



# Explosion protection in the fuel-cell vehicle

## Development of hydrogen-powered propulsion systems at DLR

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Figure 1: Fuel cell-driven vehicle

The increasing general awareness of the fact that fossil energy sources, which have dominated to date, are limited and that they pose a potential danger to the environment has recently led to a search for alternative energy sources and fuels. One of the most promising approaches is production of pure hydrogen and oxygen by water electrolysis and recombination of both gases in fuel cells. This generates electrical power and heat and produces pure water as the reaction product.

Hydrogen itself may be hazardous since it is a readily ignitable, flammable gas. The article below describes how this problem is being tackled in automotive-engineering vehicle-integrated trial systems and test facilities.

### Research into vehicle technology of the future

The German Aerospace Centre, Deutsches Zentrum für Luft- und Raumfahrt (DLR), is the National aerospace-research centre for the Federal Republic of Germany, and is a worldwide-acknowledged institution and a popular cooperation partner in international research projects. Aside from its own research, the DLR, as a space agency, is responsible for implementing German space activities by mandate of the Federal Government. The eight DLR sites currently employ a total workforce of 4,500.

The DLR has also been engaged in the new area of ›Traffic‹ since 1999, dealing with the major topics of traffic research, automotive and traffic engineering.

The DLR's Stuttgart site whose roots date back to the Jet-Propulsion Physics Research Institute, which was founded as early as 1954 at the Stuttgart airport, now houses the Institutes of Technical Thermodynamics, Combustion Engineering and Technical Physics, which make important contributions to the topics of ›Renewable Energy Research‹, ›Combustion Engineering‹ and ›High-Energy Laser Systems‹.

The Institute for Vehicle Concepts, (Institut für Fahrzeugkonzepte IFK) whose underlying vision is successful participation in efficient-mobility research, based on regenerative energy sources and energy conversion of the future, and progressive types of construction and lightweight design, was set up in 2001 with the assistance of the German Regional State of Baden-Wuerttemberg. In close cooperation with several renowned German car component suppliers, one of the projects currently underway deals with the topic development, realisation and experimental operation of a fuel-cell-powered vehicle as a mobile experimental vehicle (Figure 1). The aims of the ›HyLite®‹ Project are:

- designing and constructing an open development platform for fuel-cell propulsion systems
- developing low-cost, high-performance components for fuel-cell systems and vehicle propulsion systems,
- developing powerful cooling circuits for vehicle propulsion systems, and
- constructing and operating a powerful simulation model for fuel-cell vehicles.

### The HyLite® vehicle

Work on the development of the HyLite® vehicle commenced in 2001. The aim is to integrate a fuel-cell system in the newly designed hybrid power train of an existing vehicle. The focus of the investigations is not on the fuel cell or the fuel-cell stack – considerable developments have already been achieved in this respect in automotive engineering – but on the peripheral systems of the fuel-cell block, i.e. the air supply and the cooling system.

On the HyLite® vehicle, the electrical power train is supplied with energy from a hybrid system consisting of a PEFC/low-temperature fuel-cell system and a rechargeable battery system. The hydrogen is stored in two 200 bar pressurized-gas tanks or in metal-hydride storage vessels. Since hydrogen may release from the supply system, i.e. the fuel system, due to leaks in components, and at inter-connectors in the tubing, it was a favourable sub goal to minimise the number of detachable connections.

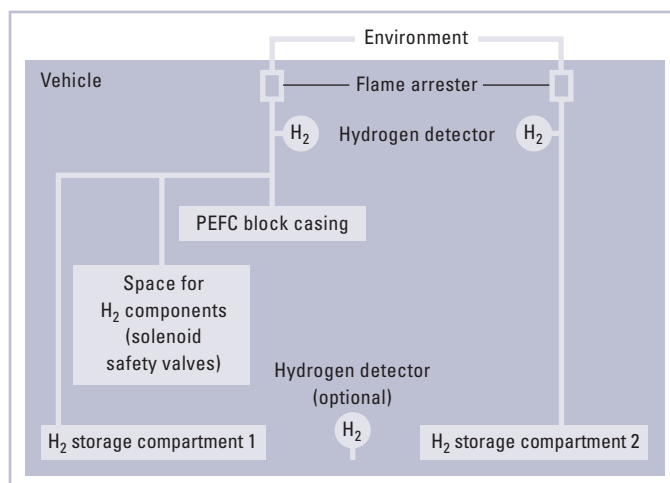


Figure 2: Schematic view of the venting and measuring concept of the hydrogen zones

The assessment of the individual subassemblies with respect to the probability of hydrogen release is fundamental to the safety concept of the vehicle. In the case of the HyLite® vehicle, three areas are considered to be critical:

- the two high-pressure gas tanks with directly attached valves and fittings
- parts of the supply and discharge lines (e.g. solenoid valves) of the hydrogen supply system connected to the fuel-cell stacks, and
- the two fuel-cell stacks with their core system itself.

These critical areas are enclosed in so-called hydrogen zones, which are designed as self-contained systems and are gastight towards the passenger compartment and the installation zones of the other peripheral systems. Particular care was taken in this case when designing the lead-through openings of the media lines and electrical cables out of the hydrogen zones. All zones have a permanent opening at the highest point and have flame arresters at the outlets of the venting lines (Figure 2).

The vehicle's safety concept is based on the following principles:

- The principle of gastight compartments with permanent openings serves to keep escaping hydrogen away from compartments without special safety measures, to discharge the hydrogen quickly and to route it directly to the ambient air outside the car. Accident situations had to be considered in the design of the piping and precautions were taken against detachment of lines and other damage to components.
- Limitation of the flow rate and shut-off of the hydrogen source means allowing only the maximum hydrogen flow rate required, and in the event of a fault, closing the pressurized-gas tanks quickly and reliably. One of the following trip conditions applies to the latter:
  - One of the three hydrogen-in-air sensors determines a hydrogen concentration exceeding 40 % of the lower explosion limit (LEL).
  - One of the crash sensors detects an overshoot of the allowed acceleration or undershoot of the deceleration values so that an inadmissible vehicle state must be assumed. ➔

- › An inadmissible operating state is detected in the fuel-cell system, such as a critical temperature or pressure value or an inadmissibly high hydrogen consumption is detected.
- › A manual emergency-stop button is pressed.
- › The gas sensors in the fuel line are designed to be intrinsically safe as they are the only active elements exposed constantly, or in the long term, to hydrogen.
- › The flame arresters serve to suppress flashback into the fuel system if released hydrogen ignites, e.g. outside the vehicle.

Besides the safety measures in the hydrogen-supply system, it is also necessary to take certain special precautions owing to the vehicle's higher than usual use of higher voltage from the electrical system. Thus for instance, accidental-contact prevention of active components is foreseen in the case of voltages exceeding 60 V. Voltage sources with output voltages exceeding 60 V, such as the fuel-cell stacks and the battery, are disconnected via power contactors if inadmissible operating states occur or if the emergency-stop buttons are actuated, as described above. In addition, faultless operation of the electronic control unit (ECU) is monitored by means of a 'watchdog' circuit, which trips a system shut-down in the event of failure of the ECU.

### Explosion protection concept for laboratory tests of the propulsion concept

A stationary test stand with a functionally equivalent system was constructed in a laboratory in order to test the fuel-cell propulsion system prior to its integration into the vehicle.

This system was, however, spatially distributed and supplemented with additional, expensive measurement and control systems in order to be able to conduct measurements on it and optimise it, and in order to allow fast component or subsystem exchange.

The structural situation and number of electrical devices, electronic measurement sensors and analytical systems required excluded the classification of the entire laboratory area as a hazardous area right from the beginning. The costs required to design all equipment as explosion protected and to convert the laboratory would have exceeded the project's budget.

As a result of this, a so-called 'explosion protection compartment', which has now also been patented (Figure 3), was developed together with the Dutch company Electromach, a subsidiary of R. STAHL. This involved simply turning the underlying principle of the type of protection pressurized enclosures 'p' on its head by not producing a safe area by means of a suitable housing and various technical measures in the hazardous area, but safely partitioning off a hazardous area in order to be able to operate it within a non-hazardous area. Out of necessity a virtue was created. The safety concept ultimately used in the vehicle is also based on safe spatial separation of the flammable hydrogen from other gaseous and fluid media, and safe compartmentalisation of a spatially very limited explosion hazard area from all sources of ignition.

The propulsion system installed in the laboratory comprises the hydrogen and oxygen supply system, the fuel-cell system, the battery, a DC/DC converter, the drive inverter for the electric motor, the motor itself, and an electrical machine on the output shaft as the load, in order to simulate realistic driving conditions. Certain sensors



Figure 3:  
Explosion protection  
compartment

and the related analysis circuitry with computing system were also installed in the laboratory. The explosion protection compartment safely separates the area in which an explosive atmosphere may occur. Inside the compartment, the hydrogen concentration is monitored with an intrinsically safe sensor. Its signal is routed via an electrical isolator into the safe area where evaluation circuitry shuts off hydrogen supply as soon as a hydrogen concentration of 40 % of the lower explosion limit is measured. The same principle is also used in the car. The equipment installed inside the compartment, such as the lighting and differential-pressure transmitter, is designed as explosion protected in order to allow for the response time of the sensor and as a precaution against the incalculable locally higher hydrogen concentrations. These are installed in the upper compartment area (Figure 4).

The explosion protection compartment is designed as gastight with respect to the laboratory, including the windows and doors. Several gastight panels for supply and discharge of hydrogen, air, fully demineralised water, and nitrogen for system inertisation and for lead-through of the electrical signal and supply lines (Figure 5) are fitted in the side panels. The test system equipment, such as the fuel cell, system components or measuring transducers, is supported on perforated metal wiring panels inside the compartment, allowing unhindered passage of gas upwards. The H<sub>2</sub>-in-air sensor is mounted at the highest point. The laboratory outer wall features an opening which is closed off partly only with heat-insulating lightweight construction elements and, which is the size of the interior of the explosion protection compartment, leading to the environment outside the laboratory building. The compartment is attached gastight to the laboratory inside wall and covers the entire opening. 15 cm-high slots, covered with fine perforated plate, are provided, both in the top section and in the bottom section, allowing unhindered passage of

gas. Should an explosion occur inside the cubicle despite all precautions, the lightweight construction elements, which drop out at a slight interior overpressure of 10 mbar, guarantee fast pressure relief into the safe area over the entire opening (Figure 6).

### Outlook

The development of hydrogen-powered vehicles has made substantial progress in the past ten years. Driven by the search for alternative fuels to satisfy the booming need for mobility worldwide, development work has now achieved a level at which initial vehicles, ready for mass production, are about to be launched into the market. However, certain hurdles still need to be overcome, in particular with respect to the required infrastructure. For instance, there are currently only three service stations providing hydrogen for vehicle refuelling in Germany (in Hamburg, Berlin and Munich).

There now appears to be nothing stopping market launch of hydrogen-fuelled vehicles from the point of view of safety technology. Those who originally raised concerns owing to the hazardous nature of hydrogen frequently failed to grasp that conventional fuels are also flammable and thus potentially explosive. However, the growing euphoria among the public that hydrogen is the perfect solution should be tempered somewhat with regard to the worldwide energy situation and decreasing fossil fuel resources. People frequently fail to see that hydrogen is not an energy source but simply a secondary fuel. The crucial point is hydrogen production. The hydrogen production is currently, as in the past, overwhelmingly dominated by usage of fossil fuel mile in front of its production with the water electrolysis process from renewable energy sources. We are still only at the start of the journey to solve this problem of the future.



Figure 4: Explosion protected lights and differential-pressure gauge



Figure 5: Media supply into the explosion protection compartment



Figure 6: Explosion pressure relief on the explosion protection compartment