantriebe für Omnibusse" (Future electric drives for buses) in Darmstadt.
- On 06.02.01, Mr Eberwein from the BVG presented the project at the UITP meeting in Maastricht.
- On 5.12.2000, Dr Schaller from MAN presented the project during the Vienna Energy Day.
- Mr Gruber from MAN presented the project in the "fuel cells bulletin", Issue 12/2000.
- On 12./13.3.2001, Mr Gruber, MAN presented the project during a seminar on "Motor Combustion" at the House of Technology, Essen.
- On 11-12, October 2000, Mr António Parente of CARRIS presented the project at the "Gás Veicular" conference in Lisbon with a lecture on "Pilhas de Combustivel Projecto em desenvolvimento subsidiado pelo Programa Thermie".
- On 20 November 2000, Mr António Parente of CARRIS presented the project at the "Protap - Pilhas de Combustivel" conference in Lisbon with a lecture on "Autocarros can Porpulsão a pilhas de combustivel".
- On 25 January 2001, Mr António Parente of CARRIS presented the project at the "Protap – Veiculos Verdes" conference in Lisbon with a lecture on "Novos desafios impostos pela aproximação ao conceito do veiculo verde".

- On 7-9 February 2001, Mr Reis Simões presented the project at the "Innovation dans les Transports Public Sur Route" conference in Maastricht.
- Mr Gruber, MAN presented the project at the Hanover Industrial Fair 2001.
- Mr Gruber, MAN presented the project at the "Bavarian Regenerative Fair" in Augsburg.
- On 9-12 July, 2001, Mr Eberwein, BVG presented the project at the "Clean Air VI - sixth international conference on Technologies and Combustion for a Clean Environment", Porto.
- Mr Eberwein, BVG presented the project at the "Bus Technik, heute und morgen: Fuel cell technology, Hanover".
- On 20-25, May 2001 Mr Antonio Parente participated in the 54th UITP World Congress in London (UK).
- On 29 June, Mr Antonio Parente participated in the APEMETA Eficiência Energética e Energias Renováveis in Lisbon and Oporto.
- On 9-12, July 2001, Mr Reis Simoes gave a presentation on *"Was there no technological development in the last 20 years ?"* within the framework of the conference 'Technologies and Combustion for a Clean Environment- Clean Air'.
- On 9-12 July, 2001, IST presented the project at "Clean Air VI - sixth international conference on Technologies and Combustion for a Clean Environment", Porto.
- In April 2001, IST presented the project at the "7th National Conference on Environmental Quality" in Aveiro.
- Mr Eberwein, BVG presented the project and discussed further challenges for the development of a hydrogen infrastructure "Hydrogen infrastructure development – how to gain a sustainable approach?" at Total in Paris, 15.06.2001.
- CARRIS prepared a leaflet on the project.
- In September 2001, MAN presented the project at the conference "BZ im Automobil (Fuel Cell Applications in Vehicles)" in Frankfurt.
- In October 2001, MAN presented the project at the Electric Vehicle Symposium EVS 18 in Berlin. In addition, the project was represented with an abstract at the EVS 18.
- On 19.09.200,1 Mr Eberwein, BVG, presented the project at the Prosper Congress "Hybrid Technology in Public Transport – Advanced transport technologies" in Karlsruhe.
- On 15 – 16.11.2001, Mr Eberwein, BVG, presented the project at the Bus Exhibition and Conference on "Marketing Environmental-Friendly Public Transport" organised by "Transporti Tutti" in Verona.
- On 06.12.2001, Mr Eberwein, BVG, presented the project at the VDV meeting on "Innovative Propulsion Systems" in Nuremberg.
- On 22.-23.01.2002, Mr Eberwein, BVG, presented the project at the Voyager Conference on "Public Transport Infrastructure and Rolling Stock" in Brussels.
- During the fourth reporting period, Carris gave an interview on a state television programme dealing with innovation issues (2010 at RTP). The central topic during that interview was the fuel cell bus.
- On 21/22 November 2001, Mr Reis Simoes presented the project at the OPET MERCOSUR road show with a presentation "Transportes -sua contribuicao para um desenvolvimento sustentavel" in SAO PAULO (Brazil).
- On 18 October 2001, Mr Antonio Parente gave a personal interview to the 2010 RTP 2 TV programme in Lisbon.
- BVG was invited to present the project at the inauguration of the new hydrogen laboratory at the German Bundesanstalt für Materialforschung und –prüfung (State Organisation for Material Research and Testing) on 18.10.2001 in Berlin.

For the inauguration of the hydrogen filling station on 23.10.2002, a large event was organised. More than 200 politicians, representatives from government and industry, technical experts and press reporters participated in the opening event. The event took place in the depot of the BVG and at the filling station. Several speeches were held during the event by:

- Ms Hinricher, Bundesministerium für Verkehr, Bau- und Wohnungswesen (Federal State Ministry for Transport, Constructions and Housing)
- Mr Wolf, Senator des Landes Berlin für Wirtschaft, Arbeit und Frauen (Senator of the Federal State of Berlin for Economy, Labour and Women)
- Mr von Arnim, Chief Executive Officer of the Berlin Transport Company
- Mr Schröter, General Manager of Total Fina Elf Germany.

Fig. 5-2 gives some impressions of the opening ceremony. The project prepared information material on the project to be handed out to the participants as well as an information poster. Linde and Total prepared dedicated information material for the participants of the inauguration event on the filling station technology and on hydrogen as a fuel. Broad press coverage of the inauguration demonstrated the the enomous public interest in this event.

Total designed a home page presenting the hydrogen filling station and the Hydrogen Competence Centre, please refer to: http://www3.total.de/framesets/umwelt_wasserstoff.htm

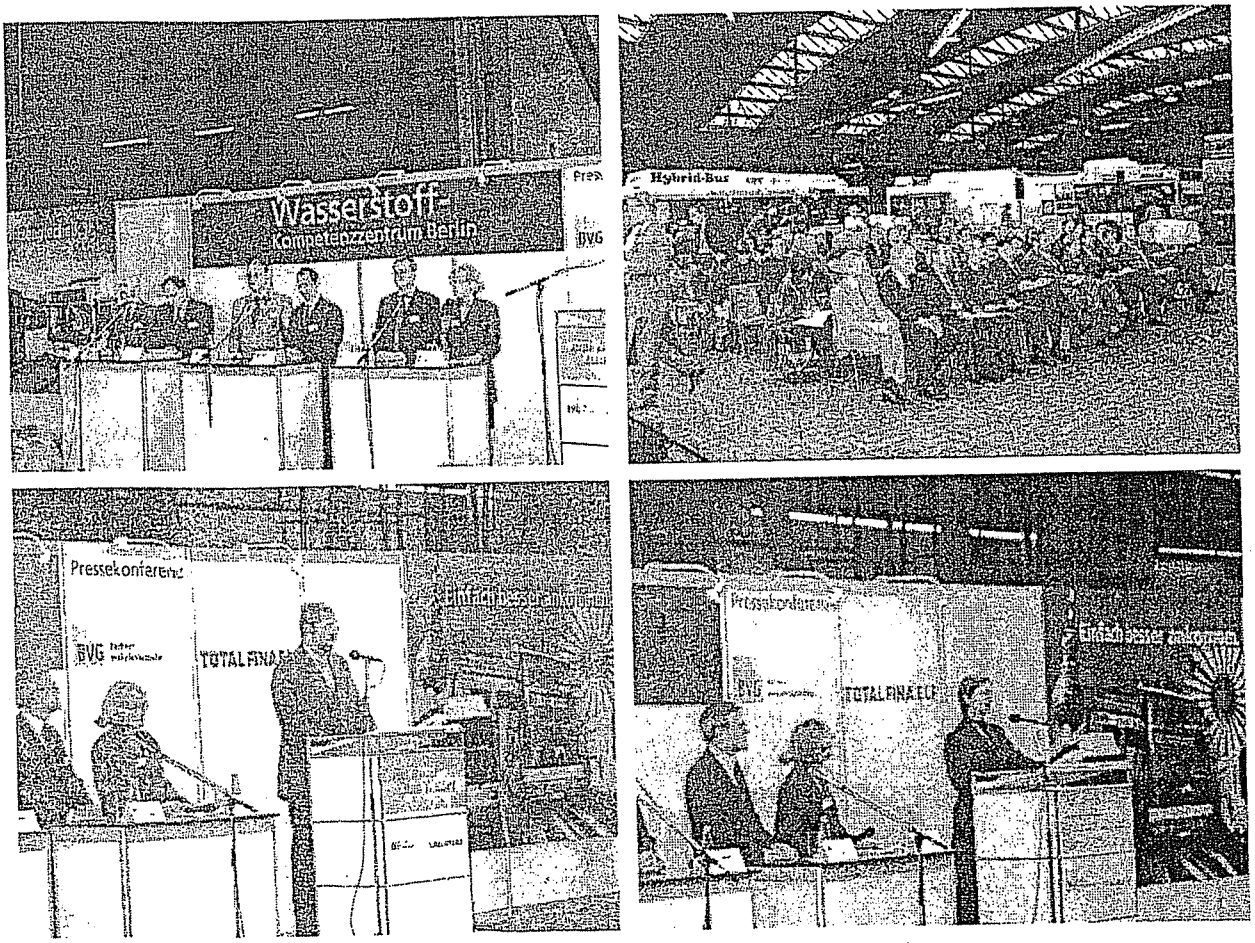


Fig. 5-2: Opening ceremony of the hydrogen filling station and Hydrogen Competence Centre inauguration: 1: Dr Weidner, Opel AG; Dr Hipp, MAN; Dr Wolf, Linde; Dr Schulz, Total; Mr Eberwein, BVG; Ms Mansfield, BVG; 2: auditorium; 3: Dr. van Arnim, BVG, 4: Dr Hinricher, Bundesministerium für Verkehr, Bau- und Wohnungswesen (Federal State Ministry for Transport, Constructions and Housing); 5: Dr Wolf, Senator des Landes Berlin für Wirtschaft, Arbeit und Frauen (Senator of the Federal State of Berlin for Econommics, Labour and Women); 6: Dr Schröter, General Manager of Total Fina Elf Germany

The project prepared its contribution to the EC brochure „Hydrogen and Fuel Cell project synopses book".

CARRIS participated in a number of different conferences, all of them related to R&D and innovation in the transport area. The participation in these conferences was a good vehicle to promote the project as well as its activities and objectives. Project dissemination was made in all conferences attended. Several documents have been prepared and used for this purpose in addition to other documentation related to the meeting. Examples of this material, e.g. the project's info leaflet, were provided in previous technical reports or form part of the phase I final report annexes. In addition, Mr Antonio Parente from CARRIS presented the project at a conference entitled "The Priorities for Technological Development" on 18 June 2002 at INETI in Portugal.

Papers on the Fuel Cell Bus Berlin, Copenhagen and Lisbon II project were presented by IST at the following conferences and workshops:

- National Conference on Environmental Quality, 18-20 April 2001, Aveiro, Portugal (paper entitled "Autocarro a pilha de combustível (Berlin, Copenhaga, Lisboa)")
- Sixth International Conference on Technologies and Combustion for a Clean Environment – Clean Air, 9-12 July 2001, Oporto, Portugal (paper entitled "Fuel cell bus Berlin, Copenhagen and Lisbon: A sustainable and environmental

Fig. 5-3: Mr Nelson Martin and Mr Tiagio Farias during the presentation of the project

technology for the urban passenger transportation sector")

- Transport and Air Pollution: 10th International Scientific Symposium, 17-19 September 2001, Boulder, CO, USA (paper entitled "The Fuel Cell Bus Berlin, Copenhagen and Lisbon: a sustainable and environmental technology for the urban passenger transportation sector")
- Urban Transport and the Environment 2002", Eighth International Conference on Urban Transport and the Environment in the 21st Century, 13 – 15 March 2002, Seville (paper entitled "Fuel cell bus Berlin, Copenhagen and Lisbon: a sustainable and environmental technology for the urban passenger transportation sector")
- Urban Transport and the Environment 2002", Eighth International Conference on Urban Transport and The Environment in the 21st Century, 13 – 15 March 2002, Seville (paper entitled "Analysis of Environmental Impact of Urban Buses: Application to a Case Study in Lisbon")

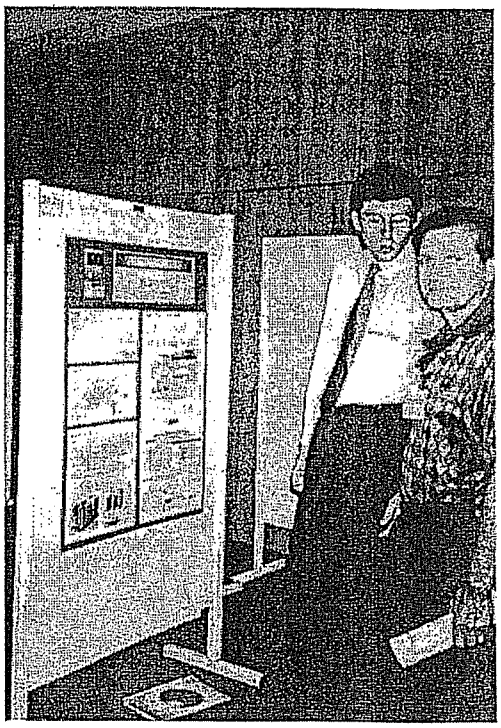


Fig. 5-4: Project presentation

- Workshop "Alternative Energy on Road Transport", Lisbon, January 29, 2002
- Workshop "Future Solutions on Road Transport", Almada, 25 May, 2002
- 7th International Conference on Modeling and Simulation of Electric Machines, Converters and Systems, Montreal, 18-21 August, 2002 (paper entitled "Hybrid Electric Buses: Dimensioning the Intermediate Electric Storage Stage")

IST also presented the project in several meetings with national and international researchers and environmental companies, such as:

- Researchers from Oporto University
- Professor Nagui Rouphail and other researchers from the Institute for Transportation Research and Education at North Carolina State University
- National Hydrogen Association (NHA), Washington D.C. (USA)
- Georgetown University Advanced vehicle development
- Natural Gas Vehicle Coalition (NGCV) Washington D.C. (USA)
- American Public Transport Association (APTA) - Washington D.C. (USA)
- Energy agencies of Lisbon (Amerlis) and Almada (Ageneal)
- Portuguese Environmental Institute (IA)
- Energy Saving Trust.

The project launched its own home page under http://euweb.de/fuel-cell-bus which is still operational.

5.2 Outlook

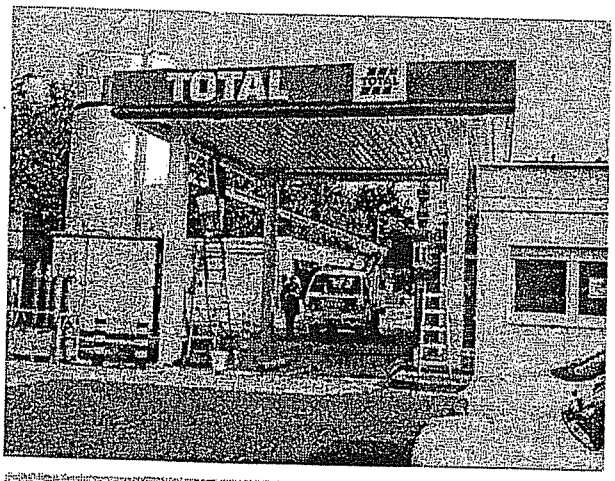
BVG started negotiations with several partners for co-operation to guarantee an efficient use of the stationary filling station, to attract further applications of mobile fuel cells and to further develop the infrastructure. National funds for a further extension of the stationary filling station from the German Ministry for Economy were granted.

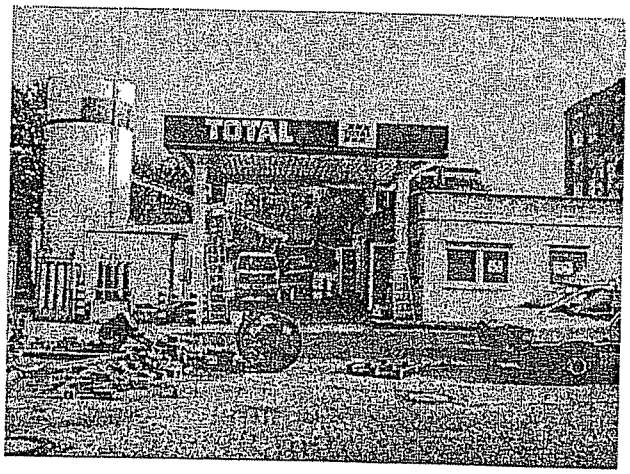
BVG has decided to develop the Usedomer Strasse location as a Fuel Cell Technology and Innovation Centre. Detailed usage and partnership concepts have been considered.

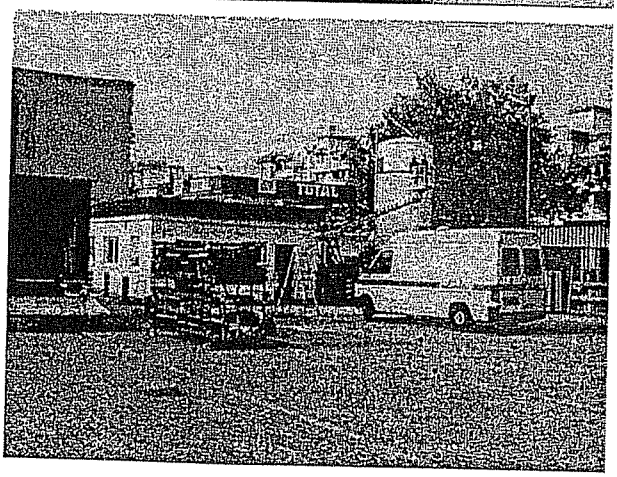
5.3 Commercialisation

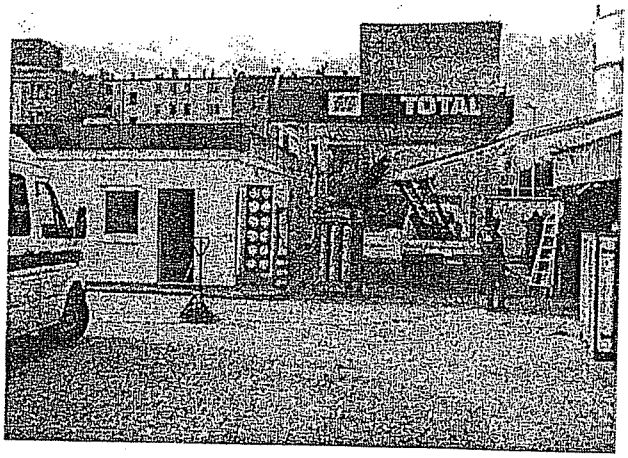
BVG undertook negotiations for co-operation on the use of the stationary filling station. BMW e.g. intend to provide hydrogen BMWs for the VIP car pool of the German government. In addition, the German automobile, mineral oil and gas industry supported by the German Ministry of Transport, Construction and Housing is preparing a large fuel cell vehicle demonstration project in Berlin which is named "Clean Energy Partnership". The BVG's stationary filling station will be used within this project and the garages of the depot will be further enlarged for the use of hydrogen-filled vehicles.

6 Photographs









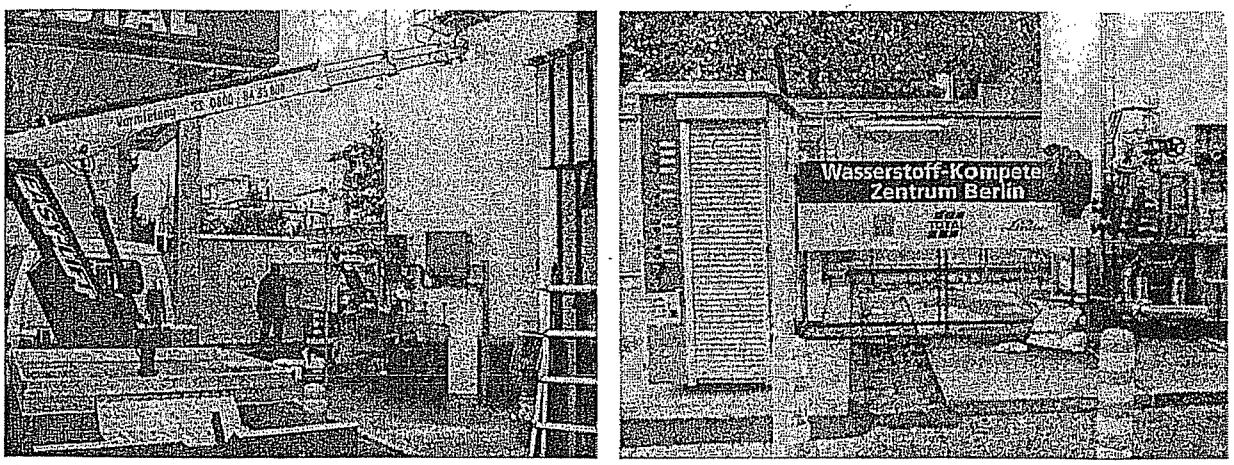


Fig. 6-1: Construction works at the hydrogen filling station and the Hydrogen Competence Centre at the Berlin Transport Company

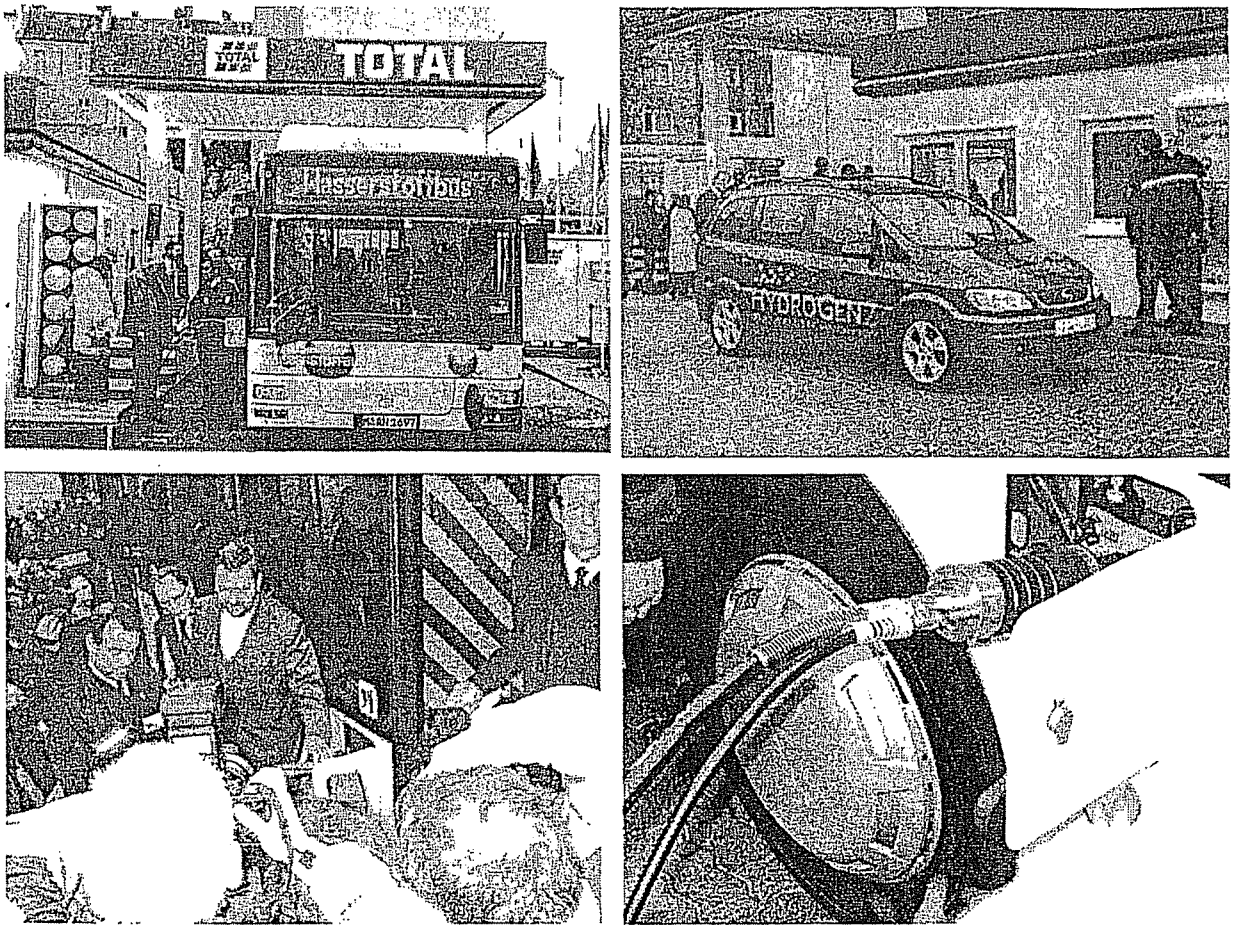


Fig. 6-2: The hydrogen bus during refilling and the Opel Saphira fuel cell car, present during the inauguration at the filling station

Fig. 6-3: Stationary hydrogen filling station