

# **Safety Aspects of Hydrogen Fuel Cell Vehicles**

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## Safety Aspects of Hydrogen Fuel Cell Vehicles

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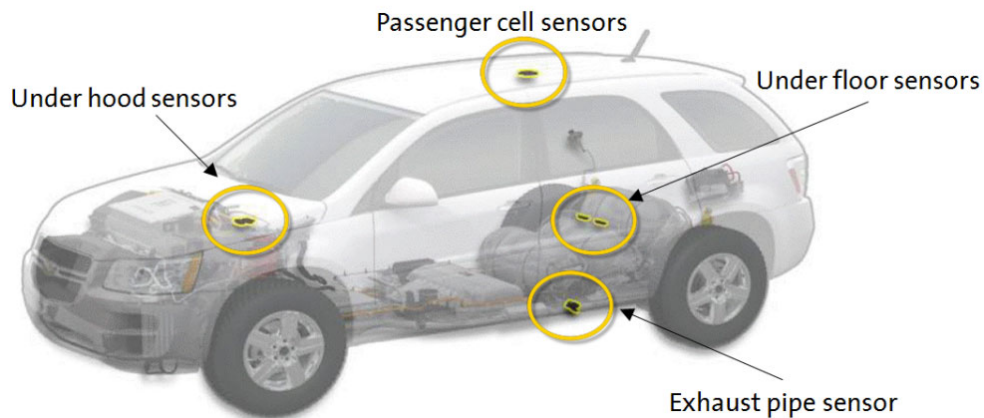
Hydrogen fuel cell vehicle safety generally focuses on three areas of vehicle safety: The fuel, the storage system, and the vehicle itself. This presentation will give an overview using the Opel HydroGen4, equipped with a 70 MPa compressed hydrogen storage system, as an example [1].

Like any fuel, hydrogen has a significant amount of chemical energy which will be released upon ignition if an oxidizer such as oxygen is available. In air, mixtures between 4 vol% H<sub>2</sub> (lower flammability limit, LFL) and 74 vol% H<sub>2</sub> (upper flammability limit, UFL) are ignitable [2]. An unintended release of hydrogen itself is not a threat as hydrogen is not toxic, but the possible risk of ignition needs to be considered in the safety assessment.

For gasoline-driven vehicles, gasoline fuel leaks can be detected in two ways. First, it is a fluid and leakages are directly visible. Second, gasoline has a characteristic smell so that some discharges may also be detected directly. In contrast, hydrogen gas is invisible and odorless. However, depending on the storage technology, additional signs of leakage may be noticeable [3]. For example, for high-pressure storage systems a leak in the high-pressure section is audible, and for liquid hydrogen systems, leakages could be visible. In any event, hydrogen sensors are used to detect hydrogen at concentration levels higher than the specific target values. In the future, by odorizing the hydrogen fuel or advanced process monitoring methods, it may be possible that hydrogen sensors will no longer be necessary.

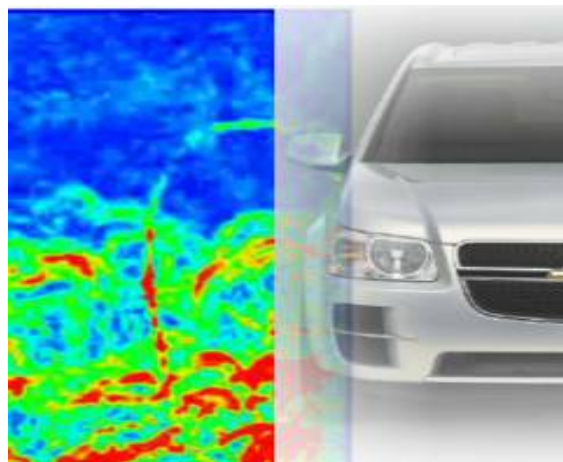
The severity of a possible ignition is predominantly proportional to the total mass of released hydrogen. However, the released mass cannot be determined easily as a hydrogen sensor detects the concentration of hydrogen only. Therefore, it is possible that a very small mass of hydrogen released causes a concentration detected above the ignition threshold, even though the actual average concentration is lower than the ignition threshold. Due to its buoyancy and diffusivity, the released hydrogen could spread in a way that only a very small area exceeds LFL. Moreover, the LFL limit is applicable to laboratory conditions and marks the transition from the region where no ignition is possible to the region where ignition is barely possible under some conditions. Thus, for a detailed study, in particular the flame propagation needs to be taken into account [4]. Considering dynamic and usual automotive environmental conditions, the actual sustainable ignition threshold is significantly above LFL [5,6].

On board the HydroGen4 fuel cell vehicle, there are seven hydrogen sensors for hydrogen leakage supervision. If the onboard supervision system detects hydrogen concentrations exceeding the threshold values, a hydrogen warning mode is enabled. The vehicle driver is notified by visible and audible signals, and fuel supply from the hydrogen storage system is shut down by closing shutoff valves. However, the driver needs to safely park the vehicle and therefore, propulsion needs to be available. Hence, propulsion in the hydrogen warning mode is provided by using the vehicle's high-voltage traction battery.



**Figure 1: Location of hydrogen sensors onboard the HydroGen4.**

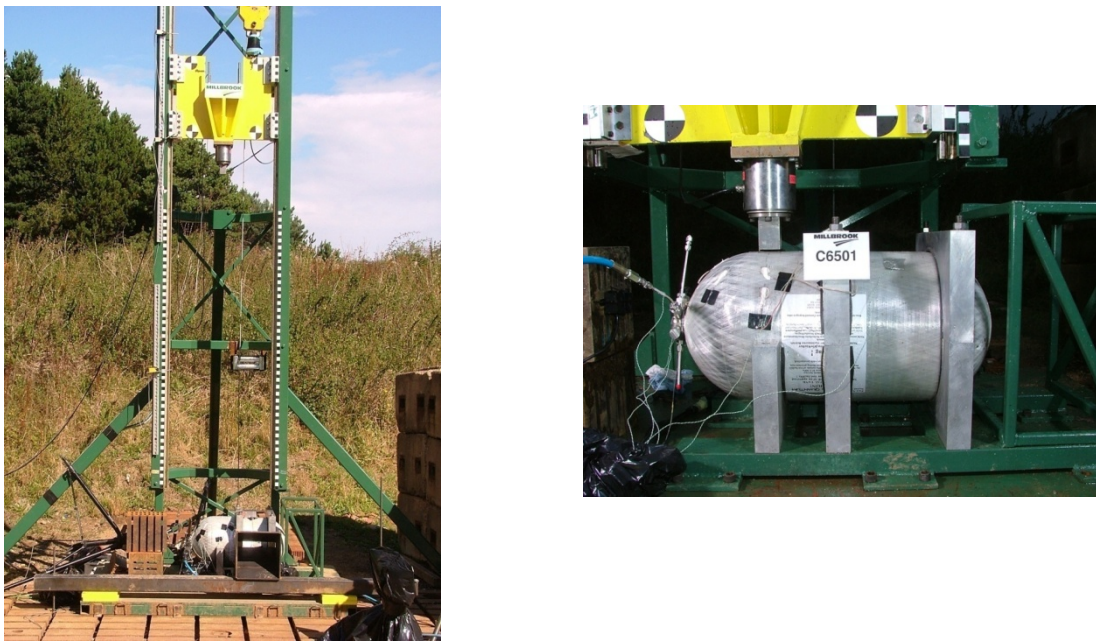
There are two challenges for the onboard supervision system: First, leakages must be detected in a timely manner. Therefore, the sensors need to be placed at selected locations. For the HydroGen4, great care has been spent in validation testing and concentration threshold assessment to define those locations. For example, the Background Oriented Schlieren Method has been refined and applied to study vehicle-level hydrogen dispersion in great detail (Figure 2) [7]. As a result, hydrogen sensors have been placed at the four locations shown in Figure 1. Second, the sensor functionality needs to be verified anytime. As under normal operating conditions no hydrogen concentration is detected, it is impossible to perform a sensor check without additional measures like e.g. hydrogen test gas which could be applied in regular vehicle service checks. Therefore, hydrogen sensors with very high reliability must be used and critical locations are currently supervised with redundant sensors.



**Figure 2: Background Oriented Schlieren (BOS) technique to assess hydrogen dispersion.**

In terms of safety, the main task of any hydrogen storage system is to contain and seal the hydrogen. The shutoff approach applies to failure detection in normal operating condition and to vehicle crash situations. To provide the vessel integrity under very harsh conditions, there

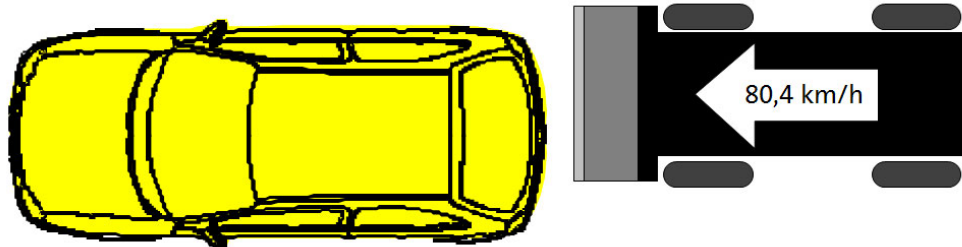
are several tests required by applicable safety codes including permeation testing, drop testing (Figure 3), vibration testing, extreme temperature testing, bonfire and gunfire testing. Most of the tests are to validate vessel performance under usual operating conditions over the vehicle's life, i.e. testing under very harsh conditions and validating the system's performance under these conditions. However, the bonfire test and the gunfire test are of destructive nature and assess functionality under worst case assumptions. The bonfire test is designed to verify that during vehicle fires affecting the vessel's integrity, the vessels are depressurized by an intended hydrogen release. In the gunfire test, the vessel is penetrated by a bullet. It is a test to verify that after vessel penetration, there is just a discharge of hydrogen rather than a vessel rupture. However, integrated in a vehicle, vessel penetration of the storage system is very unlikely even during extreme vehicle accidents. Even though the HydroGen4 withstands severe impact conditions, an additional internal test program for the storage vessels has been initiated. Several vessels have been tested against extreme impact conditions at various hydrogen pressures up to 70 MPa. In this test program, all vessels remained leak-tight and no pressure drop was observed.



**Figure 3: Drop test of HydroGen4 storage vessel.**

Concerning Hydrogen Safety, Fuel cell vehicles need to meet the applicable regulations, in particular the Federal Motor Vehicle Safety Standards FMVSS 208 and FMVSS 301 for the U.S. The HydroGen4 was designed from the beginning to meet these and other requirements. Extensive computer modeling and simulation has been performed together with accompanying component and subsystem tests. A final test according to FMVSS 208 was run on full vehicle level with an operating fuel cell and hydrogen on board. Of particular interest from a hydrogen safety perspective is the rear crash as in this test, the storage system is exposed to external loads. In the rear crash according to FMVSS 301 (Figure 4), a barrier with a mass of 1368 kg hits the standing vehicle from the rear with 70% offset at a

speed of 80.5 km/h. Also this test was performed with the HydroGen4 and the vehicle sensing system worked successfully as expected. The main shutoff valves closed automatically thereby inhibiting any further external leakage.



**Figure 4: Schematic of barrier test according to FMVSS 301.**

In summary, safe onboard handling and storage of hydrogen is verified for fuel cell vehicles. Hydrogen leakages are detected by hydrogen sensors and tank system shutoff valves are closed automatically. Concerning Hydrogen Safety, the HydroGen4 meets all applicable regulations, in particular FMVSS 208 and FMVSS 301. In addition, the storage vessels have been tested for extreme impact conditions at various hydrogen pressures up to 70 MPa.

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