

THE HAMBURG HYDROGEN FLEET W.E.I.T.

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1. BACKGROUND

The idea of driving on hydrogen is not a new one. As far back as 1807, long before the automobile was developed by Daimler and Benz and the petrol and diesel engine were invented, the first patent for a hydrogen-driven vehicle was granted to the Swiss engineer Isaac de Rivac. Almost 200 years have passed since his day and both the hydrogen-powered vehicle and the infrastructure means for refueling with hydrogen are still very much in their infancy.

Over the past few years, however, they have both progressed beyond the toddler stage thanks to the benefits of hydrogen, which have gained relevance in today's world. These include the possibility of zero emissions, unlike petrol and diesel engines, and the fact that the production of hydrogen does not depend on dwindling fossil resources. Moreover, the use of renewable hydrogen does not contribute to the looming greenhouse effect.

The great challenge posed by the introduction of hydrogen as a fuel continues to be the immense costs involved in converting our present fuel supply system to hydrogen. A combination of fuel cell powered vehicles and, in the medium to long term, hydrogen from renewable energies would mean a radical change both in the vehicle technology and fuel-supply system we know today.

2. GENERAL DESCRIPTION AND AIMS OF THE PROJECT

Given this challenge, it is useful and appropriate to test and further develop the various aspects of introducing hydrogen into our traffic system by means of small-scale pilot projects. A case in point is the W.E.I.T. (Hydrogen [in German: Wasserstoff] Energy Integration Transport) project initiated by the Hamburger Wasserstoff-Gesellschaft (Hamburg Hydrogen Association), within the context of which six transport vehicles belonging to Hamburg companies were converted for hydrogen consumption and the corresponding infrastructure was put in place.

The initial considerations with regard to W.E.I.T. arose from a feasibility study on the Euro-Québec Hydro-Hydrogen Pilot Project EQHHPP, in which 100 MW hydrogen was to be produced in Canada and shipped to Hamburg for local use. This project is not being implemented due to the high costs it would entail. The feasibility study did, however, give indications of how best to proceed. Intensive investigations were essential, especially with regard to the energetic consumption of hydrogen, since neither infrastructure nor useable and reliable technology (vehicles, stationary installations) were available. Questions of licenses and public acceptance also remained largely unclarified.

In order to pursue and forge ahead with the development of hydrogen as a fuel, the Hamburger Wasserstoff-Gesellschaft formed a project group of Hamburg companies with the aim of realising the W.E.I.T. project. The central aims of W.E.I.T. are:

- to convert and operate transport vans using hydrogen as fuel
- to provide and operate a fuel station for hydrogen
- to use these vehicles in genuine, everyday operation
- to use renewable energy for the production of hydrogen (green hydrogen)
- to obtain authorization for the filling station and vehicles
- to introduce measures to foster public acceptance

The whole project has been divided into two stages. In the first stage transport vans with a standard gasoline internal combustion engine have been converted to hydrogen and industrial hydrogen is used to fuel the vehicles. The intention is to generally demonstrate the feasibility without advanced technical systems. In the second stage, highly efficient and zero emission fuel cell vehicles will be used and the hydrogen will be produced by on site generation with an electrolyser using electricity from renewable energies. Hereby the whole energy chain from well to wheel is emission free.

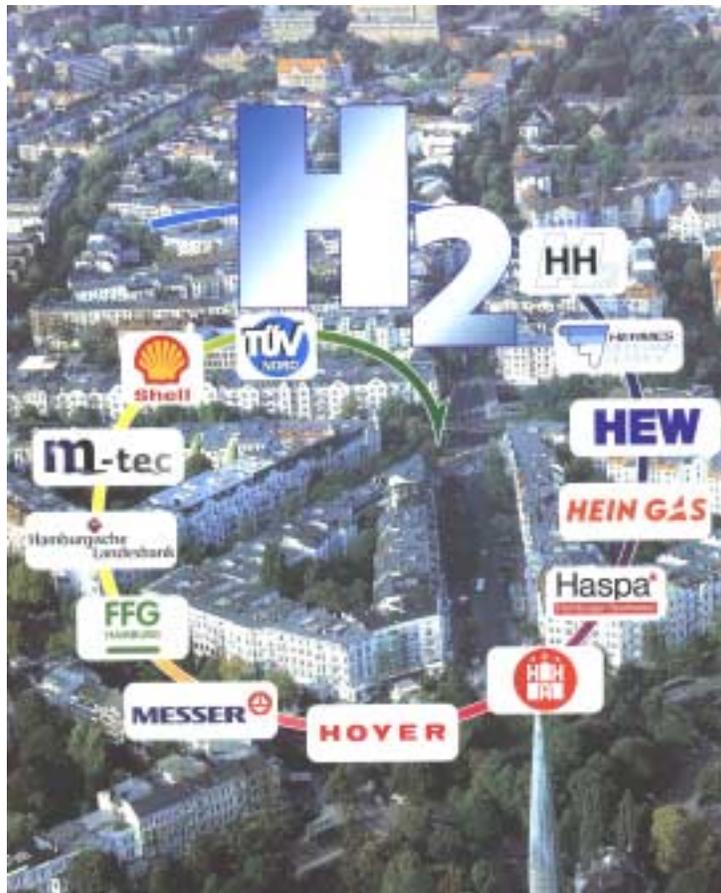


Figure 1: Project partners of W.E.I.T.

2.1 Project Partners and Management

For the implementation and coordination of the project, Hamburger Wasserstoff-Gesellschaft founded the project-management company Hamburger Wasserstoff-Agentur GmbH (HaWA) in 1997. The company is funded by contributions from the initial six project partners using the vehicles. These members of the users group (shown in Figure 1) include:

- Hermes Versand Service, a mail order company
- HEW, Hamburgische Electricitäts-Werke AG, an electricity utility
- HHA, Hamburger Hochbahn AG, a public transport company

Three other companies originally operating a vehicle under the project, HGW (Hein Gas Hamburger Gaswerke GmbH), HOYER GmbH, and HASPA (Hamburger Sparkasse), have meanwhile left the project group of vehicle operators.

In addition to the vehicle users, the project group is also supported by a “know-how group” of companies (see

Table 1), all of which contribute their own specialist know-how free of charge:

Table 1: Partners contributing know-how

Deutsche Shell AG Fahrzeugwerkstätten Falkenried GmbH, FFG Hamburgische Electricitäts-Werke AG, HEW Hamburgische Landesbank Hein Gas Hamburger Gaswerke GmbH, HGW m - tec Gastechnologie GmbH Messer Griesheim GmbH TUEV NORD Gruppe (safety authority)	technical support, lubricants, emission testing conversion of the vehicles from petrol to hydrogen management of HaWA GmbH commercial services operation of the hydrogen filling station supplier to the hydrogen filling station hydrogen supplies prototype license for the vehicles, technical advice
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The roles and responsibilities of the two groups of partners are summarized in Figure 2. The project was begun in 1997 when both of its aspects, vehicles and filling stations/infrastructure were planned.

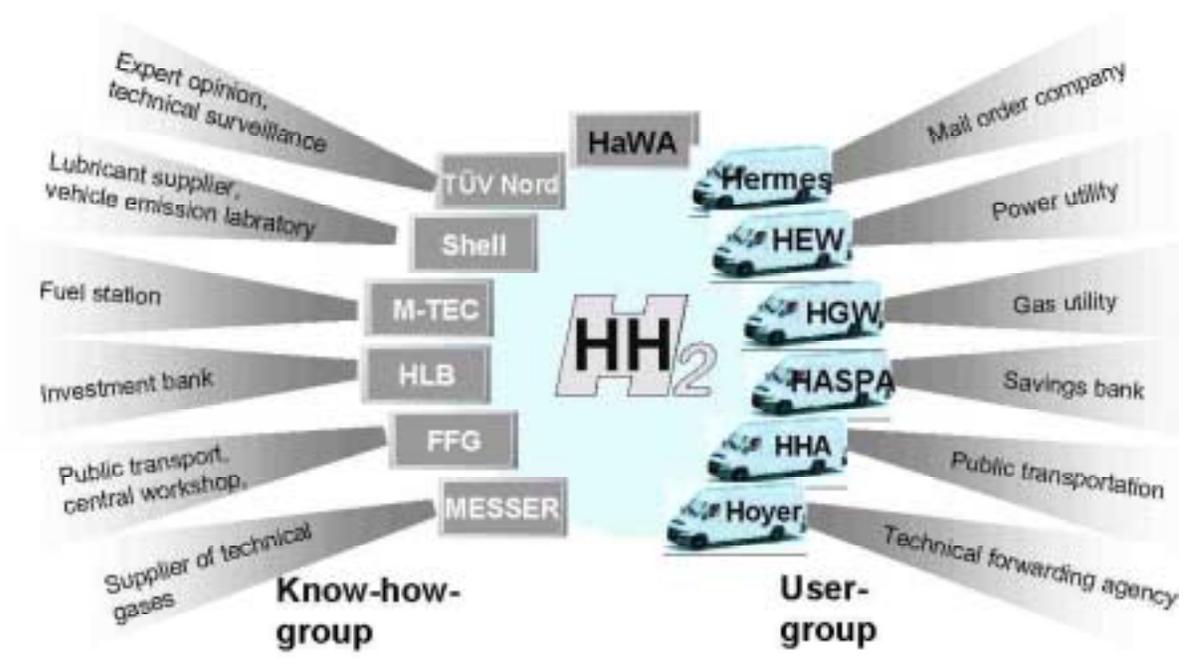


Figure 2: Roles and responsibilities of the partners in W.E.I.T.



Figure 3: The hydrogen van fleet in Hamburg



Figure 4: Van at the hydrogen refueling station

3. DESCRIPTION OF COMPONENTS

3.1 Vehicles

When it came to the vehicles, the partners decided upon a common standard in order to avoid unnecessary adjustments to different vehicle models. The vehicle chosen was a Mercedes Sprinter, a small transporter from DaimlerChrysler, the engine of which had to be converted to hydrogen.

The decision came out in favor of a combustion engine, as there were no fuel cell vehicles available at that time.

The conversion of the engines was performed by the US company Hydrogen Components Inc (HCI). The main components developed by HCI for this purpose were a new fuel feeder (CVI unit) and a modified central processing unit (CPU).

The fuel supply is provided by three high-pressure cylinders containing 115 l each (345 l in total) under a storage pressure of 200 bars. The cylinders are situated in the loading space of the vehicle. The hydrogen is fed into the CVI unit via a pressure-control line. The vehicle conversion consisted of:

- three composite cylinders containing 115 l with valves in a gas-tight box in the loading space
- filling and reflux valve with tubing
- digital fuel-tank level indicator and pressure gauge
- two electromagnetic shut-off valves (high- and low-pressure side)
- immobiliser, also triggered by the tank lid
- high- and low-pressure valve, regulator valve
- ignition system (four ignition coils with high-voltage unit)
- oxygen sensor, vacuum transducer and idle control valve
- CVI unit (constant volume injection)
- CPU electronics (central processing unit)

The vehicles were converted to hydrogen by FFG, with the help of HCI, in Hamburg. During the conversion process, a number of safety precautions were taken, based on existing regulations:

- The design and mode of operation of the hydrogen systems in the vehicles comply with TUV guidelines.
- All components hold qualification approval for hydrogen.
- The entire system has undergone a pressure test of 300 bars (bursting pressure 600 bars).
- All of the hydrogen vehicles are fitted with a number of safety features such as:
 - cylinder valves with pressure-control valves, fuse, flow regulator, and shut-off valve
 - crash-proof arrangement of all components
 - electrovalves which immobilise the system when the vehicle is parked
 - an immobiliser which secures the vehicle during refueling
 - a gas-tight system sealed off from the vehicle interior.



**200 bar
pressure gauge**

Valves and piping

Ventilation

Figure 5: Vessels in sealed compartment

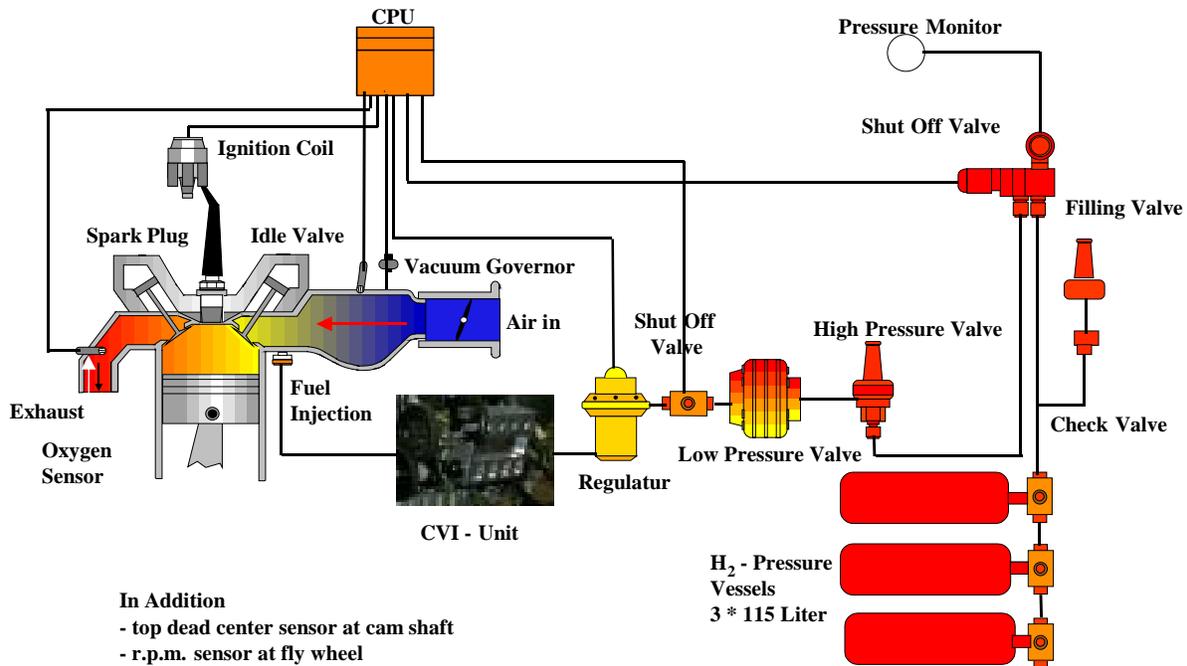


Figure 6: Equipment for hydrogen conversion

During maintenance and servicing of the vehicles, care should be taken that:

- the hydrogen systems undergo a functional, visual, and impermeability inspection as part of the annual vehicle servicing
- the composite cylinders undergo a visual inspection and pressure test every 3 years
- the cylinder valves are closed at all times when the vehicles are undergoing maintenance and repair or are at a garage
- garages are adequately ventilated
- for safety purposes, a gas indicator is used in garages.

In principle, the same safety regulations apply to hydrogen as to compressed natural gas (in agreement with VDTUeV Sheet 757).

Following retrofitting, the vehicles underwent an output and emission test. As expected, power output of the hydrogen engines was approximately 25% less than in the gasoline version (Figure 7), although the remaining power (40 kW at 3700 rpm) is sufficient for the inner-city traffic in which the vehicles are to be used. However, the reduced engine output is certainly not satisfactory for all applications. The option of installing a turbo-supercharger to improve output was not taken up—on cost grounds, and also so as not to further complicate the already sensitive management system of the engine. At 100-130 km, the vehicles' range also rules out their being suitable for universal use. In the future, storage systems of lower volume, but capable of carrying larger amounts of hydrogen in the car, will be needed.

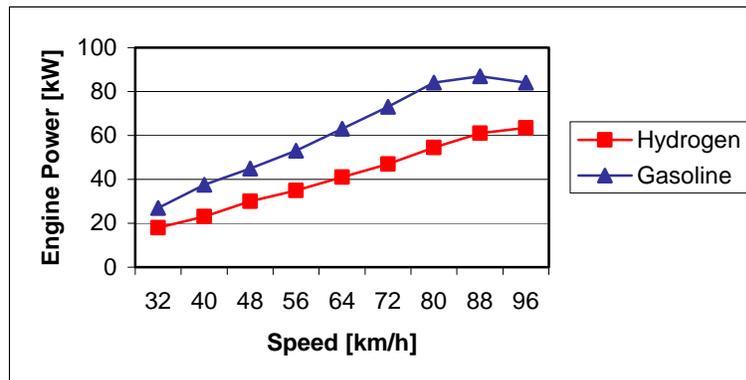


Figure 7: Comparison of engine power vs. speed for the hydrogen and original gasoline engine

The emission tests showed that almost all of the usual toxic emissions (CO, hydrocarbons) are well within limits or negligible. Only NO_x emissions are above the limit if no special emission-treatment or engine management measures are introduced—a well-known effect in hydrogen engines due to the high temperature of combustion.

In order to avoid the sparking of unspent hydrogen following unsuccessful ignition attempts, catalytic converters provided by the company dmc2 were installed directly behind the outlet valves for the catalytic conversion of the unspent hydrogen.

The total cost of a single vehicle amounted to 75,000 €, of which 25,000 € were spent on the standard vehicle and 50,000 € on converting it to hydrogen.

3.2 Filling Station

The filling station was installed in the south-east of Hamburg on the premises of Hamburger Gaswerke (see Table 2 for specifications). The hydrogen is delivered by trailer and compressed to tank pressure by means of a hydraulic compressor in a buffer storage. The hydrogen is pumped into the vehicles through a high-pressure coupling from a fuel pump fitted with a pressure gauge.

The technology used is based on that of similar natural-gas filling stations and adapted to hydrogen. It permits simple refueling which the drivers themselves can perform.

Table 2: Technical specification of the hydrogen filling station

Trailer maximal pressure minimal pressure maximal storage capacity useable capacity under standard conditions	200 bar 30 bar 3200 m ³ 2700 m ³
Compressor/booster output pressure input pressure compressor output	250 bar 200 bar/30 bar 940 m ³ /h / 115 m ³ /h
Buffer storage pressure useable capacity under standard conditions	250 bar / 200 bar approx. 35 m ³
Dispenser permissible output pressure maximal output rate	200 bar approx. 20 m ³ /min



Figure 8: Hydrogen dispenser and filling station

3.3 Hydrogen Production

The filling station is at present supplied with hydrogen by trailer. The hydrogen is industrially produced (chlor-alkali electrolysis) and does not yet meet the requirements for “green” hydrogen of the project partners. This option was chosen for the initial stage of the project, however, since the limited project resources were concentrated on converting the vehicles and setting up the filling stations.

Various alternative methods of producing green hydrogen have meanwhile been investigated, since a central objective of the project is to realize an entirely emission-free fuel-supply chain. This well-to-wheel approach includes the production of hydrogen using electricity generated from renewable sources.



Figure 9: Trailer for hydrogen supply

Initial internal studies have been conducted in collaboration with Iceland. The electricity supply in Iceland is generated 100% from renewable energy (hydroelectric power and geothermics), but uses only 17% of the country’s ecological feasible potential. It did, however, become clear that transport of the hydrogen in the small amounts required for W.E.I.T. was uneconomical and far more expensive than the cost of producing hydrogen in Iceland. The situation is similar with regard to purchasing hydrogen from Norway, which was also included in the study.

On-site production of green hydrogen using electrolysis is now the goal. Certified green electricity is to be used to supply the electrolysis plant. This solution costs far less and meets the project’s requirements for emission-free road traffic.



Figure 10: Hydrogen compressor



Figure 11: Buffer storage

4. PERFORMANCE AND OPERATIONAL EXPERIENCE (STAGE 1)

The filling station and the first vehicle were taken into operation in January 1999. Following a one-year trial period with the first transporter, the other vehicles were converted to hydrogen in 2000. The vehicles were used over a lengthy period. Below, a summary of our experience to date:

- TUV approval has been obtained following thorough tests.
- No problems were encountered in refueling with compressed hydrogen at a specially adapted filling station.
- Performance and noise were similar to gasoline or diesel engine.
- Ordinary drivers can be employed after being familiarized with the engine.
- The vehicles are not adequately reliable for universal application, particularly in view of their sensitive motor management system.
- The loading space was reduced due to size of the 345 l gas tanks.

Table 3: Comparison of diesel, natural gas, and hydrogen van

Model	Range	Output	Consumption per 100 km	Fuel costs *)	CO ₂
Fuel	km	kW	liters – diesel equivalent	€/kWh	g/kWh
Diesel	640	60	11.6	8	267
Natural gas	175	69	15.2	4.5	211
Hydrogen	115	40	13.1	11	~ 0

*) Industrial hydrogen price: 0.32 €/m³ (at atmospheric pressure)

The hydrogen vehicles differ from the standard diesel or natural gas vehicles of the same model (Mercedes Sprinter) as shown in Table 3.

Operation of the hydrogen filling station produced mainly favourable results:

- the installation of the hydrogen filling stations was based on the technical principles of natural-gas filling stations;
- the safety requirements were the same as for natural-gas filling stations;
- practically no disruption occurred in the operation to date;
- minor leakage was detected in the initial stage of operation;
- the refueling times were approximately 3 minutes;
- drivers can refuel unaided;
- there were practically no hydrogen emissions during refueling;
- the hydraulic compressor turned out to be ideally suited to this filling-station concept;
- hydrogen supply by trailer poses no problems.

5. CONCLUSION AND OUTLOOK

Summing up, the project can be assessed as follows: The conversion of vehicles to run on hydrogen is possible in principle, although the vehicles—by reason of their prototype status—do not yet have the technical maturity or reliability of conventional vehicles. As a consequence, the project partners HGW, HOYER, and HASPA were unable to use the vehicles as they had intended and therefore left the project group. In the case of the other project partners, the vehicles are deployed in less critical areas, showing that, in projects such as these, they demonstrate the possible applications of hydrogen in road traffic and thus engender acceptance of hydrogen as a new fuel.

It will not be long before fuel cell drives for the use of hydrogen in fleet vehicles will offer distinct advantages. For this reason, fuel-cell vehicles will be used in the next stage of the W.E.I.T. project. An initial DaimlerChrysler prototype (based on the Mercedes Sprinter) has been in operation by Hermes Versand Service under supervision of DaimlerChrysler since fall 2001.

Operation of the filling station proved to be relatively unproblematic. The experience gained here will also be useful for the next generation of filling stations with higher pressure (tank pressures of 350 bar or later even 700 bar). In the next stage, the hydrogen will be produced by an on site electrolyser at the filling station using renewable power.

6. CONTACT INFORMATION

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Figure 12: Mercedes Fuel Cell Sprinter (source: DaimlerChrysler)



Figure 13: Fuel cell system in the floor of the Sprinter