SGS 10 -09

BMW GTR Action items from 14th of July teleconference harmonized with G. Scheffler

1. Correct text in part A3.3.2 as needed. - BMW
Finished

2. Provide rationale and justification in Section A5.2. - BMW; GWS and Nha
Finished

3. Create a summary table of requirements from ISO standard, EC regulation and BMW proposal - BMW and ISO
Work in progress

4. Provide a separate Section for LHSS fuel delivery system (from fuel container assembly to the engine) in Section A3.4 – BMW and GWS
Proposal for one combined Section for LHSS and CGH2 in 3.4.1 => Finished

5. Reword and/or combine the 5 bullets on MAWP of Section B5.2, page 43. Decision needed on whether move these requirements to Annex 7.2 or keep in part B – BMW and GWS
Bullet point have been removed. Requirements are defined within the pass criteria of the tests in B.5.2.3, => Finished

6. B5.2.2 Material compatibility: review the material qualification requirements for CGH, specifically Section B6.2.1, to see whether the approved material can be used for LHSS or develop a separate material Section for LHSS. This should also be in Annex 7.2 - BMW and GWS

BMW waits for new OICA proposal on material compatibility and provides new proposal if necessary

7. Passing criteria in Section B5.2.3.2 is not clear. Keep the test requirements and pass/fail criteria in the Section and move the test set-up and procedures to Section 6; this should be done with other requirements - BMW and GWS
Finished

8. Section B5.2.3.3 Leak test: need to verify that the allowable permeation rate is consistent with CGH - BMW and GWS
Finished

9. Review to verify that LHSS shall meet the same in-use and post crash requirements in Section B5.3. and related test procedures - BMW and GWS Work in progress

A.3.3 HYDROGEN STORAGE SYSTEM

A.3.3.1 COMPRESSED HYDROGEN STORAGE SYSTEM

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3.3.2 LIQUEFIED HYDROGEN STORAGE SYSTEM

A.3.3.2.1 Hydrogen gas has a low energy density per unit volume. To overcome this disadvantage, the liquefied hydrogen storage system (LHSS) maintains the hydrogen at cryogenic temperatures in a liquefied state.

A.3.3.2.2 A typical liquefied hydrogen storage system (LHSS) is shown Figure 4. Actual systems will differ in the type, number, configuration, and arrangement of the functional constituents. Ultimately, the boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (and/or gaseous) hydrogen from the remainder of the fuel system and the environment. All components located within this boundary are subject to the requirements defined in this Section while components outside the boundary are subject to general requirements in Section 4. For example, the typical LHSS shown in Figure 4 consists of the following regulatory elements:

- liquefied hydrogen storage container(s),
- shut off devices(s),
- a boil-off system,
- Pressure Relief Devices (PRDs),
- the interconnecting piping (if any) and fittings between the above components.

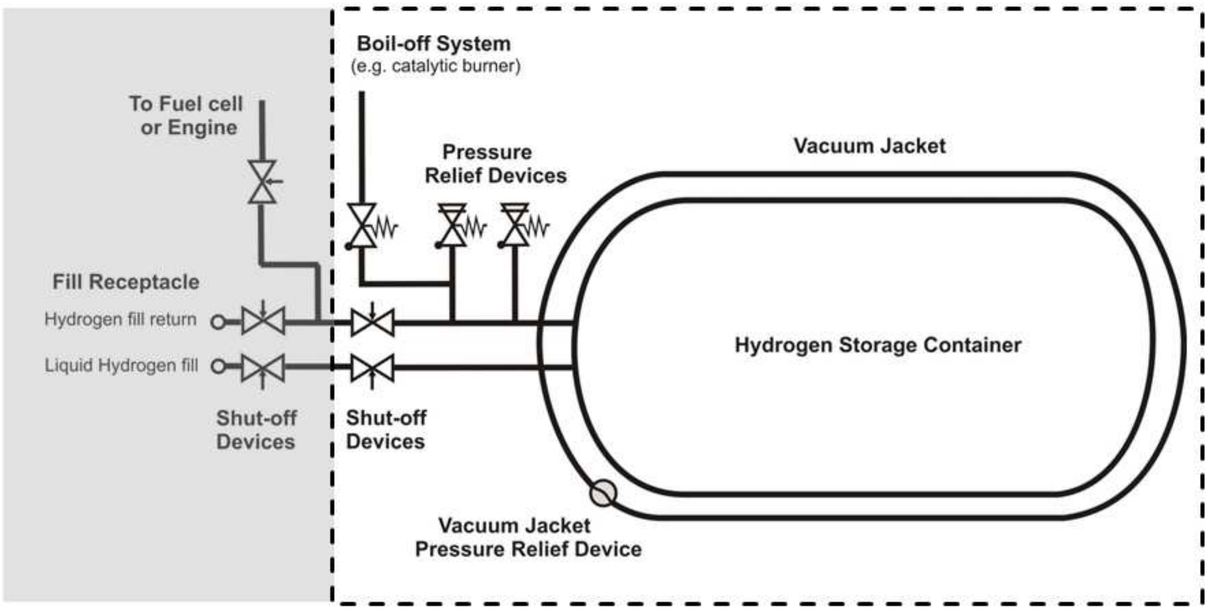

Figure 4. Typical Liquefied Hydrogen Storage System

A.3.3.2.3 During fueling, liquefied hydrogen flows from the fuelling system to the storage container(s). Hydrogen gas from the LHSS returns to the filling station during the fill process so that the liquefied hydrogen can flow into liquefied hydrogen storage container(s) without over pressurizing the system. Two shut-offs are provided on both the liquefied hydrogen fill and hydrogen fill return line to prevent leakage in the event of single failures.

A.3.3.2.4 Liquefied hydrogen is stored at cryogenic conditions. In order to maintain the hydrogen in the liquid state, the container needs to be well insulated, including use of a vacuum jacket that surrounds the storage container. Generally accepted rules or standards (such as those listed in the B7.2 annex) are advised to use for proper design of the storage container and the vacuum jacket.

A.3.3.2.5 During longer parking times of the vehicle, heat transfer will induce a pressure rise within the hydrogen storage container(s). A boil-off system limits heat leakage induced pressure rise in the hydrogen storage container(s) to a pressure specified by the manufacturer. Hydrogen that is vented from the LHSS may be processed or consumed in down-stream systems. Discharges from the vehicle resulting from over-pressure venting should be addressed as part of allowable leak/permeation from the overall vehicle.

A.3.3.2.6 In case malfunction of the boil-off system, vacuum failure, or external fire, the hydrogen storage container(s) are protected against overpressure by two independent Pressure Relief Devices (PRDs) and the vacuum jacket(s)is protected by a vacuum jacket pressure relief device.

A.3.3.2.7 When hydrogen is released to the propulsion system, it flows from the LHSS through the shut-off valve that is connected to the hydrogen fuel delivery system. In the event that a fault is detected in the propulsion system or fill receptacle, vehicle safety systems usually require the container shut-off valve to isolate the hydrogen from the down-stream systems and the environment.

A.3.4 HYDROGEN FUEL DELIVERY SYSTEM

A.3.4.1 The fundamental purpose of a hydrogen fuel delivery system is to reliably deliver hydrogen fuel to either ICE or fuel cell stack at a specified pressure and temperature for proper fuel cell or ICE operation over the full range of vehicle operating conditions. Hydrogen is delivered from the storage container(s) to the fuel cell stack or to the ICE via a series of valves, control valves, pressure regulators, filters, piping, and (a) possible (coolant) heat exchanger(s) or heaters. In the case of a liquefied hydrogen storage both liquid and gaseous hydrogen could be extracted from the storage so typically a coolant heat exchanger downstream the container shut-off device heats-up the hydrogen to the temperature range specified by the manufacturer. Similarly, in the case of compressed hydrogen storage, some thermal conditioning of the gaseous hydrogen may also be required, particularly in extremely cold, sub-freezing weather.

A.3.4.2 The fuel delivery system must reduce the pressure from levels in the hydrogen storage system to values required by the fuel cell or ICE system. In the case of 70 MPa compressed hydrogen storage system, for example, the pressure may have to be reduced from as high as 87.5 MPa to levels typically under 1MPa at the inlet of the fuel cell system and, respectively, typically under 1.5 MPA at the inlet of an ICE system. This may require multiple stages of pressure regulation to achieve accurate and stable control and over-pressure protection of down-stream equipment in the event that a fault in the regulation system occurs. Over-pressure protection may be accomplished, if necessary, by either venting excess hydrogen gas through pressure safety valves or isolating the hydrogen gas supply (by closing the shut-off valve) in the hydrogen storage system when an over-pressure condition is detected.

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A.5. RATIONALE FOR REQUIREMENTS & SCOPE

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A.5.1 COMPRESSED HYDROGEN STORAGE SYSTEM TEST REQUIREMENTS & SAFETY CONCERNS

(…)

A.5.2 LIQUIFIED HYDROGEN STORAGE SYSTEM TEST REQUIREMENTS & SAFETY CONCERNS

The containment of the hydrogen within the liquefied hydrogen storage system is essential to successfully isolating the hydrogen from the surroundings and down-stream systems. The system-level performance tests in Section B.5.2 were developed to demonstrate a sufficient safety level against burst of the container and capability to perform critical functions throughout service including pressure cycles during normal service, pressure limitation under extreme conditions and faults, and in fires.

Performance test requirements for all liquefied hydrogen storage systems in on-road vehicle service are specified in Section B 5.2. These criteria apply to qualification of storage systems for use in new vehicle production.

This Section (A.5.2) specifies the rationale for the performance requirements established in Section B.5.2 for the integrity of the liquefied hydrogen storage system. Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in Section B.5.2.1 to 5.2.4.

A.5.2.1 Rationale for B.5.2.1 Verification Tests for Baseline Metrics

A proof pressure test and a baseline initial burst test are intended to demonstrate the structural capability of the inner container.

A.5.2.1.1 Rationale for B.5.2.1.1 Proof Pressure Test

By design of the container and specification of the pressure limits during regular operation and during fault management (as demonstrated in B5.2.3.2 und B.5.2.3.3), the pressure in the inner container could rise to 110% of the Maximum Allowable Working Pressure (MAWP) during fault management by the primary pressure relief device and no higher than 150% of MAWP even in “worst case” fault management situations where the primary relief device has failed and the secondary pressure relief device is required to activate and protect the system. The purpose of the proof test to 130 per cent MAWP is to demonstrate that the inner container stays below its yield strength at that pressure.

A.5.2.1.2 Rationale for B.5.2.1.2 Baseline Initial Burst Pressure

By design (and as demonstrated in B5.2.3.3), the pressure may rise up to 150% of the Maximum Allowable Working Pressure (MAWP) when the secondary (backup) pressure relief device(s) may be required to activate. The burst test is intended to demonstrate margin against burst during this “worst case” situation. The pressure test levels of either the Maximum Allowable Working Pressure (in MPa) plus 0.1 MPa multiplied by 3.25 or the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp (where Rm is ultimate tensile strength and Rp is minimum yield strength of the container material) are common values to provide such margin for metallic liners.

Additionally, the high burst test values (when combined with proper selection of materials in B5.2.2) demonstrate that the stress levels are acceptably low such that cycle fatigue issues are unlikely for metallic containers that have supporting design calculations. In the case of non-metallic containers, an additional test is defined in 7.2.1 to demonstrate this capability as the calculation procedures have not yet been standardized by for these materials.

A.5.2.2 Rationale for B.5.2.2 Verification for Material Compatibility

Proper selection of materials for exposure to hydrogen at extremely low temperatures is required to ensure that materials will not show hydrogen embrittlement or otherwise degrade during expected operation. The test methods in B.5.2.2 reflect an internationally accepted approach to evaluate material compatibility.

A.5.2.3 Rationale for B.5.2.3 Verification for Expected On-road Performance.

A.5.2.3.1 Rationale for B5.2.3.1 Boil-off Test

During normal operation the boil-off management system shall limit the pressure below MAWP. The most critical condition for the boil-off management system is a parking period after a refueling to maximum filling level in a liquefied hydrogen storage system with a limited cool-down period of maximum 48 hours.

A.5.2.3.2 Rationale for B.5.2.3.2 Hydrogen Discharge Test

The Hydrogen discharge test shall be conducted during Boil-off of the liquid storage system. Manufacturers will typically elect to react all (or most) of the hydrogen that leaves the container, but, in order to have a hydrogen discharge criteria that is comparable to the values used for Compressed Hydrogen Storage Systems, it is to include any hydrogen that leaves the vehicle boil-off systems with other leakage, if any, to determine the total hydrogen discharge from the vehicles.

Having made this adjustment, the total hydrogen discharge from a vehicle with liquefied hydrogen storage is the same as a vehicle with compressed hydrogen storage system. According to the discussion in B.5.1.3, the total discharge from a vehicle with liquefied hydrogen may therefore be 150 mL/min for a garage size of 30.4 m^3. As with compressed gas, the scaling factor, [(Vwidth+1)*(Vheight+0.05)*(Vlength+1)/ 30.4], can be used to accommodate alternative garage/vehicle combinations to those used in the derivation of the rate, and accommodates small vehicles that could be parked in smaller garages.

Prior to conducting this test, the primary pressure relief device should be forced to activate so that the ability of the primary relief device to re-close and meet required leakage is confirmed.

A.5.2.3.3 Rationale for B.5.2.3.1 Vacuum Loss Test

In order to prove the proper function of the pressure relief devices and the compliance with the allowed pressure limits of the liquefied hydrogen storage system as described in A5.2.1 and verified in B.5.2.1, a sudden vacuum loss due to air inflow in the vacuum jacket is considered as the "worst case" failure condition. In contrast to hydrogen inflow to the vacuum jacket, air inflow causes significantly higher heat input to the inner container due to condensation of air at cold surfaces and evaporation of air at warm surfaces within the vacuum jacket.

The primary pressure relief device should be a re-closing type relief valve so that hydrogen venting will cease when the effect of a fault subsides. These valves, by globally-accepted design standards, are allowed a total pressure increase of 10% between the setpoint and full activation when including allowable tolerances of the setpoint setting itself. Since the relief valve should be set at or below the MAWP, the pressure during a simulation of the fault that is managed by the primary pressure relief device should not exceed 110% of Maximum Allowable Working Pressure (MAWP).

The secondary pressure relief device(s) should not activate during the simulation of a vacuum loss that is managed by the primary relief device as their activation may cause unnecessary instability and unnecessary wear on the secondary devices. To prove fail-safe operation of the pressure relief devices and the performance of the second pressure relief device in accordance with the requirements in B.5.2.3.3 a second test shall be conducted with the first pressure relief device blocked. In this case, either relief valves or burst discs may be used, and the pressure is allowed to rise to as high as 136 per cent MAWP (in case of a valve used as secondary relief device) or as high as 150 per cent MAWP (in case of a burst disc used as secondary relief device) during the simulation of a vacuum loss fault.

A.5.2.4. Rationale for B.5.2.4 Verification Test for Service Terminating Conditions

In addition to vacuum degradation or vacuum loss fire also may cause overpressure in liquefied hydrogen storage systems and thus proper operation of the pressure relief devices and the requirements described in Section A.5.2.3.3 have to be proven in a bonfire test.

B 5 PERFORMANCE REQUIREMENTS

B5.1 COMPRESSED HYDROGEN STORAGE SYSTEM

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B5.2 LIQUEFIED HYDROGEN STORAGE SYSTEM

This Section specifies the requirements for the integrity of a liquefied hydrogen storage system.

The hydrogen storage system will be qualified to the performance test requirements specified in this Section. All liquefied hydrogen storage systems produced for on-road vehicle service must be capable of satisfying requirements of B.5.2.

The manufacturer has to provide the confirmation of hydrogen material compatibility for the inner tank and all components in contact with hydrogen. Furthermore, the manufacturer is obliged to specify a maximum allowable working pressure (MAWP) for the inner container. In order to prove proper design and expected on-road performance of the storage the following tests have to be accomplished:

- Proof pressure test
- Baseline Initial Burst Pressure (hydraulic)
- Boil-off test
- Leak test
- Vacuum loss test
- Bonfire test

The test elements within these performance requirements are summarized in Table B.5.2.

These criteria apply to qualification of storage systems for use in new vehicle production. It does not apply to re-qualification of any single produced system for use beyond its expected useful service or re-qualification after a potentially significant damaging event.

Table B.5.2
Overview of Performance Qualification Test Requirements

B.5.2.1 Verification Tests for Baseline Metrics B 5.2.1.1 Proof pressure test B 5.2.1.2 Baseline Initial Burst Pressure, performed on the inner tank
B.5.2.2 Verification of Material Compatibility Prove of hydrogen compatibility of the materials for the inner container and all components in contact with hydrogen.

B.5.2.3 Verification for Expected On-road Performance B.5.2.3.1 Boil-off test B.5.2.3.2 Leak test B.5.2.3.3 Vacuum loss test
B.5.2.4 Verification Test for Service Terminating Performance B.5.2.4.1 Bonfire Test

B.5.2.1 Verification for Baseline Metrics

B.5.2.1.1 Proof pressure test

The inner container and the pipe work situated between the inner tank and the outer jacket shall withstand an inner pressure test at room temperature any suitable media, according to the following requirements.

The test pressure p_{test} shall be defined by the manufacturer and fulfill the following requirements:

- $p_{test} \geq 1.3$ (MAWP + 0.1 MPa)

- In case of metallic containers p_{test} shall be either at least equal to the maximum pressure of the inner container during fault management (as determined in B.5.2.3.3 and B.5.2.3.4) or the manufacturer shall prove by calculation that at the maximum pressure of the inner container during fault management no yield occurs.

- For other materials than metallic p_{test} shall be at least equal to the maximum pressure of the inner container during fault management (as determined in B.5.2.3.3 and B.5.2.3.4).

The test is passed when during at least 10 minutes after applying the proof pressure no visible deformation, no visible degradation in the container pressure and no leakage are detectable.

B.5.2.1.2 Baseline Initial Burst Pressure.

The burst test shall be performed on one sample of the inner container (hydraulically pressurized), not integrated in its outer jacket and not insulated.

The burst pressure shall be at least equal to the burst pressure used for the mechanical calculations. For steel containers that is:

- either the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 3.25;

- or the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp, where Rm means minimum ultimate tensile strength and Rp means minimum yield strength of the container material.

B.5.2.2 Verification for Material Compatibility

Definition of test procedures in order to prove the hydrogen compatibility of materials in compliance to compressed hydrogen storage has to be defined.

B.5.2.3 Verification for Expected On-road Performance

B.5.2.3.1 Boil-off test

A container shall be fueled with liquid hydrogen to the specified maximum filling level. Subsequently hydrogen should be extracted until half filling level and the system should be allowed to completely cool down for at least 24 hours and maximum 48 hours. The container shall be filled to the specified maximum filling level. The container shall pressurize until boil-off pressure is reached. The test shall last for at least another 48 hours after boil-off started and not terminated before the pressure stabilizes.

During the test the inner container pressure shall be monitored. The test is passed when the pressure stabilizes below MAWP. In particular, the pressure relief devices are not allowed to open.

B.5.2.3.2 Leak test

After the boil-off test the system shall be kept at boil-off pressure and the total discharge rate due to leakage shall be measured. The maximum allowable discharge from the hydrogen storage system is 150 ml/min for standard passenger vehicles.
[The maximum allowable discharge for systems in larger vehicles is R*150 Ncc/min where R = $(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4$ and V_{width}, V_{height}, V_{length} are the vehicle width, height, length (m), respectively.]

B.5.2.3.3 Vacuum loss test

A vacuum loss test shall be conducted with a completely cooled-down container (according to the procedure in B.5.2.3.1). The container shall be filled to the specified maximum filling level and the vacuum enclosure shall be flooded with air to atmospheric pressure. The first part of the test shall be terminated when the first pressure relief device does not open any more.

The pressure of the inner container shall be monitored during the test. The first part of test is passed when the first pressure relief device opens below or at MAWP and limits the pressure to not more than 110 per cent of the MAWP. In particular, the secondary pressure relief device is not allowed to open.

After passing the first part the test has to be repeated subsequently to re-generation of the vacuum and cool-down of the container as described above. The container shall be filled to the specified maximum filling level, the line downstream the first safety relieve device shall be blocked and the vacuum enclosure shall be flooded with air to atmospheric pressure. For steel containers the second part of the test is passed when the second pressure relief relieve device does not open below 110 per cent of the set pressure of the first safety relief device and limits the pressure in the container to maximum 136 per cent of the MAWP in case a safety valve is used, or, respectively, 150 per cent of the MAWP in case a burst disk is used as second safety relief device. For other container materials, an equivalent level of safety shall be demonstrated.

B.5.2.4 Verification Test for Service Terminating Conditions

At least one system must demonstrate the working of the pressure relief devices and the absence of rupture under the following service-terminating conditions. Specifics of test procedures are provided in Section 6.

B.5.2.4.1 Bonfire Test.

A hydrogen storage system will be filled to half-full liquid level and exposed to fire in accordance with test procedure 6.4.2.12 TBD. The pressure relief device(s) will release the contained gas in a controlled manner without rupture.

For steel containers the test is passed when the requirements relating to the pressure limits for the pressure relief devices as described in B.5.2.3.3 are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.

B.5.3. Vehicle Fuel System

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B.7 ANNEXES

B.7.1 TYPE APPROVAL REQUIREMENTS FOR COMPRESSED HYDROGEN STORAGE

(…)

B.7.2 TYPE APPROVAL REQUIREMENTS FOR LIQUEFIED HYDROGEN STORAGE

7.2.1 When using metallic containers and/or metallic vacuum jackets the manufacturer must either provide a calculation in order to demonstrate that the tank is designed according to current regional legislation or accepted standards (e.g. in US the ASME Boiler and Pressure Vessel Code, in Europe EN 1251-2 and in all other countries an applicable regulation for the design of metallic pressure vessels) or define and perform suitable tests which prove the same level of safety compared to a design supported by calculation according to accepted standards. The test shall at least include:

- Pressure cycling with a number of cycles at least three times the number of possible full pressure cycles (from the lowest to highest operating pressure) for an expected on-road performance. Pressure cycling should be conducted between atmospheric pressure and MAWP at liquid nitrogen temperatures, e.g. by filling the container to with liquid nitrogen to certain level and alternately pressurizing and depressurizing it with (pre-cooled) gaseous nitrogen or helium.

7.2.2 In the case that non-metallic materials are used for the container(s) and/or vacuum jacket(s) in addition to the mandatory tests described in chapter B.5.2 suitable tests have to be accomplished, which prove the same level of safety compared to a metallic container design supported by calculation according to accepted standards as described in 7.2.1.

B.7.3 TYPE APPROVAL REQUIREMENTS FOR FUEL SYSTEM INTEGRITY

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