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January 7, 2010

GLOBAL REGISTRY

Created on 18 November 2004, pursuant to Article 6 of the
AGREEMENT CONCERNING THE ESTABLISHING OF GLOBAL TECHNICAL REGULATIONS FOR WHEELED VEHICLES, EQUIPMENT AND PARTS WHICH CAN BE FITTED AND/OR BE USED ON WHEELED VEHICLES

(ECE/TRANS/132 and Corr.1)

Done at Geneva on 25 June 1998

Addendum

Global technical regulation No. xx

HYDROGEN POWERED VEHICLE
Established in the Global Registry on [DATE]

Appendix

Proposal and report pursuant to Article 6, paragraph 6.3.7 of the Agreement

- Proposal to develop a global technical regulation concerning Hydrogen fuel cell vehicle (ECE/TRANS/WP.29/AC.3/17)
- Final progress report of the informal working group on Hydrogen fuel cell vehicle GTR .....

UNITED NATIONS

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⏩ SGS-8 Germany comment #1&#2: include 2nd and 3rd sub-clauses in page numberings

A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

1. INTRODUCTION

A 1.1 In the ongoing debates over the need to identify new sources of energy and to reduce the emissions of green house gases, countries around the world have explored the use of various alternative gases as fuels, including compressed natural gas, liquefied propane gas, and hydrogen. Hydrogen has emerged as one of the most promising alternatives due to its virtual zero emission. In the late 1990's, the European Community allocated resources to study the issue under its European Integrated Hydrogen Project and forwarded the results, two ECE-drafts for compressed gaseous and liquefied Hydrogen, to UN-ECE. A few years later, the United States outlined a vision for a global wide initiative, the International Partnership on the Hydrogen Economy, and invited Japan, European Union, China, Russia and many other countries to participate in this effort.

» SGS-8 Germany comment #3: text in yellow

A.1.2 For decades scientists, researchers and economists have pointed to hydrogen, in both compressed gaseous and liquid forms, as a possible candidate as an alternative to gasoline and diesel as vehicle fuel. Ensuring the safe use of hydrogen as fuel is a critical ingredient in the world economies successfully transitioning to a hydrogen economy. By their nature, all fuels present an inherent degree of danger due to their energy content. The safe use of hydrogen, particularly in the compress gaseous form, lies in preventing catastrophic failures due to volatile combination of fuel, ambient air and ignition sources but also due to pressure and electric hazards.

» SGS-8 Germany comment #4: text in yellow

A.1.3 The governments have identified development of regulations and standards as one of the key requirements for a long-term promotion in commercialization of hydrogen-powered vehicles. Regulations and standards will help overcome technological barriers to commercialization, facilitate manufacturers' investment in building hydrogen-powered vehicles and facilitate public acceptance by providing a systematic and accurate means of assessing and communicating risk associated with the use of hydrogen vehicles, be it to the general public, consumer, emergency response personnel and the insurance industry.

A.1.4 The goals of this global regulation (GTR) are to develop and establish a GTR for Hydrogen Fuel Cell Vehicles (HFCV) that: (1) Attains equivalent levels of safety as those for conventional gasoline powered vehicles and (2) Is performance-based and does not restrict future technologies.

2. GTR ACTION PLAN

A.2.1 Given that hydrogen-powered vehicle technology is still emerging, WP.29/AC.3 agreed that input from researchers is a vital component of this effort. Based on a comparison of existing regulations and standards of HFCV with conventional vehicles, it is important to investigate and consider: (1) The main differences in safety and environmental aspects and (2) What items need to be regulated based on justification.

A.2.2 In June 2005, WP.29/AC.3 agreed to a proposal from Germany, Japan and United States of America regarding how best to manage the development process for a GTR on hydrogen-powered vehicles (ECE/TRANS/WP.29/AC.3/17). Under the agreed process, once AC.3 develops and approves an action plan for the development of a GTR, two subgroups will be formed to address the safety and the environment aspects of the GTR. The subgroup safety (HFCV-SGS) will report to GRSP. The chair for the group will be discussed and designated by summer of 2007. The environmental subgroup (HFCV-SGE) is chaired by European Commission and reports to GRPE. In order to ensure communication between the subgroups and continuous engagement with WP.29 and AC.3, the project manager (Germany) will coordinate and manage the various aspects of the work ensuring that the agreed action plan is implemented properly and that milestones and timelines are set and met throughout the development of the GTR. The GTR will cover fuel cell (FC) and internal combustion engine (ICE), compressed gaseous hydrogen (CGH2) and liquid hydrogen (LH2) in the phase 1 GTR. At the (X) WP.29, the GTR action plan was submitted and approved by AC.3 (ECE/TRANS/WP.29/2007/41).

SGS – 8: add ELSA

A.2.3 In order to develop the GTR in the context of an evolving hydrogen technology, the trilateral group proposes to develop the GTR in two phases:

a. Phase 1 (GTR for hydrogen-powered vehicles):
   Establish a GTR by 2010 for hydrogen-powered vehicles based on a component level, subsystems, and whole vehicle crash test approach. For the crash testing, the GTR would specify that each contracting party will use its existing national crash tests but develop and agree on maximum allowable level of hydrogen leakage. The new Japanese regulation, and any available research and test data will be used as a basis for the development of this first phase of the GTR.

b. Phase 2 (Assess future technologies and harmonize crash tests):
   Amend the GTR to maintain its relevance with new findings based on new research and the state of the technology beyond phase 1. Discuss how to harmonize crash test requirements for HFCV regarding whole vehicle crash testing for fuel system integrity.

A.2.4 The GTR will consist of the following key areas:

a. Component and subsystem level requirements (non-crash test based):
   Evaluate the non-crash requirements by reviewing analyses and evaluations conducted to justify the requirements. Add and subtract requirements or amend test procedures as necessary based on existing evaluations or on quick evaluations that could be conducted by Contracting Parties and participants. Avoid design specific requirements to the extent

possible and do not include provisions that are not justified. The main areas of focus are as follows:

i. Performance requirements for fuel containers, pressure relieve devices, fuel cells, fuel lines, etc.
ii. Electrical isolation; safety and protection against electric shock (in-use).
iii. Performance and other requirements for sub-systems integration in the vehicle.

b. Whole vehicle requirements (crash test based):
Examine the risks posed by the different types of fuel systems in different crash modes, using as a starting point the attached tables. Review and evaluate analyses and crash tests conducted to examine the risks and identify countermeasures for hydrogen-powered vehicles. The main areas of focus are as follows:

i. Existing crash tests (front, side and rear) already applied in all jurisdictions.
ii. Electrical isolation; safety and protection against electric shock (post crash).
iii. Maximum allowable hydrogen leakage.

A.2.5 Application: the contracting parties decided at this to set requirements for passenger FC vehicles only with the understanding that in the coming years, it will appropriate to extend the application of the regulation and/or establish new requirements for additional classes of vehicles, specifically, motor coaches, trucks, and two-/three-wheel motorcycles.]

3. DESCRIPTION OF HYDROGEN FUEL CELL VEHICLES

3.1 Vehicle Description

A.3.1.1 Hydrogen fuel cell vehicles (FCVs) have an electric drive-train powered by a fuel cell that generates electric power electrochemically from hydrogen. In general, FCVs are equipped with other advanced technologies to increase efficiency, such as regenerative braking systems that capture the energy lost during braking and store it in a battery or ultra-capacitors. While the various FCVs are likely to differ with regard to details of the systems and hardware/software implementations, the following major systems are common to most FCVs:

- Hydrogen fueling system
- Hydrogen storage system
- Hydrogen fuel delivery system
- Fuel cell system
- Electric propulsion and power management system

A.3.1.2 A high-level schematic depicting the functional interactions of the major systems is shown in Figure 1. Hydrogen is supplied to the fill port on the vehicle and flows to the hydrogen storage container(s) within the Hydrogen Storage System. The hydrogen supplied to and stored within the hydrogen storage container can be either compressed gas or liquefied hydrogen. When the vehicle is started, the shut-off valve is opened and hydrogen gas is allowed to flow from the Hydrogen Storage System. Pressure regulators and other equipment with the Hydrogen Delivery System reduce the pressure for use by the fuel cell system The hydrogen is electro-chemically combined with oxygen (from air) in the Fuel Cell System, and high-voltage electric power is produced by the fuel cells. The power from the fuel cells flows to the Electric Propulsion and Power Management System where it is used to power drive motors and/or charge batteries and ultra-capacitors, depending on the driver “throttle“ and brake positions and the operating state of the vehicle.

⏩⏩ SGS-8 OICA comment #1: In case of LH2 extraction of liquid hydrogen should be also allowed. According to Figure 4 the coolant heat exchanger does not contain to the LH2 storage system.

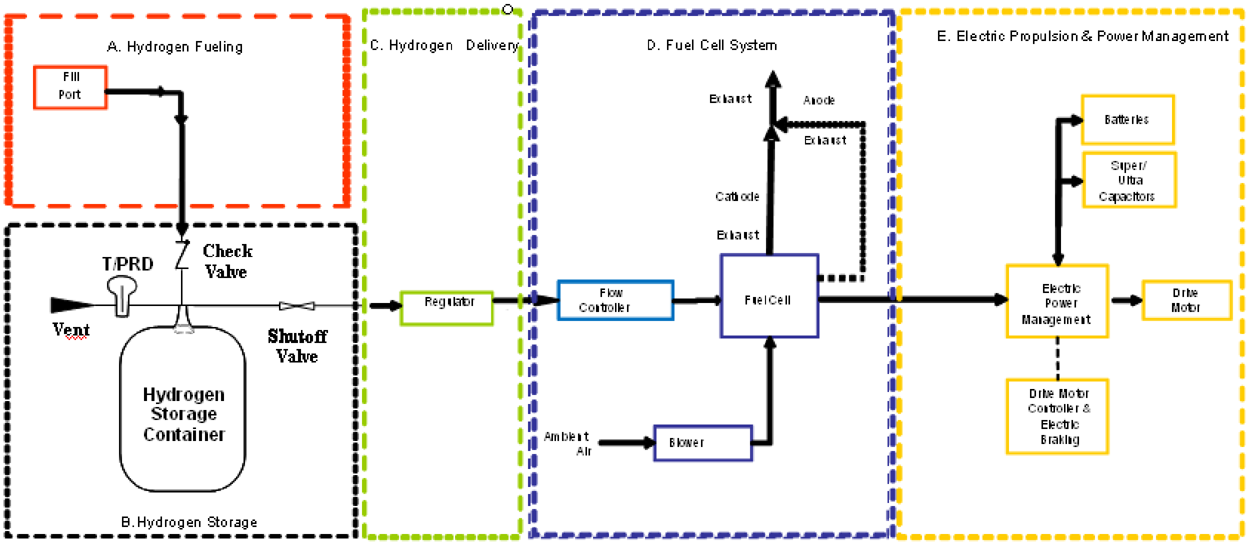


Figure 1. Example of High-level Schematic of Key Systems in FCVs

- SGS-8 increase text size

A.3.1.3 Figure 2 illustrates key components in the major systems of a typical fuel cell vehicle (FCV). The fill port is shown in a typical position on the rear quarter panel of the vehicle. As with gasoline tanks, hydrogen storage containers, whether compressed gas or liquefied hydrogen, are usually mounted transversely in the rear of the vehicle, but could also be mounted differently, such as lengthwise in the middle tunnel of the vehicle. Fuel cells and ancillaries are usually located (as shown) under the passenger compartment or in the traditional “engine compartment”, along with the power management, drive motor controller, and drive motors. Given the size and weight of traction batteries and ultra-capacitors, these components are usually located in available space in the vehicle in areas that retain proper desired weight balance for proper handling of the vehicle.

⏩⏩ SGS-8 OICA comment #2: captured in yellow text.

A.3.1.4 More detailed descriptions of the major systems are provided in the following sections.

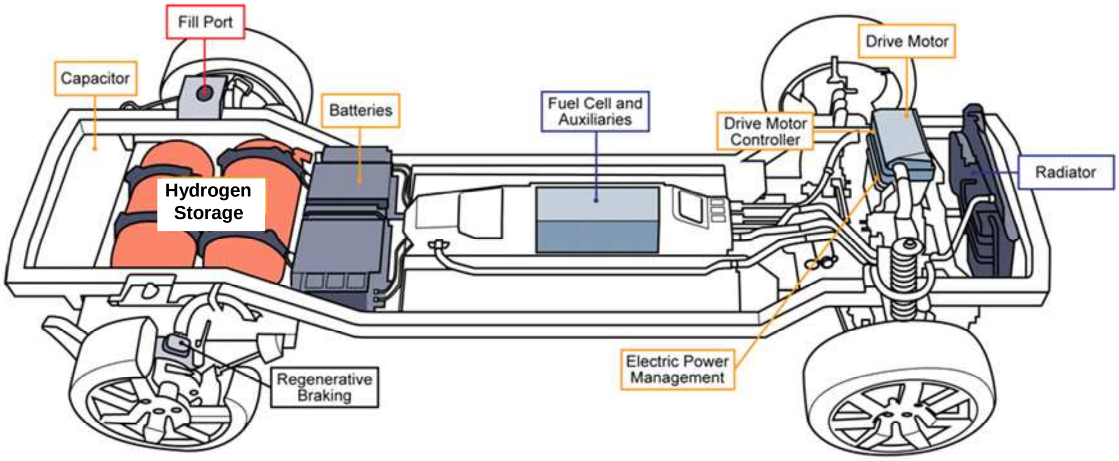


Figure 2. Example of a Fuel Cell Vehicle

3.2 HYDROGEN FUELING SYSTEM

A.3.2.1 Either liquefied or compressed gas may be supplied to the vehicle, depending on the type of hydrogen storage used by the vehicle. At present, the most common method of storing and delivering hydrogen fuel onboard is in compressed gas form where the hydrogen is dispensed at pressures up to 125% of nominal working pressure (NWP) to compensate for the effects of compression adiabatic heating during “fast fill”.

A.3.2.2 Regardless of state of the hydrogen, the vehicles are fuelled through a special nozzle on the filling stations to the fill port on the vehicle which allows a “closed system” transfer of hydrogen to the vehicle such that people in the dispensing area are not exposed to unacceptable hazards. The fill port on the vehicle also contains a check valve (or other device) that prevents leakage of hydrogen out of the fill port in the event of a fault of the back-flow prevention in the hydrogen storage system

A.3.2.3 In addition to the above features on the vehicle, the dispenser also contains safe-guards to monitor the fueling process and ensure that the temperature and pressure are consistent with the capability of the hydrogen storage system on the vehicle.

3.3 HYDROGEN STORAGE SYSTEM

A.3.3.1 The hydrogen storage system consists of all components that form the primary pressure boundary of the stored hydrogen in the system. The primary function of the hydrogen storage system is to contain the hydrogen within the storage system throughout the vehicle life.

⏩⏩ SGS-8 OICA comment #4: " …primary pressure boundary of the stored hydrogen gas (delete "gas") in the system…" – accommodated in text

A.3.3.2 At present, the most common method of storing and delivering hydrogen fuel on-board is in compressed gas form. Hydrogen can also be stored as liquid (at cryogenic conditions). Each of these types of hydrogen storage systems are described in the following sections.

3.3.1 COMPRESSED HYDROGEN STORAGE SYSTEM

A.3.3.1.1 Components of a typical compressed hydrogen storage system are shown in Figure 3. The system includes the container and all other components that form the "primary pressure boundary" that prevents hydrogen from escaping the system. In this case, the following components are part of the compressed hydrogen storage system:

- the container(s),
- the fill line check valve,
- the shut-off valve,
- the thermally-activated pressure relief device(s) (TPRD), and
- the interconnecting piping (if any) and fittings between the above components.

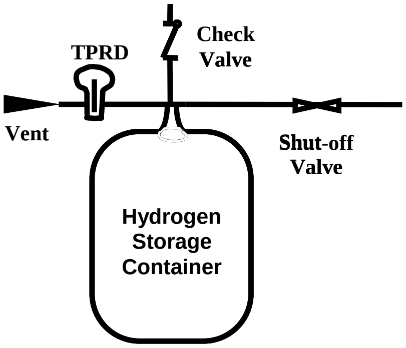


Figure 3. Typical Compressed Hydrogen Storage System

A.3.3.1.2 The hydrogen storage containers store the compressed hydrogen gas. A hydrogen storage system may contain more than one container based on the amount that needs to be stored and the physical constraints of the particular vehicle. Hydrogen fuel has a low energy density per unit volume. To overcome this limitation, compressed hydrogen storage containers store the hydrogen at very high pressures. On current development vehicles, hydrogen is typically stored at a nominal working pressure of 35 MPa or at 70 MPa , but different pressures (that are higher or lower or in between current selections) are possible in the future as commercialization proceeds. During the normal “fast fill” fueling process, the actual pressure inside the container(s) may rise to 25% above the nominal working pressure as adiabatic compression of the gas will cause a short-term pressure rise in the tanks. After approximately one (1) hour, the temperature in the container will cool to near ambient and the pressure will reduce. By definition, the settled pressure of the system will be equal to the nominal working pressure when the tank is at 15C.

⏩⏩ SGS-8 GWS comment #2: insert text marked yellow in A.3.3.1.2

⏩⏩ SGS-8 ***JASIC comment #4: The upper limit of NWP should be 70MPa.***
Rationale: The upper limit of NWP should be revised only after the hydrogen embrittlement safety is ensured. With the upper limit of NWP set at 70 Mpa, the highest pressure is 87.5 Mpa, which is 125% NWP. The facilities at hydrogen stations require the pressurization to higher than this 87.5 Mpa (100 MPa or more). The equipment capable of evaluating the hydrogen embrittlement under such high pressure is limited. If the upper limit of NWP is not provided, the result of hydrogen embrittlement evaluation may be insufficient.

SGS-8 decision on setting upper limit for storage system’s NWP: draft language for scope setting NWP and maximum pressure. Provide rationale in part A.

A.3.3.1.3 Containers are currently constructed with composite materials in order to meet the challenge of high pressure containment of hydrogen at a weight is that is acceptable for vehicular applications. Most high pressure hydrogen storage containers being evaluated in fuel cell development vehicles consist of multi-layers with an inner liner made of aluminum or thermoplastic polymer to prevent gas leakage/permeation and a resin-impregnated carbon fiber composite that is wrapped over a gas sealing inner for structural integrity.

A.3.3.1.4 During fueling, hydrogen enters the system from the hydrogen fueling system through a check valve (or shut-off valve). The check valve prevents back-flow (leakage) of hydrogen out through the hydrogen fueling line (after fueling is complete and the fueling nozzle has been disconnected).

A.3.3.1.5 The hydrogen shut-off valve prevents the out-flow of stored hydrogen when the vehicle is not operating or when a fault is detected that requires isolation of the hydrogen from down-stream systems or the environment.

A.3.3.1.6 In the event of a fire, thermally-activated pressure relief devices (TPRDs) vent (i.e., provide a controlled release of) the gas contained in compressed hydrogen storage containers before the high temperatures in a fire degrade composite and metal container materials and cause a hazardous rupture of the hydrogen storage containers. Storage containers and TPRDs that have been subjected to a fire should be removed from service and destroyed; hence, the TPRDs are designed to vent the entire contents of the container rapidly and do not reseat or allow re-pressurization of the container.

3.3.2 LIQUEFIED HYDROGEN STORAGE SYSTEM

⏩⏩⏩⏩ NOTE: highlighted text is merger of comments from Germany, OICA(BMW), and GWS that were conceptually in agreement except for OICA(BMW) check valve propoal

⏩⏩ SGS-8 OICA comment #7: put liquid hydrogen in separate section – accommodated in draft

⏩⏩ SGS-8 OICA(BMW) comment #7 – proposed text revisions highlighted in 3.3.2 text
-- except proposal for deletion of check valve *-- SGS discussion isrequired*
-- also ***except Fig 4*** *(but content of figure change is included in GWS comment #7 figure)*

⏩⏩ SGS-8 Germany comment #5: imprecise naming of pressure control devices needs correction –proposed correction accommodated in text

⏩⏩ SGS-8 GWS comment #7*: text proposal of similar content to OICA #7&8 and Germany #5 (except check valve); figure revision proposed*

A.3.3.2.1 As noted previously, 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 (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 liquefied LHSS shown in Figure 4 consists of the following regulatory elements:

- the fill line check valve,
- liquefied hydrogen storage container(s),
- shut off devices(s),
- boil-off pressure regulator(s),
- Pressure Relief Devices (PRDs),
- the interconnecting piping (if any) and fittings between the above components.

A.3.3.2.3 During fueling, liquefied hydrogen flows from the fuelling system to the storage container(s). A check valve (or shut-off valve) is located on the fill line to prevent back-flow when fuelling is complete.

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. A boil-off pressure regulator 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.3.3.2.5 In case malfunction of the boil-off pressure regulator, vacuum failure, or external fire, the hydrogen storage container(s) and the vacuum jacket(s) are protected against overpressure by Pressure Relief Devices (PRDs).Re-closing type relief valves are shown in Figure 4 as this specific type of PRD usually provides the primary function, but additional relief valves or burst disks may be used to provide redundancy or backup as PRDs (and PRD piping and connections) in liquefied hydrogen systems may be compromised by icing.

A.3.3.2.6 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, vehicle safety systems usually require the container shut-off valve to isolate the hydrogen from the down-stream systems and the environment.

⏩ SGS-8 Germany comment #6: move a PRV to downstream of shut-off valve in figure
-- text & figure accommodate Germany comments

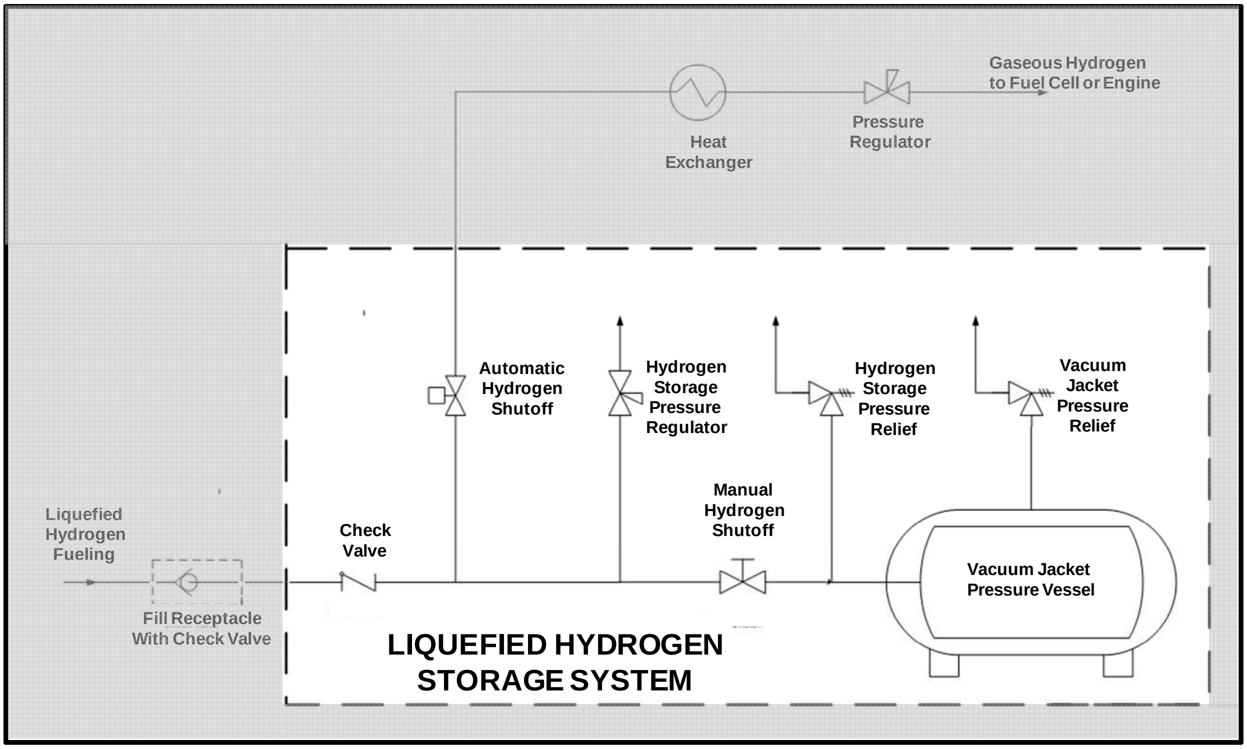


Figure 4. Typical Liquefied Hydrogen Storage System

⏩⏩ SGS-8 OICA comment #1: According to Figure 4 the coolant heat exchanger does not contain to the LH2 storage system.
-- The paragraph describing the heat exchanger is in the Delivery System in 3.4.1.

3.4 HYDROGEN FUEL DELIVERY SYSTEM

A.3.4.1 Hydrogen is delivered from the storage containers to the fuel cell stack via a series of pressure regulators, control valves, filters, piping, and possibly heat exchangers and heaters. In the case of liquefied hydroen storage, for example, the hydrogen flow that flows from LHSS may be single or two phase flow, depending on the state of the hydrogen within the storage container, and a heat exchanger is typically used to evaporate any liquefied hydrogen. The fundamental purpose of a hydrogen fuel delivery system is therefore to reliably deliver hydrogen fuel to either ICE or fuel cell stack at a specified pressure and temperature for proper fuel cell operation over the full range of vehicle operating conditions.

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 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. 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.

3.5 FUEL CELL SYSTEM

A.3.5.1 The fuel cell generates the electricity needed to operate the drive motors and charge vehicle batteries and/or capacitors. There are several kinds of fuel cells, but Proton Exchange Membrane (PEM) fuel cells are the common type used in automobiles at this time. The PEM fuel cells electro-chemically combine hydrogen and oxygen (in air) to generate electrical DC power. Fuel cells are capable of continuous electrical generation when supplied with hydrogen and oxygen (air), simultaneously generating electricity and water without producing carbon dioxide (CO_2) or other harmful emissions typical of gasoline-powered internal combustion engines (ICE).

A.3.5.2 As shown in Figure 1, typical fuel cell systems include a blower to feed air to the cathode-side of the fuel cells. Approximately 50 to 70% of the oxygen is consumed within the cells. The remainder is exhausted from the system. The fuel cell usually consumes most of the hydrogen that is supplied, but a small excess is required to ensure that the fuel cells will not be damaged. The excess hydrogen is either mixed with the cathode exhaust to produce a non-flammable exhaust from the vehicle or catalytically reacted.

A.3.5.3 The fuel cell system also includes auxiliary components and systems to remove the waste heat. Most fuel cell systems are cooled by a mixture of gylcol-water. Coolant pumps circulate the water through the fuel cells and then to radiator.

A.3.5.4 The individual fuel cells are usually “stacked” or electrically connected in series such that the power is between 300 and 600 Vdc. Since fuel cells operate a high voltage, all reactant and coolant connections (including the coolant itself) to the fuel cell need to be adequately isolated from the conductive chassis of the vehicle such that there are no shorts that could cause equipment damage or harm people when insulation is breeched.

3.6 ELECTRIC PROPULSION AND POWER MANAGEMENT SYSTEM

A.3.6.1 The electric power generated by the fuel cell is ultimately used to drive electric motors that ultimately propel the vehicle. As illustrated in Figure 2, many passenger fuel cell vehicles are front wheel drive with the electric drive motor and drive-train located in the “engine compartment” mounted transversely over the front axle; however, other configurations and rear-wheel drive are also viable options. Larger SUV-type fuel cell vehicles may be all wheel drive with electric motors on the front and rear axles or with compact motors at each wheel.

⏩⏩ SGS-8 OICA comment #12: Due to the small and compact size of electric engines electric drive trains should not be considered as front-wheel drive as standard concept – comment is accommodated in text in yellow.

A.3.6.2 The “throttle position” is used by the drive motor controller(s) to determine that the amount of power to be sent to the drive wheels. Many fuel cell vehicles use batteries or ultra-capacitors to supplement the output of the fuel cells. These fuel cell vehicles may also recapture energy during stopping through regenerative braking to re-charge the batteries or ultra-capacitors and thereby maximize efficiency.

A.3.6.3 The drive motors may be either DC or AC. If the drive motors are AC, the drive motor controller must convert the DC power from the fuel cells, batteries, and ultra-capacitors to AC. Conversely, if the vehicle has regenerative braking, the drive motor controller must convert the generated in the drive motor back to DC so that the energy can be stored in the batteries or ultra-capacitors.

4. EXISTING REGULATIONS, DIRECTIVES, AND INTERNATIONAL VOLUNTARY STANDARDS

4.1 VEHICLE FUEL SYSTEM INTEGRITY

A.4.1.1 National regulations:

- EC regulation 79-2009
- Japanese Safety Regulation article 17 and Attachment 17 – Technical Standard for Fuel Leakage in Collision, etc.
- Japanese Attachment 100 – Technical Standard For Fuel Systems Of Motor Vehicle Fuel By Compressed Hydrogen Gas
- ECE
- United States Federal Motor Vehicle Safety Standard (FMVSS) No. 301 - Fuel System Integrity.
- Canadian Motor Vehicle Safety Standards (CMVSS) 301.2 – Fuel System Integrity
- Korea Motor Vehicle Safety Standard, Article 91 – Fuel System Integrity

A.4.1.2 International Industry standards:

- ISO 17268 Compressed hydrogen surface vehicle refuelling connection devices
- ISO 23273-1 Fuel cell road vehicles — Safety specifications — Part 1: Vehicle functional safety
- ISO 23273-2 Fuel cell road vehicles — Safety specifications — Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogenSAE J2578 - Recommended Practice For General Fuel Cell Vehicle Safety
- SAE J2578 - Recommended Practice For General Fuel Cell Vehicle Safety
- SAE J2600 –
- SAE J2601 -

4.2 STORAGE-SYSTEM

A.4.2.1 National regulations:

- Japan -- JARI S001(2004) Technical Standard for Containers of Compressed Hydrogen Vehicle Fuel Devices
- Japan -- JARI S002(2004) Technical Standard for Components of Compressed Hydrogen Vehicle Fuel Devices
- EC
- FMVSS 304 - Compressed Natural Gas fuel Container Integrity.
- Korea High Pressure Gas Safety Control Law

A.4.2.2 International Industry standards:

- ISO 13985:2006 Liquid Hydrogen – Land Vehicle Fuel Tanks
- ISO 15869:2009 Gaseous Hydrogen and Hydrogen Blends – Land Vehicle Fuel Tanks (Technical Specification)
- SAE J2579 - Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles

4.3 ELECTRIC SAFETY

A.4.3.1 National regulations:

- Japanese Attachment 101 – Technical Standard for Protection of Occupants against High Voltage in Fuel Cell Vehicles
- Japanese Attachment 110 – Technical Standard for Protection of Occupants against High Voltage in Electric Vehicles and Hybrid Electric Vehicles
- Japanese Attachment 111 – Technical Standard for Protection of Occupants against High Voltage after Collision in Electric Vehicles and Hybrid Electric Vehicles
- ECE Regulation 100 - Uniform Provisions Concerning The Approval Of Battery Electric Vehicles With Regard To Specific Requirements for The Construction AND Functional Safety
- FMVSS 305 - Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection.
- CMVSS 305—Electric Powered Vehicles: Electrolyte Spillage And Electrical Shock Protection
- Korea Motor Vehicle Safety Standard, Article 18-2 – High Voltage System
- Korea Motor Vehicle Safety Standard, Article 91-4 – Electrolyte Spillage and Electric Shock Protection
- GB/T 24548-2009 Fuel cell electric vehicles - terminology
- GB/T 24549-2009 Fuel cell electric vehicles - safety requirements
- GB/T 24554-2009 Fuel cell engine - performance - test methods
- QC/T 816-2209 Hydrogen supplying and refueling vehicles -specifications

A.4.3.2 International Industry standards:

- ISO 23273-3 Fuel cell road vehicles — Safety specifications — Part 3: Protection of persons against electric shock SAE J1766—Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing

- SAE J2578 - Recommended Practice For General Fuel Cell Vehicle Safety

5. TECHNICAL RATIONALE

5.1 COMPRESSED HYDROGEN STORAGE SYSTEM TEST REQUIREMENTS & SAFETY CONCERNS

A.5.1 The containment of the hydrogen within the compressed hydrogen storage system is essential to successfully isolating the hydrogen from the surroundings and down-stream systems. The system-level performance tests in Part B were developed to demonstrate capability to perform critical functions throughout service including fueling/de-fueling and parking under extreme conditions, and performance in fires. Performance test requirements for all compressed hydrogen storage systems in on-road vehicle service are specified in PART B 5.1.

5.1.1 RATIONALE FOR PART B 5.1: HYDROGEN STORAGE TEST SYSTEM REQUIREMENTS

A.5.1.1.1 This section (A.5.1) specifies the rationale for the performance requirements established in part B for the integrity of the compressed hydrogen storage system. Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in Part B-5.1.2

A.5.1.1.2 Rationale for Part B 5.1. The storage system is defined to include all closure surfaces that provide primary containment of high pressure hydrogen storage. The definition provides for future advances in design, materials and constructions that are expected to provide improvements in weight, volume, conformability and other attributes. Performance-based requirements address known on-road stress factors and usages to assure robust qualification for suitability for vehicle service.

◆ SGS-7 Discussion: Difficulty understanding thinking behind requirements – topic remains under consideration at OICA and active discussion within SGS. SGS-7 requested drafting of rationale text to support future discussion with better clarity in understanding the proposal

⏩⏩ SGS-8 GWS comment #12: proposed rationale text follows:
A.5.1.1.3 Rationale for B.5.1.1. *The Verification Tests for Baseline Metrics support three functions: 1) Verification of consistency of the qualification batch of vessels (A.5.1.2.6), 2) Verification of Conformity of Production (A.5.1.2.7) to the qualification batch of vessels, and 3) establishing the baseline for performance qualification tests in B.5.1.2.8 and B.5.1.3.5.*

⏩⏩ SGS-8 GWS comment #13: proposed rationale text follows:
A.5.1.1.4 Rationale for B.5.1.2. The verification test for on-road performance durability ensures the system is fully capable of avoiding rupture under extreme conditions of usage that include extensive fueling frequency (perhaps associated with replacement of drivetrain components), physical assaults and harsh environmental conditions. These durability tests focus on structural resistance to rupture. The additional attention to rupture resistance under harsh

external conditions is provided because 1) the severity of consequences from rupture is high, 2) rupture is not mitigated by secondary factors (leak is mitigated by onboard leak detection linked to countermeasures). Since these extreme conditions are focused on structural stress and fatigue, they are conducted hydraulically – which allows more repetitions of stress exposure in a practical test time.

A.5.1.1.5 Rationale for B.5.1.2. Data used in developing the B.5.1.2 test protocol include:

a. Extended & Severe Service worst-case = lifetime of most stressful fuelings (empty-to-full fuelings) under extended & severe usage; 10 service-station over-pressurization events

b. Sequential performance of tests replaces on-road experience where a single vessel is subject to multiple exposures – not realistic to expect a vessel could only encounter one type of exposure through vehicle life.

c. Severe usage: Exposure to physical impacts
   i. Drop impact (B.5.1.2.2) – risk is primary aftermarket risk in vehicle repair where a new storage system, or an older system removed during vehicle service, is dropped from a fork lift during handling. The test procedure requires drops from several angles from a maximum utility forklift height. The test is designed to demonstrate that containment vessels have the capability to survive representative pre-installation drop impacts if the system does not have unalterable markers that record exposure to comparable impacts to designate that installation is not authorized.
   ii. Surface damage (B.5.1.2.3) – cuts characteristic of wear from mounting straps can wear through protective coatings – administered cuts representative of strap wear
   iii. Roadway impacts that degrade exterior structural strength and/or penetrate protective coatings (e.g., flying stone chips) (B.5.1.2.3) – administered by pendulum impact

d. Severe usage: Exposure to chemicals in the on-road environment (B.5.1.2.4)
   i. Fluids include fluids used on vehicles (battery acid & washer fluid), chemicals used on or near roadways (fertilizer nitrates & lye), and fluids used in fueling stations (methanol in gasoline).
   ii. The primary historical cause of rupture of high pressure vehicle vessels (CNG tanks), other than fire, has been stress corrosion rupture – rupture occurring after a combination of exposure to corrosive chemicals and pressurization.
   iii. Stress corrosion rupture of on-road glass-composite wrapped vessels exposed to battery acid was replicated by the proposed test protocol; other chemicals were added to the test protocol once the generic risk of chemical exposure was recognized.
   iv. Penetration of coatings from impacts and expected on-road wear can degrade function of protective coatings -- recognized as a contributing risk factor for stress corrosion cracking (rupture); capability to manage that risk is therefore required.

e. Extended & Severe Usage: Number of fueling/de-fueling cycles (B.5.1.2.4 and B.5.1.2.6)
   i. A higher than expected number of fuelings occurs if: 1) the vehicle lifetime distance traveled is higher than expected, 2) the vehicle range per full fill is lower than expected, or 3) the average vehicle fueling is less than a full fill.

ii. The high-frequency extreme number of partial fuelings is given by: (extreme-usage lifetime vehicle distance traveled) / (minimal vehicle range per full fill) / (minimal lifetime average fill volume fraction).

iii. The minimal lifetime average fill volume fraction is taken as 0.33. Reliable statistics on current fill volume fraction are not available; statistics for hydrogen-fueled vehicles will be influenced by the availability of hydrogen fueling stations. The qualification test specification is based on the assumption that a lifetime of fuelings needing <33% of fuel capacity provides a high-frequency extreme associated with a lifetime average of fuelings on intervals of 160 km (100 mi) traveled.

iv. Extreme-usage lifetime vehicle range is taken as 590000 km (366000 mi). Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) on vehicle lifetime distance traveled showed all scrapped vehicles had lifetime distance traveled below 560000 km (350000 mi) (the 3-sigma value, the 99.8th percentile, was 330000 km (260000 mi); the 6-sigma value was 590000 km (366000 mi). [Note: there is no record of vehicles reaching lifetime range as high as the 6-sigma value.]

v. Minimal vehicle range per full fill is taken as 320 km (200 mi). This is considered to be a highly conservative estimate since at present (2009) on-road hydrogen-fueled vehicles produced by high volume vehicle manufacturers have a vehicle range per full fill greater than 320 km (200 mi).

vi. Therefore, the extreme number of fuelings is taken as 5500 = 3 x 366000/200.

vii. Robustness (safety margin) of extended durability design-qualification requirement
    (a) A vehicle with a modest driving range of 320 km (200 mi) per full fueling would have to be driven over 1.5 million km (1 million mi) to require 5500 empty-to-full fuelings.
    (b) Low-volume partial fills cause markedly lower swings in temperature and pressure, and consequently markedly lower stresses than empty-to-full fill stresses. Comprehensive data is not available (stresses an order of magnitude lower than empty-to-full fuelings have been seen). Therefore, conducting the high-frequency fueling pressure cycle tests with empty-to-full fueling pressure swings provides a margin of robustness potentially on the order of x 10.

⏩⏩ SGS-8 Germany comment #21: "The basis for calculation of filling cycles should be the real driving range per refueling in combination with driver behavior. Filling cycles should be surveyed by the onboard computer."
⏩⏩ SGS-8 Germany comment #22: "Either additional gas cycling tests are required which have to be finished by hydraulic cycling to the leakage or better type III cylinders are treated in another manner."

SGS-8: maintain the current "performance based" requirement as currently in the draft GTR.

f. Extreme Pressure Conditions for fueling/de-fueling cycles (B.5.1.2.4)
    i. Fueling station over-pressurization constrained by fueling station requirements to ≤ 150% NWP

   ii. Field data on the frequency of failures of high pressure fueling stations involving activation of pressure relief controls is not available. The small number of 70MPa fueling stations currently available does not support robust statistics.
   iii. There, assurance to sustain multiple occurrences of over-pressurization due to fueling station failure is assured by requirement to demonstrate absence of leak in 10 exposures to fueling station failure followed by long-term leak-free parking and fueling/de-fueling capability.

g. Extreme environmental conditions for fueling/de-fueling cycles (B.5.1.2.6). Weather records show temperatures ≤ -40C occur in countries north of the 45-th parallel; temperatures ~50C occur in desert areas of lower latitude countries; each with frequency of sustained extreme temperature ~5% in areas with verifiable government records. [Actual data shows ~5% of days have a minimum temperature <-30C. Therefore sustained exposure to <-30C is < 5% of vehicle life since a daily minimum is not reached for a full 24 hr period] Data record examples (Environment Canada 1971-2000):
   i. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ONT%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=4157&
   ii. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=YT%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=1617&

h. Extended and Severe Usage: High Temperature Full-fill Parking up to 25 years (B.5.1.2.5)
   i. On-road experience with CNG tanks -- no stress rupture without exposure to corrosives (stress corrosion cracking) or design anomaly (hoop wrap tensioned for liner compression without autofrettage). B.5.1.2 testing that includes chemical exposure test and 1000 static full pressure exposure selects out these failures.
   ii. Laboratory experience with high pressure vessel composite strands – documentation of time-to-rupture as a function of static stress (Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein) without exposure to corrosives
   iii. Use of laboratory data to define equivalence of test failure probability for testing at 100% NWP for 25 years and testing at 125% NWP for 1000 hours is documented in SAE 2009-01-0012.
   iv. No formal data is available on parking duration per vehicle at different fill conditions. Examples of expected lengthy full fill occurrences include vehicles maintained at near full fill at all times, abandoned vehicles and collectors' vehicles.
   v. Some systems have been reported to exhibit Arrhenius fatigue rate dependence (potentially associated with resin oxidation); therefore, to accommodate possible extreme temperature acceleration of fatigue, the 1000 hr exposure is to be conducted at 85 C, the maximum potential exposure temperature. [Under-hood maximum temperatures of +82 °C have been measured within a dark-colored vehicle parked outside on asphalt in direct sunlight in 50C conditions. Also, a

compressed gas container, painted black, with no cover, in the box of a black pickup truck in direct sunlight in 49 °C conditions had maximum / average measured tank skin surface temperatures of 87 °C (189 °F) / 70 °C (159 °F)].

i. Residual Proof Pressure (B.5.1.2.7)
   i. Fueling station over-pressurization constrained by fueling station requirements to ≤ 150% NWP
   ii. Laboratory data on static stress rupture used to define equivalent probability of stress rupture of composite strands after 30 seconds at 180% NWP as after 2 hours at 150% NWP in the worst case (SAE 2009-01-0012). Fueling stations are expected to provide over-pressure protection ≤ 150% NWP.
   iii. Testing at “end-of-life” provides assurance to sustain fueling station failure throughout service.

j. Residual Strength Burst (B.5.1.2.8)
   Requirement for <20% decline in burst pressure after 1000-hr static pressure exposure is linked (in SAE 2009-01-0012) to assurance that requirement has allowance for 10% manufacturing variability in assurance of 25 years of rupture resistance at 100% NWP.

A.5.1.1.6 Rationale for B.5.1.3. The verification test for expected on-road performance requires the demonstration of capability to perform essential safety functions under worst-case conditions of expected exposures. “Expected” exposures (for a typical vehicle) include the fuel (hydrogen), environmental conditions (such as often encountered temperature extremes), and normal usage conditions (such as expected vehicle lifetime range, driving range per full fill, fueling conditions and frequency, and parking). Expected service requires sequential exposure to parking and fueling stresses since all vehicles encounter both uses and the capability to survive their cumulative impact is required for the safe performance of all vehicles in expected service.

◆ SGS-7 Discussion: Add information in SGS-7 discussion about leak focus of Expected Service in Part A background rationale information.

⏩⏩ SGS-8 GWS comment #14: following proposed test

A.5.1.1.7 Rationale for B.5.1.3. *Pneumatic testing provides stress factors associated with rapid and simultaneous interior pressure and temperature swings and infusion of hydrogen into materials; therefore, pneumatic testing is focused on the vessel interior and strongly linked to the initiation of leakage. Failure by leakage is marginally mitigated by secondary protection – monitoring and vehicle shut down when warranted (below conservative level garage flammability risk), which is expected to result in very timely repair before leakage can develop further since the vehicle will be out of service.*

A.5.1.1.8 Rationale for B.5.1.3. Data used in developing the B.5.1.3 test protocol include:

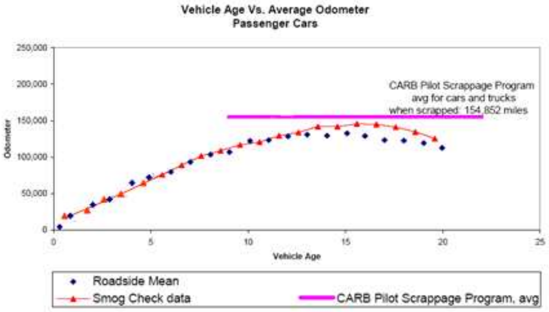
a. Proof Pressure Test (B.5.1.3.1) – routine production of pressure vessels includes a verifying, or proof, pressure test at the point of production, which is 150% NWP as industry practice.

b. Leak-Free Fueling Performance (B.5.1.3.2)
   i. Expected environmental conditions -- weather records show temperatures ≤ -40C occur in countries north of the 45-th parallel; temperatures ~50C occur in desert areas of lower latitude countries; each with frequency of sustained extreme

temperature ~5% in areas with verifiable government records. [Actual data shows ~5% of days have a minimum temperature <-30C. Therefore sustained exposure to <-30C is < 5% of vehicle life since a daily minimum is not reached for a full 24 hr period] Data record examples (Environment Canada 1971-2000):

- (a) http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ONT%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=4157&
- (b) http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=YT%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=1617&

ii. Number of fueling/de-fueling cycles
  - (a) The number of full fuelings required to demonstrate capability for leak-free performance in expected service is taken to be 500
    - (1) Expected vehicle lifetime range is taken to be 250000 km (155000 mi)



Source: Sierra Research Report No. SR2004-09-04, titled "Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator", and dated September 22, 2004.

    - (2) Expected vehicle range per full fueling is taken to be ≥ 500km (300 mi) based on 2006-2007 market survey of OICA member products.
    - (3) 500 cycles = 250000/500 ~ 155000/300
    - (4) Some vehicles may have shorter driving ranges per full fueling, and may achieve more than 500 full fuelings if no partial fuelings occur in the vehicle life. Demonstrated capability to perform without leak in 500 full fuelings is intended to establish fundamental suitability for on-road service -- leakage is subject to secondary mitigation by detection and vehicle shut-down before safety risk develops.
    - (5) Since the stress of full fuelings exceeds the stress of partial fuelings, the design verification test provides a significant margin of additional robustness for demonstration of leak-free fueling/de-fueling capability.

(b) Qualification requirement of 500 pneumatic pressure cycles is conservative when considering failure experience:

(1) On-road experience: 70MPa hydrogen storage systems have developed leaks in o-ring sealings during brief (<50 full fuelings) on-road service of demonstration prototype vehicles.

(2) On-road experience: 70 MPa hydrogen storage systems have developed temporary (subsequently resealing) leaks during brief (< 50 full fuelings) on-road service of demonstration prototype vehicles.

(3) On-road experience: mechanical failures of CNG vehicle storage associated with gas intrusion into wrap/liner and interlaminate interfaces have developed after brief on-road service (< 50 full fuelings).

(4) On-road experience: failure of CNG vehicle storage due to interior charge build-up and liner damage corona discharge is not a failure mode because static charge is carried into vessels on particulate fuel impurities and ISO 14687-2 (and SAE 2719) fuel requirements limit particulates in hydrogen fuel -- also, fuel cell power systems are not tolerant of particulate impurities and are expected to cause vehicles to be out of service if inappropriate fuel is dispensed.

(5) Test experience: mechanical failures of vehicle storage associated with gas intrusion into wrap/liner and interlaminate interfaces develop in ~ 50 full fuelings.

(6) Test experience: 70MPa hydrogen storage systems that passed NGV2 test requirements have failed during the B.5.1.3 test conditions in failure modes that would be expected to occur in on-road service (Powertech report to DOE/SAE).

⏩⏩ SGS-8 GWS comment #15: Proposed additional text to (6) above

Powertech report cites two failures of systems with tanks that have qualified for service: metal-lined composite tank valve leak and in-tank solenoid leak, polymer-lined composite tank leak due to liner failure. The polymer-lined composite tank failure by leakage was on a tank that was qualified to NGV2 modified for hydrogen. The metal-lined composite failure of the tank valve was on a valve qualified to EIHP r12b and TUV approved for use. Report conclusion: "The test sequences in SAE TIR J2579 have shown that tanks with no known failures in service either met the requirements of the tests, or fail for reasons that are understood and are representative of future service conditions"

⏩⏩ SGS-8 ISO member comment #2: delete A.5.1.1.8.b.ii(b)(6) reference to Powertech because report "does not provide any evidence in support of the statement."

SGS-8: Get verification in the PowerTech report or redraft the above language.

iii. Fueling conditions

        (a) SAE J2601 establishes fueling protocol -- 3 minutes is fastest empty-to-full fueling (compatible with typical gasoline fueling; existing in installed state-of-art hydrogen fueling stations); fuel temperature for fast fueling is ~ -40C.
        (b) Expected maximum thermal shock conditions are for a system equilibrated at an environmental temperature of ~50C subjected to -40C fuel, and for a system equilibrated at -40C subjected to indoor private fueling at ~+20C.
        (c) Fueling stresses are interspersed with parking stresses

c. Leak-free Parking at full fill (B.5.1.3.3)
    i. Leak and permeation are risk factors for fire hazards for parking in confined spaces such as garages.
    ii. The leak/permeation limit is defined to protect the worst-case condition of a tight ($30m^3$), very hot (55C) garage having low air exchange (0.03 volumetric air exchanges per hour) from reaching 25% LFL. The conservative 25% LFL limit is conventionally adopted to accommodate concentration inhomogeneities.
    iii. Data reference for garage sizes, air exchange rates, and garage temperatures are found in the EU HySafe report “Allowable Hydrogen Permeation Rate for Automotive Applications” VTEC Doc No. 06120-09-13603-1, 2009.
    iv. A localized leak test is to be conducted to ensure that external leakage cannot sustain a flame that could weaken materials and subsequently cause loss of containment. Per SAE 2008-01-0726 *Flame Quenching Limits of Hydrogen Leaks*, the lowest flow of H2 that can support a flame is 0.028 mg/sec per from a typical compression fitting and the lowest leak possible from a miniature burner configuration is 0.005 mg/sec. Since the miniature burner configuration is considered a conservative “worst case”, the maximum leakage criterion is selected as 0.005 mg/sec.
    v. Parking provides opportunity for hydrogen saturation of interlaminate layers, wrap/liner interface, liner materials, junctures, o-rings, and joinings – fueling stresses are applied with and without exposure to hydrogen saturation. Hydrogen saturation is marked by permeation reaching steady-state rate.
    vi. The maximum pressure of a fully filled vessel at 55C is 115% NWP (equivalent state of charge to 125% NWP at 85C and 100% NWP at 20C).

⏩⏩ SGS-8 OICA comment #12: Conditions for leakage should be specified (NWP?) – comment is accommodated in “vi” text above.

⏩⏩SGS-8 Germany comment #31: “The permeation rate must be limited to a value with limit per hour and per liter. The permeation rate is too high for avoiding explosion or fire hazards inside the vehicle.

⏩⏩SGS-8 ISO member comment # 16: discuss permeation rate

d. Residual Proof Pressure (B.5.1.3.4)
    i. Fueling station over-pressurization constrained by fueling station requirements to ≤ 150% NWP

ii. Laboratory data on static stress rupture used to define equivalent probability of stress rupture of composite strands after 30 seconds at 180% NWP as after 2 hours at 150% NWP in the worst case (SAE 2009-01-0012). Fueling stations are expected to provide over-pressure protection ≤ 150% NWP.

iii. Field data on the frequency of failures of high pressure fueling stations involving activation of pressure relief controls is not available. The small number of 70MPa fueling stations currently available does not support robust statistics.

e. Residual Strength Burst (B.5.1.3.5)

Requirement for <20% decline in burst pressure after lifetime service is designed to ensure stability of structural components responsible for rupture resistance; it e is linked (in SAE 2009-01-0012) to assurance that requirement has allowance for 10% manufacturing variability in assurance of > 25 years of rupture resistance at 100% NWP in B.5.1.2.5.

A.5.1.1.9 Rationale for B.5.1.4 Verification of performance under service terminating conditions is designed to prevent the severe impact of rupture under conditions so severe that hydrogen containment cannot be maintained. Fire is the service terminating condition accounted for in design qualification testing.

- ➢ SGS-7 Discussion: An engulfing bonfire test has been the traditional fire safety test – the primary objective has been to ensure the presence of a functioning TPRD.
- ➢ SGS-7 Discussion: Fire risk associated with localized fire exposure is a recognized additional risk. A fire test that accommodates localized fire exposure is TBD.

5.1.2 Supplemental Requirements for TYPE APPROVAL of Compressed Hydrogen Storage

◆ ***SGS-7 Discussion: Tentative agreement to position Section 5.1.2 in Part A with designation that these specifications could be made into mandatory requirements at the option of individual contracting parties.***

◆ ***SGS-7 EU comment: a listing of expected supplements in Part A would be helpful in providing clarity that specific supplements would be consistent with the UNGTR.***
⇒ accommodated in Part A

A.5.1.2.1 While the tests effectively address the general systems and tank issues, national or regional entities may elect to supplement Part B requirements for compressed hydrogen storage systems, which are depicted in Fig. A.3/B.5.1.1. The goal of harmonization of requirements as embodied in the United Nations Global Technical Regulations provides the opportunity to develop vehicles that can be deployed throughout Contracting Parties to achieve uniformity of compliance and resulting economies of scale; therefore, supplemental type approval requirements beyond those discussed in A.5.1.2.3 – A.5.1.2.7 are not expected.

⏩ ⏩SGS-8 Germany and ISO comments # 3: consider moving A.5.1.2 requirements to Part B

A.5.1.2.2 It is expected that type-approval certifications may elect to include the following items:

a. Material test requirements (A.5.1.2.3)
b. Qualification tests for hydrogen-flow closures (A.5.1.2.4)
c. Labeling requirements (A.5.1.2.5)
d. Verification tests for batch consistency in qualification testing (A.5.1.2.6)
e. Verification tests for conformity of production (A.5.1.2.7)

A.5.1.2.3 Material Test Requirements

Materials used in storage systems (as illustrated in Figure B.5.1.1) must comply with requirements of B.6.2.1. Manufacturers shall maintain relevant information demonstrating the suitability of materials used in the hydrogen storage system. (Rationale in A.5.1.3.3)

Material testing is intended to comprehend long-term material degradation including metallic hydrogen embrittlement. Manufacturers of storage systems must maintain information relevant to the system design that includes:

- tensile properties and softening temperature (>100C) of plastic liner material
- glass transition temperature
- resin shear strength
- coating adhesion and flexibility
- hydrogen embrittlement of metals

A.5.1.2.3.i Rationale for A.5.1.2.3: Material Test Requirements.

Compliance with Test Requirements of B.6.2.1 is required to ensure that manufacturers use materials appropriately qualified for hydrogen service and meet design specifications of the manufacturer.

⏩ ⏩SGS-8 Germany #13: “At least one “key test” (cycle test or creep rupture test) should be performed to fatigue failure and repeated during tests parallel to operation.”

⏩ ⏩SGS-8 Germany #14: Material requirements should include “Tests parallel to operation have to be introduced. This is the best way to ensure fatigue properties not weaker than assessed by design type tests.”

SGS-8: Germany recommends manufacturers monitor residual life of containers. Draft text for part A.

A.5.1.2.4 Qualification Tests for Hydrogen-Flow Closures

Closures that isolate high pressure hydrogen from the remainder of the fuel system and the environment include:

- temperature-activated pressure relief device(s) (TPRD, a TPRD opens and remains open when the system is exposed to fire.)
- check valve(s) (A check valve prevents reverse flow in the vehicle fill line.)
- shut-off valve(s) (A shut-off valve between the storage container and the vehicle fuel system defaults to the closed position when unpowered.)
- ~~components, fittings and fuel lines between the storage container(s) and the closure device(s).~~

TFG – due to Japan's proposal (B5.1), the fourth bullet is removed.

All closures shall be qualified to durable and reliable performance according to specified qualification tests. CSA North America is currently addressing component requirements for shut-offs, and check valves (CSA HGV 3.1) and PRDs (HPRD1-2009) for hydrogen service based on testing with hydrogen fuel and experience with CNG vehicles and previously existing standards. When completed, these documents will be advanced to ISO as NWIPs.

SGS-8: Note: these test procedure references must be identified before the completion of the GTR.

The entire storage system does not have to be re-qualified if the subsystem components (excluding the storage container) are exchanged for components having comparable function, fittings, and dimensions, and meeting the comparable component performance qualification specifications/testing. However, a change in the TPRD hardware, its position of installation and/or venting lines requires re-qualification with the fire test.

⏩ ⏩ SGS-8 ISO member comment # 9: require re-qualification if any subsystem components are exchanged.

⏩ ⏩SGS-8 Germany comment #15: "If subsystems or components are changed the function, strength and material compatibility must be proved in dependence of the type of change." „If the eutectic or the pressure bearing parts are changed also the durability tests must be performed."

A.5.1.2.4.i Rationale for A.5.1.3.4: Qualification Tests for Hydrogen-Flow Closures.

The containment of the hydrogen within the Compressed Hydrogen Storage System is essential to successfully isolating the hydrogen from the surroundings and down-stream systems. The system-level performance tests in Part B were developed to provide qualify the storage system for pressure cycling, fast fills, extreme temperatures, sustained pressure (parking), and engulfing/localized fire. The system-level testing also includes severe environmental factors, however, additional assurance of the durability and reliability of moving parts (the hydrogen flow closures) is provided by more strenuous qualification for these subsystem elements.

A.5.1.2.5 Markings. Tank label will contain the NWP, date of manufacture, manufacturer, unique identifying number and xx-year lifetime expiration data.

⏩ ⏩ SGS-8 GWS comment #16: proposed rationale text follows:
A.5.1.2.5.i Rationale for A.5.1.2.5: Markings.
Labeling containers with NWP provides information to protect against inadvertent installation of a container in a vehicle intended for higher pressure fueling. Labeling containers with lifetime in years is consistent with static hold testing (parking) required in design qualification testing. Containers in NGV service that have not sustained physical damage have historically been re-qualified for service beyond 15 years after visual inspection.
Labeling containers with the manufacturer and unique identifying number (manufacturer required to maintain production quality control records in A.5.1.2.7) provides traceability.

⏩ ⏩ SGS-8 JASIC comment #3: Need rationale for service limit of storage systems. Japan regulation is currently 15 years.
SGS-8: continue the discussion on end-of-life requirement and service/inspection requirement.

⏩ ⏩ SGS-8 Germany comment #34: ***Marking for container must show data for safety & traceability (e.g., manufacturer, date of manufacture, serial number, CGH or LH, NWP, capacity in liters, date of removal from service). Components must have 3 markings for safety and traceability (e.g., manufacturer, serial number, MAWP). (Not sufficient for manufacturer to be required to maintain records)***

⏩ ⏩ SGS-8 JASIC comment #7: Providing information on current Japanese requirement for marking as background information

Close to the receptacle:

1. *Number of containers installed*
2. *Limitation of fueling time*
3. *Duration of validity of the test result*
4. *Maximum fueling pressure (NWP)*
5. *Chassis No.*
6. *5,500 times or 11,250 times (under discussion)*

On the vehicle:

1. *Symbol and No. of the container*
2. *Symbols and Nos. of attachments*
3. *Limitation of fueling time*
4. *Chassis No.*

On the container:

1. *Code of the name of the Technical Service*
2. *Name or code of the container manufacturer*
3. *Type of high-pressure gas (CHG)*
4. *Classification of the container (VH3 or VH4)*
5. *Symbol of the container*

6. Inner volume
7. Date (day/month/year) at which the container passed the test
8. Limitation of fueling time
9. Pressure for pressure-resistance test
10. Maximum fueling pressure
11. Allowed scar depth of CFRP parts

⏩⏩ SGS-8 ISO member comment # 18: proposal:

a) "H_2 ONLY";
b) "DO NOT USE AFTER XXXX-XX", where XXXX-XX identifies the year and the month of expiry;
c) manufacturer's identification;
d) container identification (a serial number unique for every container);
e) water capacity (l);
f) "USE ONLY MANUFACTURER-APPROVED NON-RECLOSING THERMALLY ACTIVATED PRESSURE RELIEF DEVICE";
g) date of manufacture (year in four digits and month in two digits);
h) NWP (MPa) at temperature (°C);
i) if labels are used, there is an additional requirement for a unique identification number and the manufacturer's identification to be permanently marked on an exposed metal surface in order to permit tracing in the event that the label is destroyed;

A.5.1.2.6 Verification Tests for Consistency of Performance in Design Qualification

Design qualification testing is only meaningful if the tested unit(s) is representative of expected design performance. Vessels submitted for design qualification are expected to have representative initial burst pressure and pressure cycle life. The following tests are designed to verify consistency of performance within the batch of vessels used to qualify the design.

i. Burst Pressure. The manufacturer will supply documentation (measurements and statistical analyses) to establish that the burst pressure of every unit is controlled to > 180% of NWP. In addition, the manufacturer will supply documentation to establish the median burst pressure of new storage containers, BP_0, and to establish that the burst pressure of every unit is controlled to > 90% BPo. [To accommodate at least $\pm$10% manufacturing variability, BP_0 must be $\geq$ 200% NWP.]

Three (3) randomly selected new vessels from the design qualification batch of at least 10 vessels will be hydraulically pressurized until burst (6.4.2.1 test procedure). All vessels tested must have burst pressures $\geq$ 180% NWP and within 10% of BP_0; if not, BP_0 is reset to the highest burst pressure measured that is greater than the original BP_0 supplied by the manufacturer. The resultant BP_0 is used to satisfy requirements of B.5.1.2.8 and B.5.1.3.5 for design qualification (performance verification) and Conformity of Production (A.5.1.2.7).

⏩⏩ SGS-8 GWS comment #18: proposed text for rationale follows:

A.5.1.2.6.i(a). Rationale for A.5.1.3.6.i: Verification Tests for Consistence of Performance in Design Qualification -- Burst Pressure*. Design qualification provides assurance of on-road performance only if systems tested in design qualification are representative of all produced storage systems. Safety risk results if a* *system tested in design qualification is considerably stronger or more durable or more reliable than the typical system. Therefore, design qualification provides testing to verify that variability in burst pressure is within ranges accommodated by qualification testing. Vessels that are significantly stronger than the intended production mid-point cannot be presented for design qualification testing – if a significant difference in strength from the intended production median is discovered, the production median is adjusted to assure that production units have comparable strength to the units presented for design qualification. The manufacturer cannot present systems for testing that have superior properties to expected production units, and cannot give a low value for BPo to allow for production of weaker units.*

◆ ***Requirement for consistency of batch remains under consideration at OICA***
◆ **SGS-7 Discussion:** ***add rationale to capture discussion in SGS-7 – accommodated in A.5.1.2.6.i(a)***

ii. Pressure Cycle Life. The manufacturer will supply documentation (measurements and statistical analyses) to establish that the pressure cycle life (PCL) if every production unit is $\geq$ 5500. In addition, the manufacturer will supply documentation to establish the median pressure cycle life of new storage containers, PCL$_0$, or the manufacturer may simply document that PCL$_0$ is $\geq$ 11,000 cycles (2 times the minimum number of cycles required for all production units).

Three (3) randomly selected new vessels from the design qualification batch of at least 10 vessels will be hydraulically pressure cycled to 125% NWP for 11,000 cycles or until leak occurs (B.6.2.2.2 test procedure). All vessels tested must have a pressure cycle life $\geq$ 5500. If no leak occurs within 11,000 cycles, then the recorded pressure cycle life is equated to 11,000. If all 3 vessels do not have a pressure cycle life within 25% of PCL$_0$, PCL$_0$ is set to the highest cycle life measured that is greater than the original PCL$_0$ supplied by the manufacturer. PCL$_0$ will be used to satisfy requirements for Conformity of Production with Design Qualification (A.5.1.2.7).

⏩ ⏩ SGS-8 Germany comment #18: suggests following text as replacement of ¶ of A.5.1.2.6.ii

At least 3 new storage **systems** will undergo ambient hydraulic pressure cycling from <2MPa to 150%NWP without rupture **or leak** for 11,000 cycles (2 times the number of cycles required for 5.1.2.2.1.4) ~~or until leak occurs~~. The pressure cycle life, PCL, of a storage **system** is the number of cycles until leak. **Cycle tests should be continued to failure.** All 3 storage **systems** must have a pressure cycle life, PCL, within 25% of PCL0. PCL0, the average of the measured PCLs, is the baseline pressure cycle life for 5.1.3.2.

⏩ ⏩ SGS-8 GWS comment #19: proposed text for rationale follows:
A.5.1.2.6.ii(a) ***Rationale for A.5.1.3.6.ii: Verification Tests for Consistency of Performance in Design Qualification – Pressure Cycle Life.***

Design qualification provides assurance of on-road performance only if systems tested in design qualification are representative of all produced storage systems. Safety risk results if a system tested in design qualification is considerably stronger or more durable or more reliable than the typical system.
The, design qualification provides testing to verify that if the mid-point of pressure cycle life measurements is close to the minimum performance requirement, then the variability in pressure cycle life should not be so large as to leave doubt that a much superior system may be qualified but routine production systems with much lower fatigue resistance may not have reserves sufficient to satisfy the full series of testing even though they may satisfy the 5500 ambient-temperature pressure cycle life minimum. To prevent manufacturers from establishing production targets (such as PCLo) that are substantially less than the capability of vessels presented for design qualification, the production target is adjusted if vessels presented for testing differ significantly from the production target, PCLo, provided by the manufacturer. Note: that the requirement for production monitoring to maintain the mid-point pressure cycle life over multiple batches only applies to systems designed for pressure cycle life below 11,000; i.e., close to the minimum. If vessels are designed to have a pressure cycle life close to the minimum requirement, then either the variability should be tightly controlled or the targeted production pressure cycle life, PCLo, should be high enough to accommodate the wide variability.

⏩⏩ SGS-8 OICA comment #14: Not clear when in the case of high variability the value is set the highest one. To be clarified.
-- note: A.5.1.2.6.ii(a) suggests rationale text for added clarity.

SGS-8: revisit later

- ◆ ***[SGS-7 Discussion: This is to prevent manufacturers from establishing production targets less than the capability of vessels presented for design qualification. Also, vessels presented for design qualification should be representative of expected nominal performance of the qualification batch (and production batches). Also, if vessels are designed to have a pressure cycle life close to the minimum requirement, then either the variability should be tightly controlled or the nominal (median) pressure cycle life should be high enough to accommodate the wide variability.]***

◆ ***SGS-7 Discussion: Requirement for consistency of batch remains under active consideration at OICA***

A.5.1.2.7 Verification Tests for Conformity of Production with Design Qualification

Design qualification testing is only meaningful if the tested unit(s) is representative of expected performance of production units. Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in B.5.1.2. Establishing of key metrics of units tested for performance is required for documentation of correspondence of manufacturing units.

Manufacturers of storage systems must provide the following information to regulatory authorities upon request.

i Documentation of Routine Production (Each Produced Unit). Documentation should include results of routine leak tests, proof pressure tests, and dimension, and NDE examinations verifying that expansion and flaw sizes are within design specifications. Documentation should show that components providing closure functions, such as the shut-off valve, check valve and the TPRD meet industry standards.

◆ SGS-7 Discussion: observation that specific test procedures for dimensional and NDE examinations are not detailed – responsibility of manufacturer to select appropriate testing for system design and materials – not fully discussed at SGS-7.

ii. Documentation of Periodic Production Tests (Batch/Lot Tests). Documentation should include measurements and statistical analyses used to confirm:

(a) that the initial burst pressure of every produced unit is ≥ 180% NWP and ≥ 90% BP$_0$ (established in B.5.1.1.1 and discussed in A.5.1.2.6). [The requirement that the burst pressure of production units be controlled to > 90% BPo and ≥ 180% NWP provides assurance that the full range of production vessels are accommodated in performance requirements and effectively requires that BPo ≥ 200% NWP.]

⏩⏩ ***SGS-8 GWS comment #10: proposed revised text for clarification****: Appropriate multi-batch statistics shall be used to monitor trends in the overall production midpoint, and appropriate corrective action will be undertaken as needed to maintain the midpoint burst pressure of units at ≥ BPo.*

A.5.1.2.7.ii(a)(1) Rationale for A.5.1.2.7.ii(a) is contained within A.5.1.2.6.i(a)

◆ ***SGS-7 Discussion: Requirement for conformity of production remains under consideration at OICA***

◆ ***SGS-7 Discussion: Clarification ("appropriate statistics … " and rationale drafted based on SGS-7 discussion***

(b) that the average (hydraulic) pressure cycle life of new storage containers is ≥ PCL$_0$ (established in B.5.1.1.2 and discussed in A.5.1.2.6) and that the pressure cycle life of every produced unit is ≥ 5500.

⏩⏩ ***SGS-8 GWS comment #10: proposed revised text for clarification****:Appropriate statistics of batch pressure cycle life measurements shall be used to verify the multi-batch production midpoint is maintained at ≥ PCLo*

A.5.1.2.7.ii(b)(1) Rationale for A.5.1.2.7.ii(b) is contained within A.5.1.2.6.ii(a):

◆ ***SGS-7 Discussion: Requirement for consistency of batch mains under consideration at OICA***

5.2 LIQUEFIED HYDROGEN STORAGE

◆ ***SGS-6&7 Discussion: Add Part A section for liquefied hydrogen storage system to this section to specify the rationale for the requirements established in part B for the integrity of the liquefied hydrogen storage system. Germany will provide text.***

◆ ***SGS-6&7 Discussion: Germany to provide rationale & proposal for liquefied storage requirements***

5.3. VEHICLE FUEL SYSTEM REQUIREMENTS & SAFETY CONCERNS

5.3.1 IN-USE REQUIREMENTS

◆ ***SGS-7 Discussion:*** *Below are the items from the TUV proposal that were recommended for Part A. Draft an explanation why the SGS decided to move these proposed requirements to part A (e.g., no performance test procedure (only subjective visual inspection); expectation of need for qualitative judgements to adjust to future design innovations, regulatory goal to avoid prescriptive requirements that historically lead to limitation of technology/design advancements.)*

⏩⏩SGS-8 several parties' comments: discuss decision to move material to Part A

A.5.3.1.1 The following features of the fuel system are recommended practices for continued safe vehicle performance:

a. The hydrogen fuel system of a vehicle shall function in a safe and proper manner. It shall reliably withstand the chemical, electrical, mechanical and thermal service conditions.

b. The materials used in the hydrogen fuel system shall be compatible with gaseous or liquid hydrogen.

c. A hydrogen fuel system shall fulfil at least the following functions:
   i. refuelling
      (a) protection against overpressure
      (b) excess flow protection
      (c) automatic shut-off (automatic isolation of the fuel storage system)
      (d) safety management
   ii. boil-off management for LH2

d. No component of the hydrogen fuel system, including any protective materials that form part of such components, shall project beyond the outline of the vehicle or protective structure.

e. The hydrogen fuel system shall be installed such that it is protected against damage under normal operating conditions.

f. An excess flow system for the fuel line and the filling line shall be part of the hydrogen system

g. A pressure relief device shall be provided and installed into the opening of a container or at least one container in a container assembly, or into an opening in a valve assembled into the container.

◆ ***SGS-7 Discussion: This issue is being addressed by the storage system's fire test. Provide explanation in Part A.***

⏩⏩ ***SGS-8 JASIC comment #5: require TPRD, check valve & shut-off valve to be mounted directly on or within each container.***

⏩⏩ ***SGS-8 Japan comment (slides on Japan crash tests): Rationale for requiring PRD, shut-off valve and check-valve on each gas storage vessel is that vehicle crash testing can't cover all on-road events, so leak risks may be missed. Additional requirement may reduce risks not covered by crash tests.***

h. Rigid fuel lines shall be secured such that they shall not be subjected to critical vibration or other stresses, e.g. they shall be supported at an interval of 1 m or less.

> ◆ ***SGS-7 Discussion: Justification for not accepting the Japanese requirement shall be provided in part A. Also, recommended practices can be mentioned as part of the write-up***.

i. During the refilling process the hydrogen system shall have the means to provide electrical continuity with the refilling facilities before hydrogen transfer is permitted.

◆ ***SGS-7 Discussion: Japan will provide test data for justification.***

j. The fueling receptacle shall be secured against maladjustment and rotation. The receptacle shall also be protected from unauthorized interference, and the ingress of dirt and water as far as is reasonably practicable, e.g. a locked hatch. It shall be safe against reasonably foreseeable handling errors.

k. The gas fueling receptacle shall not be installed in the passenger compartment, luggage compartment and other places where ventilation is not sufficient.

A.5.3.1.2 Rationale for Hydrogen discharge system (B.5.3.1.2)

A.5.3.1.2.1 Pressure relief systems. The vent line of storage system discharge systems (TPRDs and PRDs) should be protected by a cap to prevent blockage by intrusion of objects such as dirt, stones, and freezing water. Hydrogen exhaust should not be directed to cause damage within the vehicle – hence, not at exposed electrical terminals, exposed electrical switches or other ignition sources. It should not be directed to cause accumulation within the vehicle – hence, not at passenger or luggage compartments. High pressure discharge should not release directly toward potential approaching emergency responders – hence, not forward or horizontally (parallel to the ground).

A.5.3.1.2.2 Fuel cell / engine exhaust systems.

⏩⏩ SGS-8 GWS comment #8: propose the following rationale:
In order to ensure that the exhaust discharge from the vehicle is non-hazardous a performance-based tests is defined to demonstrate that the region is non-ignitable.
The 3 second rolling-average accommodates extremely short, non-hazardous transients up to 8% without allowing ignition. Tests of flowing discharges have shown that propagation from the ignition source readily occurs above 10% hydrogen, but does not propagate below 8% hydrogen. (SAE Technical Paper 2007-01-437 „Development of Safety Criteria for Potentially Flammable Discharges from Hydrogen Fuel Cell Vehicles" (2007 SAE World Congress)). By limiting the hydrogen content of any instantaneous peak to 8%, the hazard to people near the point of discharge is controlled even if an ignition source is present. The time period of the rolling-average is determined to ensure that the space around the vehicle remains non-hazardous as the hydrogen from exhaust diffuses into the surroundings; this is the case of a idling vehicle in a closed garage. In order to readily gain acceptance for this situation by building officials and safety experts, US building codes and internationally-recognized standards such as IEC 60079 require that the space be less than 25% LFL (or 1% hydrogen) by volume. The time limit for the rolling-average was determined by assuming an extremely high hydrogen discharge rate that is equivalent to the input to a 100 kW fuel cell engine. The time was then calculated for this hydrogen discharge to fill the nominal space occupied by a passenger vehicle (4.6m x 2.6m x 2.6m) to 25% LFL. The resultant time limit was conservatively estimated to be 8 seconds for a "rolling average", demonstrating that the 3-second used in this document is appropriate and accommodates variations in garage and engine size.

A.5.3.1.3 Rationale for Protection against flammable conditions: Single Failure Conditions (B.5.3.1.3). Dangerous situations can occur if unintended leakage of hydrogen reaches flammable concentrations.

◆ ***SGS-7 Discussion: several issues remain under consideration with regard to telltale; continue discussion in SGS-8.***

a. The on-board hydrogen container should be equipped with a shut off valve that can be automatically activated.

b. Protection against the occurrence of 4% by volume hydrogen in air (or greater) in the passenger compartment, luggage compartment, and spaces within the vehicle that contain unprotected ignition sources is important.

i. Vehicles may achieve this objective by design (for example, where spaces are vented to prevent increasing hydrogen concentrations).

ii. If the vehicle achieves this objective by detection of hydrogen concentrations in air of 4% or greater, then the main hydrogen shutoff valve(s) shall immediately close to prevent further increases and provide for dissipation of the hydrogen, and the driver shall be provided with a warning through a visual telltale.

(a) The SGS agreed that the GTR should include a provision requiring a telltale/warning system that would alert the driver when hydrogen leakage results in concentration levels at or above 4% by volume within the passenger compartment, luggage compartment, and spaces with unprotected ignition sources within the vehicle. The SGS also agreed that the telltale should alert the driver in case of a malfunction of the hydrogen detection system.

⏩⏩ SGS-8 OICA comment #16: "… shut off valve …" rather than "pressure relief valve"
–comment is accommodated in text above.

~~***⏩⏩ SGS-8 OICA comment #16: consider providing a warning triggered by concentration (lower than 4% perhaps) before warning when shut-off valve closes.***~~

(b) The GTR requires that the system shall be able to respond to either scenario and instantly warn the driver. The shut-off telltale shall be inside the occupant compartment in front of and in clear view of the driver. The group discussed also whether it is necessary to make the telltale warning visual only or in case of the shut-off, add an audible warning. There is no data to suggest that the warning function of the telltale would be diminished if it is only visual so for the time being the group did not add the requirement that the warning should be audible as well. It is up the manufacturer to decide whether they would like to add this feature.

(c) Telltale Color Requirement: The SGS agreed that the two scenarios for the warning to go off should be differentiated so that the driver and occupants can make appropriate decisions. It was agreed that the color of the light for the system working correctly ("On/Run") should be green. Manufacturers are permitted to use the telltale in a steady or flashing mode to indicate normal operation of the system.

(d) Malfunction of the detection system warning: The group believed that differentiating between the two scenarios will clearly communicate to the driver exactly which condition is occurring and facilitate better decisions by the driver. In case of the detection system failure, the telltale warning light should be amber/orange. In case of the emergency shut-off of the valve, the telltale light should be red. In the context of the hydrogen system telltale, the amber/yellow warning would be "cautionary", communicating properly to the driver the level of urgency with which the driver shall seek to remedy the malfunction of this important safety feature. Specifically, in case of the detection system malfunction it shall not be necessary to stop and abandon the vehicle. It was discussed in the group that in such case, the driver would continue driving to the destination or place, where it would be reasonable to expect that somebody would be able to inspected and service the vehicle.

(e) Telltale labeling: While the group agreed on the need for the hydrogen detection system malfunction and the hydrogen container shut-off telltale, there was no consensus among the participants as to what symbol should be used for the telltale; how it should be identified. In terms of labeling the hydrogen system malfunction telltale, it was discussed to label the telltale with a letter "H", the international symbol for hydrogen from the Periodic Table of Elements. It is also the letter "H" that that the Japanese manufacturers chose as symbol for the hydrogen system telltales in their vehicles. SGS, however, after considering comments from all stakeholders, including the industry, did not stipulate what symbol to use at this point.

(f) Telltale location: The SGS is leaving the location of the telltale up to the manufacturers in recognizing that stipulating a specific location would not increase or decrease safety of the hydrogen vehicle. It is also anticipated that manufacturers would like to have the discretion whether to place such warning on the panel or heads up display. Instead, SGS members believe it is sufficient to stipulate that the telltale shall be in the direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened ensuring that manufacturers will choose a reasonable location for the telltale. The group, therefore, does not anticipate that the manufacturer would place the telltale in a less prominent location such as the vehicle's central console, for example.

⏩⏩ SGS-8 ISO member comment: "The tell-tale should be prescribed. Same warning when conditions of 5.2.1.2.3 are met." (4% and system malfunction)

◆ SGS-6 Discussion: Insert rationale for TPRD discharge directions

◆ SGS-6 Discussion: Insert rationale for exhaust H2 discharge limit
Description of the fuel cell's operation and its discharge of diluted fuel; and exhaust system's operation including figures…
Explain the 3-second moving interval

A.5.3.1.4 Lower Flammability Limit (LFL) *(Background for B.3.9):* Lowest concentration of fuel in which a gas mixture is flammable. National and international standard bodies (such as NFPA and IEC) recognize 4% hydrogen in air as the LFL. See the US Department of Interior, Bureau of Mines Report 503 for further information. Flammability limits (LFL, UFL) depend on mixture temperature, pressure and the presence of dilution gases, and are assessed using specific test methods (e.g., ASTM E681-04). While the LFL value of 4% is appropriate for evaluating flammability in general surroundings of vehicles or inside passenger compartments, this criterion may be overly restrictive for flowing gas situations where ignition requires more than 4% hydrogen in many cases. Whether an ignition source at a given location can ignite the leaking gas plume depends on the flow conditions and the type of ignition. At 4% hydrogen in a stagnant room-temperature mixture, combustion can only propagate in the upward direction. At approximately 8 to 10% hydrogen in the mixture, combustion can also be propagated in the downward and horizontal directions and the mixture is readily combustible regardless of location of ignition source.

◆ ***SGS-6 Discussion: Insert NHTSA test report on fire hazard study.***

5.3.2 POST CRASH REQUIREMENTS

◆ **SGS-7 Discussion:** ***Insert explanation for contracting parties maintaining their existing crash tests in phase 1.***

◆ **SGS-7 Discussion:** ***Explain the heat calculation from gasoline to hydrogen. Explain the different between the Japanese limit and OICA limit. (check Japan's presentation submitted in SGS-5)***

◆ **SGS-7 Discussion:** ***Insert explanation for crash test leakage limit and monitoring time.***

◆ **SGS-7 Discussion:** ***Insert explanation for alternative fuel for crash test***

⏩⏩ SS-8 GWS comment #9: proposed text follows:

A.5.3.2.1 Rationale for crash test leakage limit and correspondence to requirements for gasoline vehicles.

The criterion for post-crash hydrogen leakage is based on allowing an equivalent release of combustion energy as permitted by FMVSS 301 for gasoline vehicles. Using 42.7 MJ/kg as the lower heating value for gasoline, an allowable energy loss of 72 590 kJ is permitted over the 60 minute interval after motion has ceased. (US DOT Transportation Energy Data Book: Liquid Fuel/LHV (MK/kg): conventional gasoline/43.438, reformulated or low-sulfur gasoline/42.348, CA reformulated gasoline/42.490, US conventional diesel/42.781, Low-sulfur diesel/42.602)

The allowable loss of hydrogen (on a mass basis) can be calculated using the lower heating value of hydrogen (119 863 kJ/kg) as follows:

$$m_H = \frac{72590\ \text{kJ}}{119863\ \text{kJ/kg}} = 0.606\text{kg}$$

Converting this mass of hydrogen to an expanded volume at standard temperature (15C) and pressure yields:

$$\frac{606\ \text{g}}{2\,(1.00794)\ \text{g/mol}}\ \text{x}\ 22.41\ \text{L/mol} \times \frac{288}{273} = 7107\ \text{L}$$

As confirmation of the hydrogen leak rate, JARI conducted ignition tests of hydrogen leaks ranging from 131 NL/min up to 1000 NL/min under a vehicle and inside the engine compartment. Results showed that, while a loud noise can be expected from ignition of the hydrogen, the sound pressure level and heat flux were not enough (even at a 1000 NL/min leak rate) to damage the under floor area of the vehicle, release the vehicle hood, or injure a person standing 1 m from the vehicle (SAE Technical Paper 2007-01-0428 "Diffusion and Ignition Behavior on the Assumption of Hydrogen Leakage from a Hydrogen-Fueled Vehicle").

The loss of fuel represents the allowable release for the entire compressed hydrogen storage system on the vehicle. In the case of multiple hydrogen storage tanks that are isolated from each other after crash, it may be necessary to measure hydrogen loss individually (using the approach in this appendix) and then sum this to determine the total loss of compressed hydrogen from the vehicle.

5.3.3 SUPPLEMENTAL REQUIREMENTS FOR TYPE APPROVAL OF FUEL SYSTEMS

⏩ ⏩ SGS-8 several parties' comment: consider moving material in A.5.3.3 to Part B

A.5.3.3.1   Overpressure protection for the low pressure system.

⏩ ⏩ SGS-8 Germany comment #38: proposed test

The hydrogen system downstream of a pressure reducer shall be protected against overpressure due to the possible failure of the pressure regulator. The set pressure of the overpressure protection device shall be lower than or equal to the maximum allowable working pressure for the appropriate section of the hydrogen system.

⏩ ⏩ SGS-8 ISO member: "Overpressure protection for the low pressure system should be covered." – accommodated by Germany proposed text

⏩ ⏩ SGS-8 USA comment: put overprotection provisions in Part A for Type Approval – accommodated by proposed text above (Germany comment #38)

◆ SGS-7 Discussion: Insert rationale for [not] regulating the secondary pressure system (downstream of the pressure regulator)
-- See A.5.3.3.1.a for this rationale.

A.5.3.3.1.a Rationale for Overpressure Protection in Part A rather than Part B

⏩ ⏩ SGS-8 USA comment: following text provided for rationale

i. An overall policy and specific provisions for detection of leakage of hydrogen fuel in the enclosed and semi-enclosed areas have already been established. These provisions require shutoff of the fuel system and a warning to the driver in the event that hydrogen gas reaches 4% concentration levels in those areas. The concern with downstream pressure limits is to prevent leaks and possible bursts. The provisions mentioned in this paragraph (i.e., shutoff at 4%) already address the leakage scenario. The following rationales will explain that it's not necessary to regulate low pressure system for burst.

ii. It is not necessary to regulate hydrogen systems down-stream of the compressed hydrogen storage system based on the fact that the systems are less than 25 bar-liters as used in the European Pressure Equipment Directive (PED).   While the survey of all manufacturers is incomplete, it seems highly probably that all current and foreseeable hydrogen systems (even for buses) are well less than 25 bar-liter trigger-point of the PED.   These systems, therefore, do not contain adequate "energy" to pose a significant hazard. Even with an ultra-conservative burst calculation, the real risk is within a couple feet of the burst.

iii. While injuries are possible if people are within close proximity and underneath of the vehicle floor of the low pressure hydrogen systems, the likelihood and severity of such events can be effectively managed through the use of “standard engineering practice” (SEP) as defined in many existing standards such as SAE J2579. In the USA, the occupation safety and health agency (OSHA) work rules would require lock-out; tag-out (LOTO) before any repairs on the low pressure system itself. We expect that other countries would have similar safety procedures when servicing pressure systems.

iv. Currently, there are other critical components of the fuel system that would result in worse consequences in the event of malfunction such as fuel shut-off valve or thermal PRD – and we do not have any provisions for those.

v. The vehicle’s safety is being addressed at the system level and that subjective "design guidance" requirements, component-level requirements, and in some cases design-specific requirements are appropriate for industry codes and standards, which provide a valuable resource to help manufacturers design their products in accordance with best industry practices. Thus, industry codes and standards are ideally suited for this type of requirements. It is not necessary for government regulations and this GTR to micro-manage specific component designs by including such detailed provisions.

vi. This requirement is provided in Part A of the GTR as a recommended advisory – not as specific regulatory requirement in Part B of the GTR.

A.5.3.3.2 Air Tightness of Piping.

The fuel system shall be tested for hydrogen leakage according to test procedure B.6.1.4.

⏩⏩ SGS-8 USA comment: move provisions for Air Tightness to Part A section for supplemental requirements for Type Approval.

⏩⏩ SGS-8 ISO member comment: “Airtightness test and shut-off valves: There is a need for further discussion on these matters.“

⏩⏩ SGS-8 JASIC comment #6: following text provided as draft Rationale for Air Tightness Testing

A.5.3.3.2.1 Basic Concept. Due to its low molecular weight, hydrogen leaks more easily than other gases. Also, because it diffuses extensively, there is a risk of explosion when hydrogen-air mixtures that are within the flammable range accumulate in an enclosed space. For these reasons, the Japanese standards are designed based on the following three principles:

- *a. No hydrogen leaks shall occur.*
- *b. If any hydrogen should leak, it shall be detected and shut off.*
- *c. If any hydrogen should leak, it shall not accumulate and/or enter closed or semi-closed spaces.*

A.5.3.3.2.2 Hydrogen Leak Test for the Piping System

Since it is essential that no hydrogen leaks occur in the hydrogen system, including the fuel piping system, the standards state that no gas leaks shall occur in the hydrogen system.

Although the permissible hydrogen leak amount at the time of crashes is specified as a performance requirement, the crash test conditions (speed, crash point, crash direction) merely represent the most statistically-probable conditions observed in data on many traffic accidents in various regions and do not cover all the possible conditions.

The purpose of this crash test requirement is to prevent dangerous leaks even in the unusual situations under the normal use and thus does not ensure that no hydrogen leaks will occur under any condition. Likewise, the requirement to install hydrogen sensors in the vehicles is designed to ensure safety in the event of any hydrogen leak based on Principles b and c.

For these reasons, some kind of provision will be necessary to confirm that no hydrogen leaks occur (Principle a). As regards the piping system, the performance requirement to test new vehicles for leaks at the specified locations on the hydrogen system with valve checker or gas detector will be necessary.

** Additional Explanation*

This standardization is necessary because, under the Japanese Safety Regulations, the same tests as those performed on in-use vehicles at the time of periodic inspection must be performed on new vehicles at the time of type approval testing as well.

A.5.3.3.3 Markings

◆ [SGS-6 Discussion: should a label shall be provided close to the receptacle, for example, inside a refilling hatch, showing the following information: gas type (GH2 or LH2) "xx" MPa for GH2-storage systems where "xx" = nominal working pressure of the container(s).]

⏩⏩ SGS-8 Germany comment #41: proposed text:

A label shall be provided close to the receptacle, for example, inside a refilling hatch, showing the following information:
- **gas type** (GH2 or LH2)
- **NWP = "xx" MPa @ 15°C** for GH2-storage systems where "xx" = nominal working pressure of the container(s).at 15°C which describes the permitted filling mass
- **MAWP = "yy" MPa** for GH2 and LH2 storage systems to show the maximum allowable working pressure for the tank and the high pressure components
- **Removal of containers from service latest: mm.yy**, date of date of removal from service of containers

Comments: Canada - service/inspection date and end of life based on miles driven.
OICA – need to identify where to place the information for (1)fueling (2) container.

SGS-8: members provide a recommended list of information for label and marking.

5.4. ELECTRIC SAFETY REQUIREMENTS & SAFETY CONCERNS

Purpose: This section specifies the requirements for vehicle's high voltage system.

A.5.4.1 In-Use Requirements

A.5.4.2 Post-Crash Requirements

◆ ***SGS-7 Discussion: Describe the Japanese regulation; Other government regulations and Industry standards***

6. DISCUSSION OF KEY ISSUES

◆ ***SGS-7 Discussion: Define topics***

7. BENEFITS AND COSTS

SGS-8: provide a statement to clarify the recommended requirements for type approval.

B. TEXT OF REGULATION

1. PURPOSE

B.1 This regulation specifies safety-related performance requirements for hydrogen-powered vehicles. The purpose of this regulation is to minimize human harms that may occur as a result of fire, burst or explosion related to the vehicle fuel system and/or from electric shock caused by the vehicle's high voltage system.

⏩ SGS-8 Germany comment #10: text marked in yellow in B.1

2. APPLICATION / SCOPE

B.2 This regulation applies to all hydrogen-powered vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.

3. DEFINITIONS

B.3 For the purpose of this regulation, the following definitions shall apply:

Hydrogen-powered vehicle: any motor vehicle that uses compressed gas or liquefied hydrogen as fuel to propel the vehicle including fuel cell and internal combustion engine vehicle.

B.3.1 Vehicle fuel system: all components used to store or supply hydrogen fuel to the storage system or to the fuel cell module or internal combustion engine (ICE).

B.3.2 Storage system: The Hydrogen Storage System consists of the pressurized container(s), Pressure Relief Devices (PRDs), shut off device(s), and all components, fittings and fuel lines between the container(s) and these shut off device(s) that isolate the stored hydrogen from the remainder of the fuel system and the environment.

⏩ ⏩ SGS-8 JASIC comment #5: delete text marked yellow in B.3.2

B.3.3 Pressure relief device (PRD): A device that, when activated under specified performance conditions, is used to release fluid from a pressurized system and thereby prevent failure of the system. Thermally activated PRDs remain open once activated and are designated TPRDs.

B.3.4 Pressure relief valve: A pressure relief device that opens at a preset pressure level and can re-close.

B.3.5 Check valve: A valve that prevents reverse flow in the vehicle fuel line.

B.3.6 Shut-off valve: A valve between the storage container and the vehicle fuel system that can be automatically activated and defaults to the closed position when unpowered.

B.3.7 Single failure: a failure caused by a single event, including any consequential failures resulting from this failure.

B.3.8 Fuel cell module: Fuel cell modules are comprised of one or more fuel cell stacks; connections for conducting fuels, oxidants, and exhausts; electrical connections for the power delivered by the stacks; and means for monitoring and/or control. Additionally, fuel cell modules may incorporate means for conducting additional fluids (e.g., cooling media, inert gas), means for detecting normal and/or abnormal operating conditions, enclosures or pressure vessels, and ventilation systems.

B.3.9 Lower Flammability limit (LFL): Lowest concentration of fuel at which a gaseous fuel mixture is flammable at normal temperature and pressure. The lower flammability limit for hydrogen gas in air is 4% by volume (A.5.3.1.4).

⏩⏩ SGS-8 OICA Comment #17: provide value for LFL -- provided in text above and A.5.3.1.4

B.3.10 UFL: Highest concentration of fuel at which there is sufficient oxidant in the gas mixture for the mixture to be flammable. The UFL of hydrogen is 74% in air.
Remove if not used in section 5.

B.3.11 The exhaust's point of discharge: geometric center of the area where fuel cell purged gas is discharged from the vehicle.

B.3.12 High voltage: Classification of an electric component or circuit, if its maximum working voltage is > 60 V and ≤ [1500] V of direct current (DC) or > 30 V and ≤ [1000] V of alternate current AC.

B.3.13 High voltage: High voltage is defined as greater than or equal to 60 VDC and 30 VAC. Refer to ELSA document

B.3.14 Enclosed or semi-enclosed spaces: Volumes within the vehicle (or the vehicle outline across openings) that are external to the hydrogen system and its housings (if any) where hydrogen may accumulate (and thereby pose a hazard) such as the passenger compartment, luggage compartment, cargo compartment, or space under the hood.

⏩⏩ SGS-8 OICA comment #17: text above
⏩⏩ SGS-8 Germany comment: similar text -- except for inclusion of space under vehicle, which requires SGS discussion
SGS-8: Text accepted

4. GENERAL REQUIREMENTS

B.4.1 Each hydrogen-powered vehicle shall meet the requirements of section 5.1 and 5.2. In addition, vehicles using high voltage shall meet the requirement of section 5.3.

B.4.2 Each contracting party under the UNECE 1998 Agreement will maintain its existing national crash tests and use the limit values of section 5.1.3.1 for compliance.

5. PERFORMANCE REQUIREMENTS

5.1 COMPRESSED HYDROGEN STORAGE SYSTEM

◆ Chair Comment: As a result of consensus at the Budapest and Mainz meetings, the OICA proposal is accepted as the working draft for the storage requirements for this GTR.

⏩⏩ SGS-8: Section 5.1, contains OICA's recommendation for the storage system -- corresponding relevant recommendations received from SGS participants are marked by the symbol ⏩⏩

B.5.1 This section specifies the requirements for the integrity of the compressed hydrogen storage system. As illustrated in Figure B.5.1.1, the hydrogen storage system consists of the high pressure storage container(s) and closures of openings into the high pressure storage container(s). Closures include the temperature-activated pressure relief device(s) (TPRD), check valve(s), shut-off valve(s) and all components, fittings and fuel lines that isolate the high pressure storage system from the remainder of the fuel system and environment. The **check valve, shut-off valve and TPRD(s) shall be mounted directly on or within each container.**

TFG – agreement with Japan's proposal.

SGS-8: OICA raised reservation. The rationale will be provided in part A.

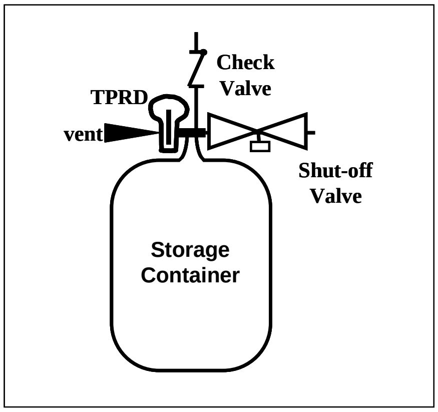


Figure B.5.1.1 Generic Hydrogen Storage System

⏩⏩ SGS-8-05 ISO comment #4 ISO recommends specifying 4 types of tanks. A new technology may have failure mode that are linked to service conditions that have not been planned in the testing. A re-evaluation of the test program should be done before allowing new types of tanks. Also, by keeping the types of tanks, the testing program can be adjusted based on the known failure mode. For example, only Type IV tanks have to be subjected to the permeation test.

TFG – keep item open for SGS meeting

SGS-8: decision to not specify tank type; Germany states study reservation; and everyone is requested to submit text for rationale in part A.

The hydrogen storage system will be qualified to the performance test requirements specified in this Section B.5.1. All new hydrogen storage systems produced for on-road vehicle service must be capable of satisfying requirements of B.5.1. Qualification requirements for on-road service include:

B.5.1.1 Verification Tests for Baseline Metrics
B.5.1.2 Verification Test for Performance Durability
B.5.1.3 Verification Test for Expected On-Road Performance
B.5.1.4 Verification Test for Service Terminating Performance

The test elements within these performance requirements are summarized in Table B.5.1. Test procedures are specified in Section B.6.

⏩⏩ SGS-8 ISO comment # 8: The proposed tests are still under discussion in the SGS.

~~The storage system does not have to be re-qualified if the subsystem components are exchanged for components with comparable function, fittings, and dimensions, and meet comparable component performance qualification specifications. A change in the TPRD hardware, its position of installation and/or venting lines requires re-qualification with a bonfire test.~~

TFG – remove; already part A, section A.5.1.2.4

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.

◆ SGS-7 Discussion: move previous paragraph to Part A?

Table B.5.1
Overview of Performance Qualification Test Requirements

B.5.1.1 Verification Tests for Baseline Metrics 5.1.1.1 Baseline Initial Burst Pressure 5.1.1.2 Baseline Initial Pressure Cycle Life	
Note: SGS-7 DRAFT listed an alternative hydraulic test for systems meeting material requirements (B.6.4.1.6). SGS-7 discussion accepted the alternative test as the baseline hydraulic test – consistent with OICA recommendation to SGS-8.	**B.5.1.2 Verification Test for Performance Durability (sequential hydraulic tests)** B.5.1.2.1 Proof Pressure Test B.5.1.2.2 Drop (Impact) Test B.5.1.2.3 Surface damage B.5.1.2.4 Chemical Exposure and Ambient Temperature Pressure Cycling Tests B.5.1.2.5 High Temperature Static Pressure Test B.5.1.2.6 Extreme Temperature Pressure Cycling B.5.1.2.7 Residual Proof Pressure Test B.5.1.2.8 Residual Strength Burst Test
B.5.1.3 Verification Test for Expected On-road Performance	**Note:** SGS-7 DRAFT listed an alternative to the pneumatic series testing. OICA/Japan response to

(sequential pneumatic tests) B.5.1.3.1 Proof Pressure Test B.5.1.3.2 Ambient and Extreme Temperature Gas Pressure Cycling Test (pneumatic) B. 5.1.3.3 Extreme Temperature Static Gas Pressure Leak/Permeation Test (pneumatic) B.5.1.3.4 Residual Proof Pressure Test B.5.1.3.5 Residual Strength Burst Test (Hydraulic)	SGS-7 request for resolution of pneumatic testing alternatives is listed here (left column) – requirement of pneumatic test series for all compressed storage systems. Requirement to satisfy material requirements (B.6. 2.1) is retained in material test requirements listed in A.5.1.2.3 for Contracting Parties having Type Approval certification regulations.
B.5.1.4 Verification Test for Service Terminating Performance B.5.1.4.1 Fire Test (pneumatic)	

Pneumatic tests

B.5.1.1 Verification Tests for Baseline Metrics

B.5.1.1.1 Baseline Initial Burst Pressure.

The manufacturer shall supply documentation (measurements and statistical analyses) that establishes the median burst pressure of new storage containers, BP$_0$. The BP$_0$ is used to satisfy requirements of B.5.1.2.8 and B.5.1.3.5 for design qualification (performance verification).

Three (3) new containers selected from the ~~design qualification~~ batch of at least 10 containers will be hydraulically pressurized until burst (B.6.2.2.1 test procedure). All vessels tested must have a burst pressure within 10% of BP$_0$.

TFG – Text changed for clarification
SGS-8: Provide a rationale and example in part A.

> ⏩ ⏩ ***SGS-8 Germany comment #17: suggests following text as replacement of A.5.1.2.6.i***
> *Baseline Initial Burst Pressure Test: At least 3 new storage **systems** will undergo a hydraulic burst test. The following requirements shall be demonstrated:*
> *1. The initial burst pressure of each container is ≥ 180% NWP,*
> *2. BPo, the average value, shall be ≥ 200% NWP and*
> *3. The manufacturing variability of the 3 burst results shall be ≤ 20% NWP*
>
> ⏩ ⏩ ***SGS-8 GWS comment #17: replace "median" with "mid-point"***

TFG - Comment on whether the 5.1.1.1 and 5,1,2 tests should be done at system level or container? Can the hydraulic tests be done with all attachments? Get information from Germany/technical service center.

SGS-8: Tests can be done at the container level except for the bonfire.

~~***⏩⏩ SGS-8 ISO comment #10: The initial burst pressure test should retain the commonly used burst ratio that are based on the type of fiber as follows. Also stress ratio should be considered (see SGS-6-11 Revised, clause 5.1.5). The Powertech validation testing program does not provide the confidence that the new testing approach will detect all tanks that would fail in service. The number of samples that were tested to prove this concept was limited to one tank.***~~

- ~~***Metal: 2,25 X working pressure (WP)***~~
- ~~***Glass: 2,4 WP for type 2, 3,4 WP for type 3 and 3,5 WP for type 4***~~
- ~~***Aramid: 2,25 WP for type 2, 3,0 WP for type 3 and 3,0 WP for type 4***~~
- ~~***Carbon: 2,25 WP for WP greater than 35 MPa***~~
- ~~***Carbon: 2,0 x WP for WP of 35 MPa and higher***~~

TFG - recommends removing the above ISO's requirement

B.5.1.1.2 Baseline Initial Pressure Cycle Life.

Three (3) new vessels selected from the design qualification batch of at least 10 vessels will be hydraulically pressure cycled to 125% NWP without rupture for 11,000 cycles (2 times the number of cycles required for 5.1.2.) or until leak occurs (B.6.2.2.2 test procedure). The pressure cycle life, PCL, is the number of cycles until leak. All vessels tested must have PCL ≥ 5500. If no leak occurs within 11,000 cycles, then PCL is equated to 11,000. If all 3 vessels do not have a PCL within 25% of PCL_0, the nominal (average) PCL supplied by the manufacturer, then PCL_0 is set to the highest cycle life measured that is greater than the original PCL_0 supplied by the manufacturer.

⏩⏩ SGS-8 ISO comment #11: This LBB test should be retained in the GTR

> ***⏩⏩ SGS-8 Germany comment #18: suggests following text as replacement of ¶ of A.5.1.2.6.ii***

At least 3 new storage **systems** will undergo ambient hydraulic pressure cycling from <2MPa to 150%NWP without rupture **or leak** for 11,000 cycles (2 times the number of cycles required for 5.1.2.2.1.4) ~~or until leak occurs~~. The pressure cycle life, PCL, of a storage **system** is the number of cycles until leak. **Cycle tests should be continued to failure**. All 3 storage **systems** must have a pressure cycle life, PCL, within 25% of PCL0. PCL0, the average of the measured PCLs, is the baseline pressure cycle life for 5.1.3.2.

TFG – The previous hydraulic pressure was at 150%. This is a tentative proposal. OICA is expected to submit a new proposal at the next meeting.

SGS-8: LBB is incorporated in the tests and OICA is expected to submit a new proposal by the next meeting with rationale (as well as the change to 125%).

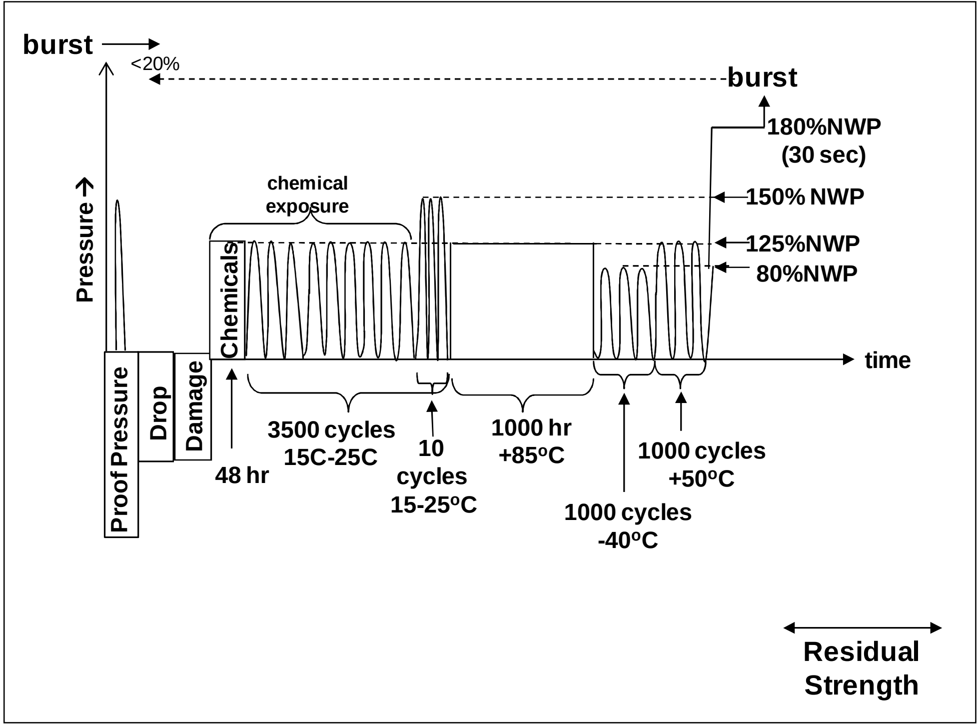
B.5.1.2 Verification Test for Performance Durability (Hydraulic sequential tests)

A hydrogen storage system must not leak during the following sequence of tests, which are applied in series to a single system and which are illustrated in Figure B.5.1.2. At least one system must be tested to demonstrate the performance capability. Specifics of applicable test procedures for the hydrogen storage system are provided in Section B.6.2.2.

⏩ ⏩ SGS-8 ISO comment #12: A boss torque test should be included for composite tanks with non load sharing liners.

TFG – OICA will provide a rationale in part A for not including the boss torque requirement. Need to address the leakage up stream of the shut-off valve.

SGS-8: Not include boss torque test in part B. OICA will provide rationale in part A. Japan raises a study reservation.



TFC – change the last 1000 cycles to 85C.

Figure B. 5.1.2 Verification Test for Performance Durability (hydraulic)

⏩ ⏩ SGS-8 ISO comment #13: The SGS still need to determine if taxis should be considered as commercial applications. If this is the case, commercial applications should be subjected to 11500 cycles as opposed to the 5500 cycles.
TFG – The rationale for 5500 cycles is in part A. Draft rationale to include taxi issue.

SGS-8: OICA provided rationale and data in part A. However, members are requested to submit data on taxis.

⏩ ⏩ SGS-8 ISO comment #14: We propose to change the proposed series of pneumatic tests to the combination of hydraulic and pneumatic tests that ISO provided in the SGS-6-11 Revised.

ISO requests for additional time to study the proposal.

B.5.1.2.1 Proof Pressure Test. A system will be pressurized to 150%NWP in accordance with test procedure B.6.2.2.3.

B.5.1.2.2 Drop (Impact) Test. The storage container will be dropped at several impact angles in accordance with test procedure B.6.2.2.4.

⏩⏩ SGS-8 Germany comment #24: drop system, not container, including valves & TPRD.
TFG – Germany will verify whether the hydraulic sequential test can be conducted with single container – with or without the attachments (in place of a system). Same for Germany comments #26, 27 and 28.

SGS-8: Tests are accepted as proposed. Bonfire test is recommended at system level by Germany.

B.5.1.2.3 Surface Damage Test: The storage container will be subjected to surface damage in accordance with test procedure B.6.2.2.5.

B.5.1.2.4 Chemical Exposure and Ambient-Temperature Pressure Cycling Test. The storage container will be exposed to chemicals found in the on-road environment and pressure cycled to 125% NWP at 15C-25C for 3500 pressure cycles in accordance with test procedure B.6.2.2.6. Chemical exposure will be discontinued before the last 10 cycles, which are conducted to 150% NWP.

◆ SGS-7 Discussion: EC representative is considering; awaits OICA refinement.

⏩⏩ SGS-8 Germany comment #26: hydraulically cycle system, not container, including valves & TPRD

B.5.1.2.5 High Temperature Static Pressure Test. The storage container will be pressurized to 125%NWP at 85C for 1000 hr in accordance with test procedure B.6.2.2.7).

B.5.1.2.6 Extreme Temperature Pressure Cycling. The storage system will be pressure cycled at -40C to 80%NWP for 1000 cycles and at +50C to 125%NWP for 1000 cycles in accordance with test procedure B.6.2.2.2).

B.5.1.2.7 Hydraulic Residual Pressure Test. The storage container will be pressurized to 180%NWP and held 30 seconds without burst in accordance with test procedure B.6.2.2.3.

⏩⏩ SGS-8 Germany comment #27: hydraulically burst system, not container, including valves & TPRD

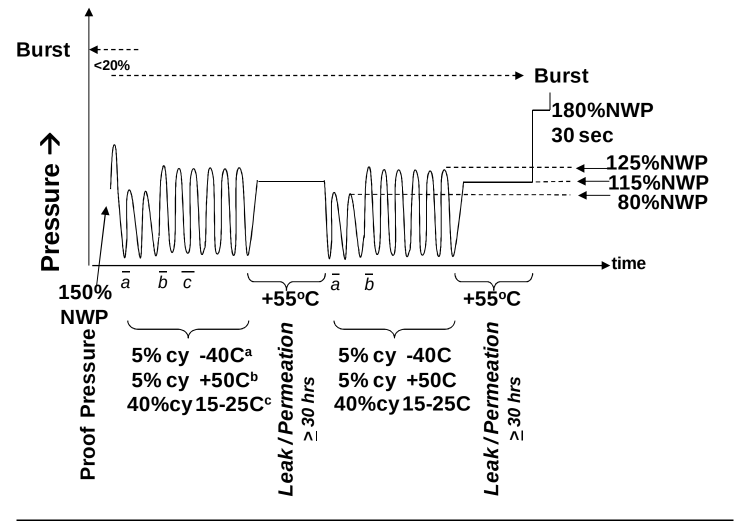
B.5.1.2.8 Residual Burst Strength Test. The storage container will undergo a hydraulic burst test to verify that the burst pressure is within 20% of the baseline initial burst pressure determined in B.5.1.1.1 in accordance with test procedure B.6.2.2.1.

⏩⏩ SGS-8 Germany comment #28: hydraulically burst system, not container, including valves & TPRD

SGS-8: Germany comments #26, 27 and 28 are addressed except for the bonfire test which is recommended at system level

B.5.1.3 Verification Test for Expected On-road Performance (Pneumatic sequential tests)

A hydrogen storage system must not leak during the following sequence of tests, which are illustrated in Figure 5.1.3. Specifics of applicable test procedures for the hydrogen storage system are provided in Section 6.



a Fuel/defuel cycles @-40°C with initial system equilibration @ -40°C, 5 cycles with +20°C fuel; 5 cycles with <-35°C fuel
b Fuel/defuel cycles @+50°C with initial system equilibration @+50°C, 5 cycles with <-35°C fuel
c Fuel/defuel cycles @15-25°C with service (maintenance) defuel rate, 50 cycles

Figure B.5.1.3 Verification Test for Expected On-Road Performance (pneumatic/hydraulic)

B.5.1.3.1 Proof Pressure Test: A system will be pressurized to 150%NWP in accordance with test procedure 6.4.2.3).

B.5.1.3.2 Ambient and Extreme Temperature Gas Pressure Cycling Test. The system will be pressure cycled using hydrogen gas for 500 cycles in accordance with B.6.2.2.8 test procedure. Half of the cycles will be performed before exposure to static pressure (B.5.1.3.3) and half of the cycles will be conducted after the initial exposure to static pressure (B.5.1.3.3). In each case, 10% of cycles (5% of the total number of cycles) will be to 125% NWP at +50C and 95% relative humidity, 10% to 80% NWP at -40C, and the remainder to 125% NWP at ambient temperature (15C-25C). The hydrogen gas fuel temperature will be between -35C and -40C. Five of the cycles will be performed after temperature equilibration of the system at 50C and 95% relative humidity, and five cycles after equilibration at -40C; an additional five cycles will be performed with >20C fuel temperature equilibration at -40C. Fifty of the cycles will be performed using a defueling rate ≥ the maintenance defueling rate.

⏩⏩ *SGS-8 Germany comment #30: Improve clarity of test description*

TFC – work on the text to clarify the test requirement and test procedure.

ISO requests for additional time to study the proposal.

SGS-8: OICA will provide rationale for the proposed test. Clarify the text to separate the test requirement from test procedure.

B.5.1.3.3 Extreme Temperature Static Pressure Leak/Permeation Test. The system will be held at 115%NWP and 55C with hydrogen gas until steady-state permeation or 30 hours, whichever is longer in accordance with 6.4.2.9 test procedure. The test will be performed after 250 pressure cycles are conducted in B.5.1.3.2 and again at the completion of B.5.1. 3.2. The maximum allowable discharge from the compressed hydrogen storage system is 150 ml/min for standard passenger vehicles. [The maximum allowable discharge for systems in different size 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.]

⏩ ⏩ SGS-8 Germany comment #31: "The permeation rate must be limited to a value with limit per hour and per liter. The permeation rate is too high for avoiding explosion or fire hazards inside the vehicle.

⏩ ⏩ SGS-8 ISO member comment # 16: discuss permeation rate

TFG – defer to SGS-8

If the measured permeation rate is greater than 0.005 mg/sec (3.6 cc/min), then a localized leak test shall be performed in accordance with B.6.2.2.10 test procedure to ensure no point of localized external leakage is greater than 0.005 mg/sec (3.6 cc/min).

◆ SGS-7 Discussion: Recommendation for permeation limit remains under consideration at OICA/HySafe

SGS-8: Make sure the unit is consistent. OICA/Paul Adams will provide rationale for the permeation limit. Cite the Hysafe report and discuss different limits from Japan and EC.

B.5.1.3.4 Residual Proof Pressure Test (hydraulic). The storage container will be pressurized to 180%NWP and held 30 seconds without burst in accordance with B.6.2.2.3 test procedure.

B.5.1.3.5 Residual Strength Burst Test (hydraulic). The storage container will undergo a hydraulic burst test in accordance with B.2.2.1 test procedure to verify that the burst pressure is within 20% of the baseline burst pressure determined in B.5.1.1.1).

B.5.1.4 Verification Test for Service Terminating Conditions

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

B.5.1.4.1 Fire Test. A hydrogen storage system will be pressurized to NWP and exposed to fire in accordance with test procedure 6.4.2.12 TBD. A temperature-activated pressure relief device will release the contained gases in a controlled manner without rupture.

⏩⏩ ***SGS-8 Germany comment #32: proposed text follows***:

One hydrogen storage system will be pressurized with hydrogen to NWP ***and a second system will be pressurized with hydrogen to 20% of NWP*** *and exposed to an engulfing fire. If activated, temperature-activated pressure relief device* ***shall*** *release the contained gases in a controlled manner.* ***The container shall not burst.***

Question on rationale for 20% NWP container (ECE-R110)

◆ ***SGS-6&7 Canada and US Comment: Localized fire test is under consideration***

SGS-8: Continue discussion at the next meeting.

◆ ***SGS-7 Discussion supported removal of penetration test. No justification available or expected (other than USA firemen appreciation of gunfire testing).***

⏩⏩***SGS-8 ISO member comment # 17: The penetration test should be included as part of these tests. The penetration test has historically been used for composite tanks both used for the transport of gases (ISO 11119) and onboard applications.***

SGS-8: No penetration test.

B.5.2 Liquefied Hydrogen Storage System

◆ **SGS-7 Discussion:** ***add LH storage section; BMW will write requirements***

SGS-8: BMW will provide the proposal prior to the next meeting.

B.5.3 Vehicle Fuel System.

This section specifies requirements for the integrity of the hydrogen fuel delivery system, which includes the hydrogen storage system, piping, joints, and components in which hydrogen is present.

◆ ***SGS-6 Discussion: Co-sponsors will discuss with project manager.***

B.5.3.1 Requirements – in use:

B.5.3.1.1 Gas fueling port: Gas fueling port shall prevent reverse flow.

⏩⏩ ***SGS-8 ISO member comment: require compliance with ISO 17268 for 35MPa***.

SGS-8: OICA will provide text to ensure proper fueling (over pressure and electric static discharge) and provide example per industry standards.

[the vehicle's fuel system shall be airtight]

B.5.3.1.2 Hydrogen discharge systems

B.5.3.1.2.1 Pressure relief systems.

a) TPRDs and PRDs. The outlet of the vent line, if present, for hydrogen gas discharge from TPRD(s) and/or PRD(s) of the storage system shall be protected, e.g. by a cap.

b) TPRDs. The hydrogen gas discharge from TPRD(s) of the storage system shall not be directed:

- into the enclosed or semi-enclosed spaces.
- into or towards any vehicle wheel housing
- towards hydrogen gas containers
- forward from the vehicle, or horizontally (parallel to road) from the back or sides of the vehicle

c) Other pressure relief devices. The hydrogen gas discharge from other pressure relief devices shall not be directed:

- towards exposed electrical terminals, exposed electrical switches or other ignition sources
- into or towards the vehicle passenger or cargo compartments
- into or towards any vehicle wheel housing
- towards hydrogen gas containers

d) The requirements of B.5.3.1.2.1 will be verified by visual inspection.

⏩⏩ SGS-8 Germany comment #37: move (d) to chapter 6 -- establish visual inspection as a formal test procedure in the test procedure section.

SGS-8: Move visual inspection to section 6.

B.5.3.1.2.1 Fuel cell / vehicle exhaust system. At the vehicle exhaust system's point of discharge, the hydrogen concentration level shall (1) not exceed 4% average by volume during any moving three-second time interval during normal operation including start-up and shutdown (2) and not exceed 8% at any time.

B.5.3.1.3 Protection against Flammable Conditions: Single Failure Conditions

◆ SGS-7 Discussion: several issues remain under consideration with regard to a telltale alert; expect to revisit topic in SGS-8.

SGS-8: discuss Japan's proposal on Air Tightness of Piping. OICA will work on a proposal for air tightness requirement.

⏩⏩ SGS-8 OICA comment #20, GWS comment #6, & Germany comment #39: draft text in B.5.3.1.3.1, B.5.3.1.3.2, B.5.3.1.3.3 and B.5.3.1.3.4

B.5.3.1.3.1 Hydrogen leakage and/or permeation from the hydrogen storage system shall not be allowed to directly vent to the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contain unprotected ignition sources

B.5.3.1.3.2 Any single failure downstream of the main hydrogen shut off valve shall not result in a hydrogen concentration in air greater than 4% by volume in the passenger compartment.

B.5.3.1.3.3 If during operation, a single failure ~~downstream of the main hydrogen shutoff~~ results in a hydrogen concentration greater than 4%, by volume in air in the enclosed or semi-enclosed spaces of the vehicle then the main shutoff shall be closed.

B.5.3.1.3.4 During operation, a warning shall be provided (per B.5.3.1.3.5) if the main shutoff is closed (per B.5.3.1.3.3) or if leakage causes the concentration to be greater than 4% in the passenger, luggage, or cargo compartments.

SGS-8: The above 4 paragraphs are accepted. Provide explanation in part A for during "operation."

TFG – Germany's concern on protection of low pressure system is addressed by B 5.3.1.3. ? continue discussion in SGS-8.

B. 5.X The vehicle fuel system downstream of a pressure reducer shall be protected against burst.

SGS-8: SGS agrees with the above draft. An example for compliance will be given in part A.

⏩⏩ SGS-8 USA comment: recommend s following text for B.5.3.1.3.3: "If a single failure (remove -downstream of the main hydrogen shut off valve) of the fuel system results in a hydrogen concentration in air greater than 4% by volume within enclosed or semi enclosed volumes on the vehicle, the main hydrogen shutoff valve shall close (original OICA proposal) and a warning to the driver shall be provided."

⏩⏩SGS-8 ISO member: "4 % is the lower flammability limit. It should be lowered to 1 %."

B.5.3.1.3.5 The warning shall be given by a tell-tale light with the following properties:

a. Shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened
b. Shall appear perceptually upright to the driver while driving
c. Shall be yellow or amber in color if the detection system malfunctions and shall be red in the event a 4% concentration is detected
d. When illuminated, shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions, when the driver has adapted to the ambient roadway light conditions
e. Shall remain continuously illuminated while the cause (4% concentration or detection malfunction) exists and the ignition locking system is in the "On" ("Run") position
f. Shall extinguish at the next ignition cycle after the cause for alerting the driver has been corrected
g. Shall comply with the following designations:

Cause	Colour
Detection system malfuncation	Yellow
Hydrogen leakage	Red

◆ SGS-7 Discussion: Current draft text is consistent with last point of discussion in Canada; still under discussion
◆ SGS-7 Discussion: OICA is considering a new proposal to address hydrogen leakage.

⏩⏩ SGS-8 *Germany comment #40: replace B.5.3.1.3.5 with:*

Driver warning: The vehicle shall be equipped with a visual ~~or acoustic~~ indicator (e.g. tell-tale) that provides a warning to the driver in the event of 5.2.1.2.2 or in the event of a malfunction of the hydrogen leakage detection system

⏩⏩ ***SGS-8 USA comment: Keep telltale visibility requirement in Part B***

> SGS-8: The telltale visibility requirement is accepted. Provide discussion on symbol/telltale requirement in part A.

◆ ***SGS-7 Discussion: Use UNECE- R121 for terminologies***

B.5.3.2 Requirements - post crash

B. 5.3.2.1 Fuel leakage limit: the rate of uncontrolled hydrogen gas leakage measured and calculated by 6.1 shall not exceed an average of 118 NL per minute within 60 minutes after the crash.

◆ ***SGS-7 Discussion: US recommendation: hydrogen shall not accumulate to $\geq$ 4% in the passenger, luggage (trunk) or cargo compartment within 60 minutes after the crash.***

◆ ***SGS-7 discussion: Use J2578 calculation for 118 NL.***
◆ ***SGS-7 discussion: Use Japan's informal paper for justification in part A***

B.5.3.2.2 The hydrogen fuel leakage shall not result in a hydrogen concentration in air greater than 4% by volume in the passenger, luggage and cargo compartments.

⏩⏩ ***SGS-8 USA comment: include text of B.5.3.2.2***
SGS-8: continue the discussion at the next meeting.

B.5.4 Electric safety

B.5.4.1 Requirements and test procedures - in-use

◆ ***SGS-7 Discussion: See OICA proposal***

B.5.4.1.1 Performance requirements

B.5.4.2 Requirements and test procedures - post crash

6. TEST CONDITIONS AND PROCEDURES

6.1 Compliance Tests for Fuel System Integrity

6.1.1 Crash Test for Fuel System Integrity

The crash tests used to evaluate post-crash hydrogen leakage are those already applied in the respective jurisdictions.

To evaluate possible hydrogen discharge following the vehicle crash tests, the following procedure should be used.

a) Compressed Gaseous Hydrogen Storage:

The gas container shall be filled with helium to minimum 90% of the nominal working pressure. The main stop valve and shut-off valves, etc. for hydrogen gas, located in the downstream hydrogen gas piping, shall be kept open immediately prior to the impact.

The pressure and temperature of the gas shall be measured immediately before the impact and 60 minutes after the impact either inside the gas container or upstream of the first pressure-reducing valve downstream of the gas container.

The rate of hydrogen gas leakage shall be measured by the following procedure.
The helium gas pressure immediately before the impact and 60 minutes after the impact, upstream of the first pressure-reducing valve either within the gas container or the one located downstream of the gas container shall be converted to the pressure at 0°C using equation1.

Equation 1: $P_0' = P_0 \times \{273 / (273 + T_0)\}$
where:
P_0' : Helium gas pressure converted to pressure at 0 °C before impact (MPa abs)
P_0 : Measured helium gas pressure before impact (MPa abs)
T_0 : Measured helium gas temperature before impact (°C)

$P_{60}' = P_{60} \times \{273 / (273 + T_{60})\}$
where:
P_{60}' : Helium gas pressure converted to pressure at 0 °C 60 minutes after impact (MPa abs)
P_{60} : Measured helium gas pressure 60 minutes after impact (MPa abs)
T_{60} : Measured helium gas temperature 60 minutes after impact (°C)

The gas density calculated from equation 2 before the impact and 60 minutes after the impact shall be calculated using the pressure at 0°C converted from the helium gas pressure upstream of the first pressure-reducing valve within the gas container or the one located downstream of the gas container obtained from equation 1.

Equation 2: $\rho_0 = -0.0052 \times (P_0')^2 + 1.6613 \times P_0' + 0.5789$
where:
ρ_0 : Helium gas density before impact (kg/m^3)
$\rho_{60} = -0.0052 \times (P_{60}')^2 + 1.6613 \times P_{60}' + 0.5789$
where:
ρ_{60} : Helium gas density 60 minutes after impact (kg/m^3)

The helium gas volume before the impact and 60 minutes after impact shall be calculated from equation 3 using the gas density obtained from equation 2. However, the internal volume shall be the internal volume of the gas container in cases where the helium gas pressure has been measured inside the gas container; and the internal volume of the container down to the first pressure-reducing valve located downstream of the gas container in cases where the helium gas pressure has been measured upstream of the first pressure-reducing valve located downstream of the gas container.

Equation 3: $Q_0 = \rho_0 \text{ x } V \text{ x } (22.4 / 4.00) * 10^{-3}$
where:
Q_0 : Helium gas volume before impact (m^3)
V : Internal volume (L)

$Q_{60} = \rho_{60} \text{ x } V \text{ x } (22.4 / 4.00) * 10^{-3}$
where:
Q_{60} : Helium gas volume 60 minutes after impact (m^3)
V : Internal volume (L)

The rate of helium gas leakage shall be calculated.
$\Delta Q = (Q_0 - Q_{60}) \text{ x } 10^3$
$RHe = \Delta Q / 60$
where:
ΔQ : Volume of helium gas leakage 60 minutes after impact (NL)
RHe : Rate of helium gas leakage (NL/min)

The rate of helium gas leakage shall be converted to the rate of hydrogen gas leakage.
$RH = 1.33 \text{ x } RHe$
where:
RH : Rate of hydrogen gas leakage (NL/min)

b) Liquid Hydrogen Storage:

The fuel storage container shall be filled with liquid nitrogen (LN2) to minimum the mass equivalent of the maximum quantity of LH2 that may be contained in the inner vessel and then the system shall be pressurized with a gaseous N2 up to typical operating pressure.

The main stop valve and shut-off valves, etc. for hydrogen, located in the downstream hydrogen gas piping, shall be kept open immediately prior to the impact.

After the collision, the liquid hydrogen storage system must be tight, i.e. bubble free* if using detecting spray. No uncontrolled release of the test fluid is allowed.

** With bubble detection spray, any leakage in the range above 0,1Pa l/s can be detected. In case of N2 used as test fluid, the corresponding detectable hydrogen leakage would be about 0,5 Pa l/s (that is far below 1 NL per minute!).*]

B.6.1.2 Compliance Test for Single Failure Conditions

[Preparation:
The test shall be conducted without any influence of wind.
Special attention shall be paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.
Prior to the test the vehicle has to be prepared to allow remotely controllable hydrogen releases from the hydrogen system. The number and location of the release points downstream of the main hydrogen shutoff valve shall be defined by the vehicle manufacturer taking worst case leakage scenarios into account.
Only for the purpose of the test hydrogen concentration detectors have to be installed in enclosed or semi enclosed volumes on the vehicle.
If there is structure taken to prevent hydrogen from intruding into passenger compartments, it is not necessary to have H2 concentration measurement points in the passenger compartments.

Example hydrogen concentration measurement locations can be found in the document "Examples of hydrogen concentration measurement points for testing".

Procedure:
i) Vehicle doors, windows and other covers shall be closed.
ii) Start the propulsion system, allow it to warm up to its normal operating temperature and leave it operating at idle for the test duration.
iii) A leak shall be simulated using the remote controllable function.
iv) The hydrogen concentration shall be measured continuously until the concentration does not rise anymore for 3 minutes or until the main hydrogen shutoff valve is closed.
v) If during the test the hydrogen concentration at one of the measurement locations exceeds 4% significantly, the test shall be terminated.]*

[ ] this part of the proposal still needs to be confirmed]*

⏩⏩ SGS-8 OICA comment #21: Consider Japanese Regulation Attachment 100 for test procedure for B.6.1.2:

B.6.1.2.1 Test condition
B.6.1.2.1.1 Test vehicle. Start the fuel system of the test vehicle, warm it up to its normal operating temperature and leave it operating for the test duration. If the vehicle is not a fuel cell vehicle, warm it up and keep it idling. If the test vehicle has a system to stop idling automatically, measures shall be taken so as to prevent the engine from stopping.
B.6.1.2.1.2 Test gas. Mixture of air and hydrogen gas with 4% hydrogen or a lower concentration shall be used.
B.6.1.2.2 Test method.
B.6.1.2.2.1 Preparation for the test. If necessary for blowing the test gas to the hydrogen gas leakage detector without fail, the following measures be taken.

- *Attach a test gas induction hose to the hydrogen gas leakage detector.*

- *Enclose hydrogen leak detector with a cover to make gas stay around hydrogen leak detector.*

B.6.1.2.2.2 Execution of test.

- *Blow test gas to the hydrogen gas leakage detector.*
- *Confirm the warning provided*
- *Confirm the main shut-off valve closed. To confirm the operation of the main shut-off valve of the hydrogen supply, the monitoring of the electric power to the shut-off valve or of the sound of the shut-off valve activation may be used.*

6.1.3 Compliance Test for Fuel Cell Vehicle Exhaust System

a. The fuel cell system of the test vehicle shall be warmed up. (is this the worst case scenario? Should this be removed to include all vehicles' stages?)
b. The measuring device shall be warmed up before use.
c. Place the measuring section of the measuring device on the centre line of the exhaust gas flow within 100 mm from the exhaust gas outlet.
d. Perform the test procedure below while continuously measuring the hydrogen concentration:
   With the vehicle in a stationary state, start the fuel cell system. After a lapse of at least one minute turn off the system and continue the measurement until the fuel cell system shut down procedure is completed.]
e. The measurement device must have a measurement response time of less than 300 milliseconds.

◆ ***SGS-7 Discussion: OICA will provide the response time for the measuring device***

◆ ***SGS-8 GWS comment #11:***
The standard ISO instrumentation requirement is a factor of 6-10 of the measured value. Therefore, the 3-second rolling average requires a sensor response (90% of reading) and recording rate of less than 300 milliseconds.

◆ ***SGS-7 Discussion: Japan will submit its test procedure for consideration***.

6.1.4 Compliance Test for Air Tightness of Piping

⏩⏩ SGS-8 *JASIC proposal for consideration:*
With the motor vehicle held stationary and the pressure applied to piping, etc., check to see if hydrogen gas leakage is present at confirmable sections of the piping, etc. from the high-pressure section to the fuel cell stack (the engine in vehicles other than fuel cell vehicles), using a gas detector or detector liquid, such as soap water.
B.6.1.4.1. Hydrogen leak detection is performed with the fuel cell stack, etc. activated.
B.6.1.4.2. Hydrogen leak detection is performed, mainly at joints, by using gas leak detector or detecting agent (e.g., soap solution).
B.6.1.4.3. When the gas leak detector is used, detection is performed by letting the detector suck in air for about 10 seconds at locations as close to piping, etc. as possible.

B.6.1.4.4. When the gas detecting agent is used, hydrogen gas leak detection is performed immediately after applying the agent. In addition, visual check is also performed a few minutes after the application of agent in order to check for bubbles caused by trace leaks.

B.6.2 TEST PROCEDURES FOR COMPRESSED HYDROGEN STORAGE

B.6.2.1 Material Qualification

◆ ***SGS-7 Discussion: Requirements for B.6.2.1 tests are in Part A – should test procedures (B.6.2.1) also move to Part A if text of requirements remains in Part A?***

B.6.2.1.1 Plastic liner tensile test. For containers with plastic liners, two plastic liners shall be tested at -40C in accordance with ISO 527-2. The tensile yield strength and ultimate elongation shall be within the manufacturer's specifications.

B.6.2.1.2 Plastic liner softening temperature test. For containers with plastic liners, the softening temperature of polymeric materials from finished liners shall be determined based on the A50 method in ISO 306. The softening temperature shall be ≥ 100C.

B.6.2.1.3 Glass transition temperature test. For containers with composite wraps, the glass transition temperature of resin materials shall be determined in accordance with ASTM D3418. Test results shall be within the manufacturer's specifications.

B.6.2.1.4 Resin shear strength test. For containers with composite wraps, resin materials shall be tested on a sample coupon representative of the over-wrap in accordance with ASTM D2344. After boiling in water for 24 hours the minimum shear strength of the composite shall be 13.8MPa.

B.6.2.1.5 Coating test. For containers with external environmental coatings, coatings shall be evaluated as follows:

a) adhesion strength based on ISO 4624; the coating shall exhibit an adhesion rating of 4.

b) flexibility based on ASTM D522 Method B with a 12.7 mm mandrel at the specified thickness at -20C; the coating shall exhibit no apparent cracks

c) impact resistance in accordance with ASTM D2792. The coating at room temperature shall pass a forward impact test of 18 J.

d) water exposure based on ASTM G154 using an exposure of 1000 hours. There shall be no evidence of blistering. The adhesion shall meet a ration of 3 when tested in accordance with ISO 4624.

e) salt spray exposure in accordance with ASTM B117 using an exposure of 500 hours. There shall be no evidence of blistering. The adhesion shall meet a rating of 3 when tested in accordance with ASTM D3359.

B.6.2.1.6 Metal hydrogen compatibility.

a) Steel

In all applications where steel comes in contact with hydrogen, hydrogen compatibility should be demonstrated. Steels that meet requirements of Sections 6.3 and 7.2.2 of ISO 9809-1:1999 are recognized as hydrogen compatible for low stress applications.

The following steels are recognized as suitable for high pressure hydrogen gas applications: SUS316L, AISI316L, AISI316 and DIN1.4435; all must have $\geq$ 12% nickel composition and $\leq$ 0.1% magnetic phases by volume. These steel applications may not include welds.

Other steels must be qualified for high pressure hydrogen gas applications by meeting the following performance-based test requirements:

TBD .

- SGS-7 Discussion: Test procedures are expected to be developed in 2010 by industry standards organizations and presented for inclusion in 6.2.1.6.

b) Aluminum

Aluminum alloys that meet the requirements of Sections 6.1 and 6.2 of ISO 7866:1999 are recognized as hydrogen compatible for low stress applications.

The following aluminum alloys are recognized as suitable for use in contact with hydrogen in the hydrogen storage system, as defined in Figure 2, or in any other high-stress applications in contact with hydrogen: A6061-T6, A6061-T62, A6061-T651 and A6061-T6511. These aluminum applications may not include welds.

Other aluminum alloys must be qualified for high pressure hydrogen gas applications by meeting the following performance-base test requirements:

TBD

- SGS-7 Discussion: Test procedures are expected to be developed in 2010 by industry standards organizations and presented for inclusion in 6.2.1.6.

B.6.2.2 Test Procedures for Performance Durability (B.5.1.2)

B.6.2.2.1 Burst Test (Hydraulic). The burst test shall be conducted at ambient temperature using a non-corrosive fluid. The rate of pressurization shall be $\leq$1.4 MPa/s for pressures higher than 150% of the nominal working pressure. If the rate exceeds 0.35 MPa/s at pressures higher than 150% NWP, then either the container shall be placed in series between the pressure source and the pressure measurement device, or the time at the pressure above a target burst pressure shall exceed 5 seconds. The burst pressure of the container shall be recorded.

B.6.2.2.2 Pressure Cycling Test (Hydraulic). The test shall be performed in accordance with the following procedure:

a) Fill the container with a non-corrosive fluid.
b) Stabilize the temperature of the container and fluid at the specified temperature and relative humidity at the start of testing; maintain the environment, fueling fluid and container skin at the specified temperature for the duration of the testing. The

container temperature may vary from the environmental temperature during testing.

c) Pressure cycle between <2 MPa and the target pressure at a rate not exceeding 10 cycles per minute for the specified number of cycles.

d) Maintain and monitor the temperature of the hydraulic fluid within the container at the specified temperature.

B.6.2.2.3 Proof Pressure Test. The system should be pressurized smoothly and continually with a non-corrosive fluid until the target test pressure level is reached and then held for at least 30 seconds. The component should not leak or suffer permanent deformation. All mechanical components should be functional after completion of the test.

B.6.2.2.4 Drop (Impact) Test (Unpressured). One or more storage containers will be drop tested at ambient temperature without internal pressurization or attached valves. All drop tests may be performed on one tank, or individual impacts on a maximum of 3 tanks. The surface onto which the tanks are dropped should be a smooth, horizontal concrete pad or similar flooring. The tank(s) should be tested in the following sequence:

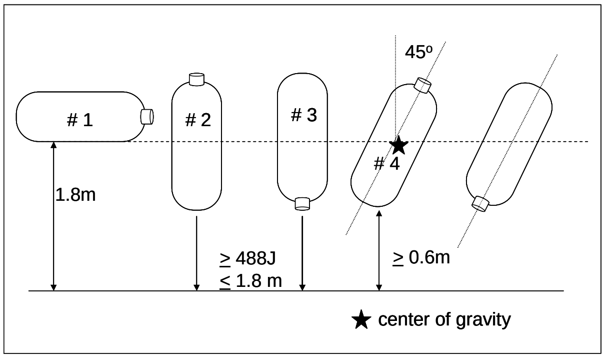
a) Drop once from a horizontal position with the bottom 1.8 m above the surface onto which it is dropped.

b) Drop once onto each end of the tank from a vertical position with a potential energy of not less than 488J, but in no case should the height of the lower end be greater than 1.8 m.

c) Drop once at a 45 ° angle, and then for non-symmetrical and non-cylindrical tanks rotate the tank through 90 ° along its longitudinal axis and drop again at 45 °C with its center of gravity 1.8 m above the ground. However, if the bottom is closer to the ground than 0.6 m, the drop angle should be changed to maintain a minimum height of 0.6 m and a center of gravity of 1.8 m above the ground.

No attempt should be made to prevent the bouncing of tanks, but the tanks may be prevented from falling over during the vertical drop test described in b) above.

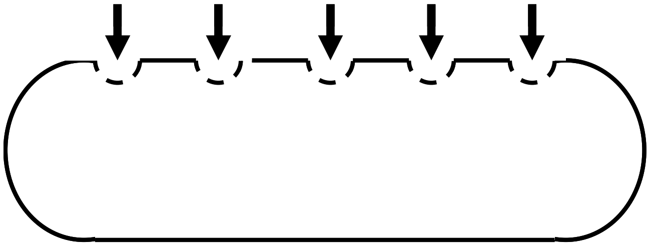
Following the drop impact, the containment vessel subjected to the 45^{o} impacts should then be subjected to further testing as specified in 5.2.2. The vessel(s) subjected to horizontal and vertical drop impacts, if different from the vessel subjected to a 45^{o} drop impacts, should be subjected to 1000 hydraulic ambient-temperature pressure cycles per the test procedure defined in 6.4.2.2.



B.6.2.2.5 Surface Damage Test (Unpressured). The test should proceed in the following sequence:

a) Surface Flaw Generation: Two longitudinal saw cuts are made on the bottom outer surface of the unpressurized horizontal storage container along the cylindrical zone close to but not in the shoulder area. The first cut will be at least 1.25 mm deep and 25 mm long toward the valve end of the vessel. The second cut will be at least 0.75 mm deep and 200 mm long toward the end of the tank opposite the valve.

b) Pendulum Impacts: The upper section of the horizontal storage container should be divided into five distinct (not overlapping) areas 100 mm in diameter each (see Figure). After 12 hrs preconditioning at –40 °C in an environmental chamber, the center of each of the five areas should sustain impact of a pendulum having a pyramid with equilateral faces and square base, the summit and edges being rounded to a radius of 3 mm. The center of impact of the pendulum should coincide with the center of gravity of the pyramid. The energy of the pendulum at the moment of impact with each of the five marked areas on the containment vessel should be 30J. The tank should be secured in place during pendulum impacts and not under pressure.



"Side" View of Tank

B.6.2.2.6 Chemical Exposure and Ambient-Temperature Pressure Cycling Test. Each of the 5 areas of the unpressured vessel preconditioned by pendulum impact (6.4.2.5b) should be exposed to one of five solutions: 1) 19% (by volume) sulfuric acid in water (battery acid), 2) 25% (by volume) sodium hydroxide in water, 3) 5% (by volume) methanol in gasoline (fluids in fueling stations), 4) 28% (by volume) ammonium nitrate in water (urea solution), and 5) 50% (by volume) methyl alcohol in water (windshield washer fluid).

Orient the test vessel with the fluid exposure areas on top. Place a pad of glass wool approximately 0.5 mm thick and 100 mm in diameter on each of the five preconditioned areas. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted across its surface and through its thickness for the duration of the test.

The exposure of the vessel with the glass wool should be maintained for 48 hrs with the vessel held at 1.25% NWP (applied hydraulically) and ambient temperature (15C – 25C) before the vessel is subjected to further testing.

Perform pressure cycling to the specified target pressures according to B.6.2.2.1 at ambient temperature (15C-25C) for the specified numbers of cycles. Remove the glass wool pads and rinse the vessel surface with water before conducting the final 10 cycles to specified final target pressure.

B.6.2.2.7 Static Pressure Test (Hydraulic). Pressurize the storage system to the target pressure in temperature-controlled chamber. Hold the temperature of the chamber and the non-corrosive fueling fluid at the target temperature within ±5C for the specified duration.

B.6.2.3 Test Procedures for On-Road Performance (B.5.1.3)

(Pneumatic test procedures are provided; Hydraulic Test elements are described in 6.4.2)

B.6.2.3.1 Gas Pressure Cycling Test (Pneumatic). At the onset of testing, stabilize the storage system at the specified temperature, relative humidity and fuel level at least 24 hrs. Maintain the specified temperature and relative humidity within the test environment throughout the remainder of the test. (When required in the test specification, the system temperature should be stabilized at the external environmental temperature between pressure cycles.) Pressure cycle between <2 MPa and the specified maximum pressure. Control the fill rate to a constant 3-minute pressure ramp rate; control the temperature of the hydrogen fuel dispensed to the vessel to the specified temperature. Control the defueling rate to ≥ the intended vehicle's maximum fuel-demand rate. Conduct the specified number of pressure cycles. If devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls (or equivalent measures).

B.6.2.3.2 Gas Permeation Test (Pneumatic). A storage system shall be fully filled with hydrogen gas (full fill density equivalent to 100% NWP at 15 °C is 113% NWP at 55 °C) and held at 55^{o}C in a sealed container. The total steady-state discharge rate due to leakage and permeation from the storage system shall be measured.

B.6.2.3.3 Localized Gas Leak Test (Pneumatic). A bubble test (or alternative method with sufficient accuracy) may be used to fulfill this requirement. The following guidance is provided for conducting the bubble test:

a. The exhaust of the shutoff valve (and other internal connections to hydrogen systems) may be capped for this test (as the test is focused at external leakage). At the discretion of the tester, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. In general, the tester should estimate the gas leakage based on the size and rate of bubble formation.
b. Note: Visual detection of unacceptable leakage should be feasible. When using standard leak-test fluid, the bubble size is expected to be approximately 1.5 mm in diameter. For a localized rate of 0.005 mg/sec (3.6 cc/min), the resultant allowable rate of bubble generation is about 2030 bubbles per minute. Even if much larger bubbles are formed, the leak should be readily detectable. For example, the allowable bubble rate for 6 mm bubbles would be approximately 32 bubbles per minute.

If the permeation test conducted in 6.4.2.9 yields a total discharge less than the specified allowable localized leak, then localized leak testing is not necessary as the total system leakage is already below the localized leak requirement.

B.6.2.3.4 Proof Leak Test (Pneumatic). A bubble test (or alternative method with sufficient accuracy) to verify local leakage should be conducted as follows: a) The exhaust of the shutoff valve (and other internal connections to hydrogen systems) may be capped for

this test (as the test is focused at external leakage).
At the discretion of the tester, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. In general, the tester should estimate the gas leakage based on the size and rate of bubble formation. b) When using standard leak-test fluid, the bubble size is expected to be approximately 1.5 mm in diameter and the resultant allowable rate of bubble generation is about 2030 bubbles per minute. Even if much larger bubbles are formed, the leak should be readily detectable. For example, the allowable bubble rate for 6 mm bubbles is still approximately 32 bubbles per minute.

B.6.2.4 Test Procedures for Service Terminating Conditions (B.5.1.4)

B.6.2.4.1 Fire Test (pneumatic). TBD

7. ANNEXES