Hydrogen-Powered Vehicles: A Comparison of the European Legislation and the Draft UNECE Global Technical Regulation

by C Visvikis

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CLIENT PROJECT REPORT

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by C Visvikis (TRL)

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	Hydrogen-Powered Vehicles: A Comparative Analysis of the European Legislation and the Draft UNECE Global Technical Regulation
Client:	**European Commission, DG Enterprise and Industry**
	Peter Broertjes

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The views expressed are those of the author(s) and not necessarily those of the European Commission.

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Contents

Executive summary

The European Commission awarded a project to TRL to compare the European legislation on the type-approval of hydrogen-powered vehicles with a new (draft) United Nations Economic Commission for Europe (UNECE) global technical regulation. The specific objectives of the project were:

1. To provide a comparative analysis of the European legislation on hydrogen-powered vehicles (i.e. Regulations (EC) No. 79/2009 and (EU) No. 406/2010) against the draft UNECE global technical regulation;
2. To investigate potential implications for safety of any differences between the European and the draft global requirements.

This report presented the findings of the work and included:

1. Detailed tables (in the appendices) comparing each technical requirement in Regulation (EU) No. 406/2010 with the corresponding requirement in the draft global regulation (where available);
2. A discussion of the key differences and potential implications summarised in a table (in Section 4.5).

Overall, the work showed that there are fundamental differences between the European legislation and the draft global technical regulation. There are insufficient tests or real-world data to determine, with certainty, which is more stringent. There are aspects of a hydrogen storage system and its installation that are regulated in Europe, but are not included in the draft global technical regulation. However, the performance requirements in the global regulation appear, on balance, to be more stringent than those in the European legislation. That said, the penetration test is a potentially significant omission from the draft global technical regulation. Hydrogen containers may be unlikely to experience gunfire during their service life, but there could be implications for security if future containers were to become susceptible to rupture under gunfire. In these circumstances, hydrogen vehicles might become targets for vandalism or terrorism.

The performance tests in the draft global technical regulation (particularly those for compressed hydrogen storage systems) represent a new approach to the qualification of hydrogen storage systems. The test procedures were derived from similar tests in SAE TIR J2579; however, the specific procedures in the draft global technical regulation have not been validated.

The draft global technical regulation was developed by the UNECE Informal Group on Hydrogen and Fuel Cell Vehicles – Subgroup on Safety. This subgroup included several European stakeholders. Nevertheless, further consultation with European stakeholders would give them the opportunity to comment on the differences between the European legislation and the draft global technical regulation highlighted in this report.

A programme of experiments to validate the test procedures in the draft global technical regulation would develop the knowledge on the testing of hydrogen storage systems and would improve the understanding of the potential implications of transposing these procedures into the European legislation.

A new test procedure can be validated by checking that it displays three important characteristics:

1. The capacity to deliver repeatable results with identical products (in the same laboratory);
2. The capacity to deliver reproducible results with identical products (in different laboratories);
3. The capacity to distinguish between products of different quality (and particularly to eliminate those that are at risk of failing in service).

The co-chairs, co-sponsors, European Commission and other stakeholders have expressed a strong interest in initiating a new programme of validation to further assess the draft global technical regulation and to provide a robust rationale for the requirements.

1 Introduction

The European Commission awarded a project to TRL to compare the European legislation on the type-approval of hydrogen-powered vehicles with a new (draft) United Nations Economic Commission for Europe (UNECE) global technical regulation. The specific objectives of the project were:

1. To provide a comparative analysis of the European legislation on hydrogen-powered vehicles (i.e. Regulations (EC) No. 79/2009 and (EU) No. 406/2010) against the draft UNECE global technical regulation;
2. To investigate potential implications for safety of any differences between the European and the draft global requirements.

The European legislation and the draft global technical regulation both specify requirements relating to the safety of hydrogen storage on-board a vehicle. Nevertheless, they were developed by different working groups with different objectives. Highlighting any differences between them, and the potential implications for vehicle safety, will prove useful in the event that the draft global technical regulation is adopted (and hence it becomes necessary to begin the process of transposing the global requirements into European legislation).

The remainder of this report presents the findings of the project. Section 2 provides an overview of the European legislation. A similar overview of the draft global technical regulation follows in Section 3. The main comparative analysis is presented in Section 4. Section 5 draws together the overall conclusions of the project and suggests further work. Detailed tables comparing the technical requirements in Regulation (EU) No. 406/2010 with those in the draft global technical regulation are set out in Appendix A for compressed (gaseous) hydrogen storage systems and in Appendix B for liquefied hydrogen systems.

2 The European legislation

Directive 2007/46/EC establishes a framework for the approval of motor vehicles, and of systems and components intended for such vehicles. In the past, there were no specific provisions for hydrogen-powered vehicles within the framework directive. However, on 4th February 2009, Regulation (EC) No. 79/2009 on the type-approval of hydrogen-powered vehicles was published in the Official Journal of the European Communities. The "hydrogen regulation" amends Annexes IV, VI and XI of Directive 2007/46/EC with the aim of specifying harmonised safety requirements for hydrogen-powered vehicles.

Regulation (EC) No. 79/2009 contains general requirements for the type-approval of hydrogen components and systems and lists applicable test procedures. It also contains general requirements for the installation of hydrogen components and systems. These are fundamental provisions laid down by the European Parliament and the Council and adopted through the co-decision procedure[1].

More detailed requirements and test procedures that implement the fundamental provisions in the hydrogen regulation are set out in a separate regulation adopted by the Commission with the assistance of a regulatory committee. Commission Regulation (EU) No. 406/2010, implementing Regulation (EC) No.79/2009 was published in the Official Journal of the European Communities on 18th May 2010. This "implementing regulation" was developed with the assistance of the Hydrogen Working Group, which is made up of representatives of EU Member States, automotive industry, component manufacturers, hydrogen associations and other stakeholders.

Regulation (EU) 406/2010 was the main focus for the comparative analysis presented in this report because it contains the main technical requirements and test procedures that correspond to those in the draft global technical regulation. Figure 1 illustrates how the main technical requirements in Commission Regulation (EU) No. 406/2010 are structured.

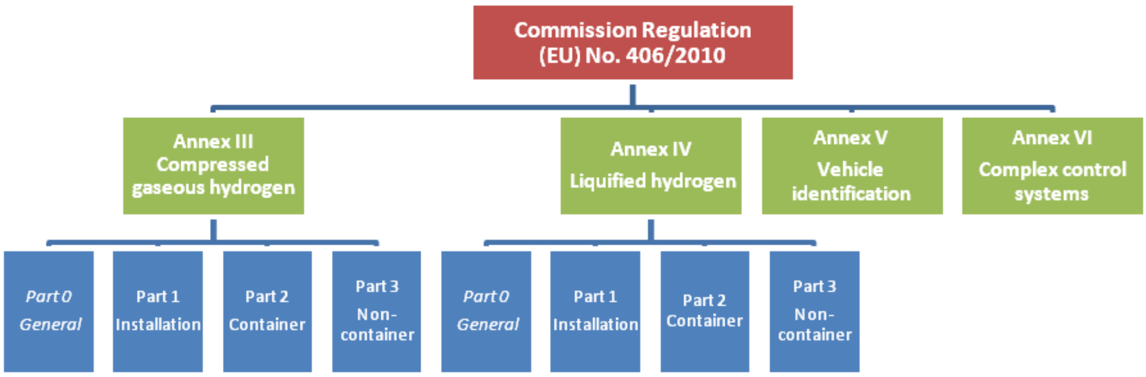

Figure 1: Structure of Commission Regulation (EU) No. 406/2010

As Figure 1 shows, the technical requirements in Commission Regulation (EU) No. 406/2010 are set out in a series of annexes. Annex III and Annex IV contain requirements for the safety of hydrogen storage on-board the vehicle, including any components in contact with hydrogen. Each annex comprises four parts: an initial (unnumbered) part sets out general requirements; part 1 sets out requirements for the installation of hydrogen components and systems; part 2 deals with the container; and part 3 deals with other components. Parts 2 and 3 include both technical requirements and test procedures.

[1] The co-decision procedure is now known as the "ordinary legislative procedure" after the Lisbon Treaty came into force.

3 Draft UNECE global technical regulation

A global technical regulation on hydrogen-powered vehicles is being developed, with a target date of 2011 for completion of the vehicle safety elements. It is being administered by the World Forum for Harmonisation of Vehicle Regulations (WP.29), which is a subsidiary body of the UNECE. This has been possible through the 1998 Global Agreement, which seeks to promote international harmonisation through the development of global technical regulations. The 1998 Agreement is also open to countries that are not signatories to the 1958 Agreement and hence do not necessarily recognise or apply UNECE regulations.

The global technical regulation on hydrogen-powered vehicles will ultimately specify requirements for both their safety and their environmental performance. It is being developed by two subgroups: a subgroup on safety reports to the Working Party on Passive Safety (GRSP) and a subgroup on environmental aspects reports to the Working Party on Pollution and Energy (GRPE). The subgroup on safety has prepared a draft global technical regulation that contains only the safety elements. Their aim is to deliver a level of safety for hydrogen-powered vehicles that is equivalent to that for conventional vehicles, and to establish performance-based requirements that do not restrict future technologies. Figure 2 illustrates the structure of the draft global technical regulation (GRSP Working Document number ECE/TRANS/WP.29/GRSP/2011/33, submitted for the 50th Session of GRSP).

The technical requirements in the draft global technical regulation are set out in three sections. Section B.5 specifies performance requirements, section B.6 specifies test conditions and procedures and section B.7 specifies optional requirements and procedures for vehicles with liquefied hydrogen storage systems. Within sections B.5 and B.6, the global technical regulation covers: compressed hydrogen storage; the vehicle fuel system; and electrical safety. Electrical safety is not included in the European regulations for hydrogen-powered vehicles, but would be dealt with instead by UNECE Regulation 100. Similarly, the vehicle fuel system requirements in the global regulation cover in-use and post-crash. However, the European regulations do not include post-crash requirements because these will be dealt with by the frontal and side impact legislation (UNECE Regulations 94 and 95, respectively).

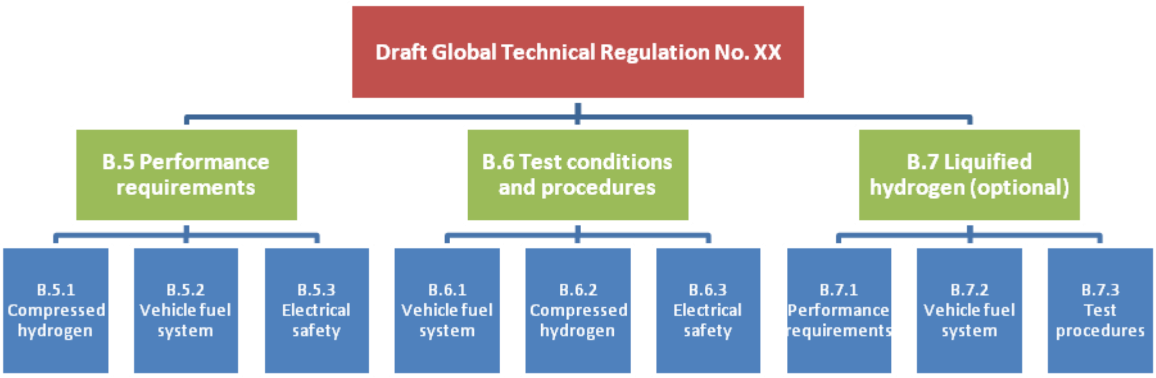

Figure 2: Structure of the draft global technical regulation

A global technical regulation is not a legislative document. However, a contracting party to the 1998 Global Agreement that votes in favour of establishing a global technical regulation is obliged to begin the process of transposing the global requirements into their local legislation. Contracting parties may adapt or modify the specifications in the global regulation for their local legislation, but they may not increase the levels of stringency or performance.

4 Comparative analysis

4.1 Overview

This section presents the main comparative analysis between the European legislation and the draft global technical regulation. The following European legislation was examined:

- Regulation (EC) No. 79/2009 of the European Parliament and of the Council of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC;
- Commission Regulation (EU) No. 406/2010 of 26 April 2010 implementing Regulation (EC) No. 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles.

Although both European regulations were considered, Regulation (EU) No. 406/2010 was the main focus for the analysis because it contains all the main technical requirements and test procedures.

The draft global technical regulation was still being developed and amended during the course of this project. The comparative analysis was made initially with the following document:

- Draft Global Technical Regulation No. xx Hydrogen Fuelled Vehicle (dated 8 November 2010, with document reference SGS-TF).

This document was discussed at a Task Force meeting of the UNECE Informal Group on Hydrogen and Fuel Cell Vehicles – Subgroup on Safety. The comparative analysis was updated as subsequent versions of the draft global technical regulation were released. This report now relates to the following document:

- Draft Global Technical Regulation No. xx Hydrogen Fuelled Vehicle (GRSP Working Document number ECE/TRANS/WP.29/GRSP/2011/33).

This version of the draft regulation was prepared for submission to the WP.29 Secretariat as a formal document to the 50th Session of GRSP (scheduled for 6-9 December 2011). However, at the time of writing, some technical issues remain to be resolved and further updates may be made to the document. Any open issues in the draft global technical regulation that might affect the findings of the comparative analysis are highlighted in the subsequent sections of this report.

4.2 Differences in philosophy and approach

Regardless of the technical content, there are fundamental differences in philosophy and approach between Regulation (EU) No. 406/2010 and the draft global technical regulation. This section explores these differences and discusses their implications.

One of the most immediate differences is in the type of requirements they contain. Regulation (EU) No. 406/2010 includes both design and performance requirements for hydrogen components and systems and their installation in vehicles. European type-approval regulations often contain a combination of design and performance requirements. Design requirements typically set out clear instructions about the characteristics of a component or system, or the way it should function. They are assessed by inspection and ideally, they are objective and unambiguous. Performance requirements specify a level of performance that must be met with a particular test procedure or measurement. They are inherently less prescriptive than design requirements because they specify an outcome rather than a design characteristic, but they rely on the availability of robust test procedures.

There are numerous design requirements in Regulation (EU) No. 406/2010. Many relate to the installation of the hydrogen storage system. For example, paragraph 9.3 in Part 1 of Annex III states: "Flammable materials used in the vehicle shall be protected from liquefied air that may condense on un-insulated elements of the fuel system". This example illustrates how design requirements can sometimes be subjective. For instance, it does not say what level of "protection" is required or how it should be assessed. However, it was written for a European type-approval regulation in the knowledge that a certified technical service will be involved in the process and would be capable of determining, in a consistent way, whether the requirement has been met.

The draft global technical regulation is predominantly performance-based, with relatively few design requirements. This means that some aspects of a hydrogen system and its installation in a vehicle are regulated in Europe, but are not included in the draft global technical regulation. This is because the European regulation specifies a design requirement with no corresponding (design or performance) requirement in the draft global regulation.

Another fundamental difference relates to the way that the performance of the hydrogen system is tested. The European regulation specifies performance requirements and test procedures for hydrogen systems, which compliment the design requirements. Crucially, however, the tests are carried out on each component separately (and in some cases on material samples). The container is tested, and so are all of the other components of the hydrogen system, provided they have a nominal working pressure of above 3 MPa (in the case of compressed gaseous systems). In contrast, the draft global regulation tests only the container and any components that form the primary pressure boundary. System-level testing is also specified in the global regulation, but this applies only to the primary pressure boundary.

As a result of these differences, the European regulation is more prescriptive than the draft global technical regulation. However, the global regulation is intended to be compatible for all contracting parties, whether they operate on the principle of self-certification or type-approval.

Once the draft global regulation is adopted by WP.29, the process of transposing the requirements into European legislation would be expected to begin. These (largely performance-based) requirements could essentially replace the current performance requirements in Regulation (EU) No. 406/2010 (for containers and hydrogen components within the primary pressure boundary). But by keeping the design requirements and performance requirements for components outside the primary pressure boundary, the Commission could ensure there is no decrease in the overall level of safety afforded by the European regulation (assuming the transposed requirements deliver at least the same level of safety). This may not be full harmonisation, in the sense that an identical regulation applies everywhere, but these European requirements are unlikely to contradict anything transposed from the global regulation.

4.3 Compressed (gaseous) hydrogen systems

A comprehensive table comparing the requirements for compressed (gaseous) hydrogen systems in Regulation (EU) No. 406/2010 with those in the draft global technical regulation is presented in Appendix A. This remainder of this section discusses the key differences and their potential implications.

4.3.1 *Classification of container type and specification of tests*

Regulation (EC) No. 79/2009 requires that compressed (gaseous) hydrogen containers are classified as follows:

- Type 1 – Seamless metallic container;

- Type 2 – Hoop wrapped container;
- Type 3 – Fully wrapped container with a seamless or welded metallic liner;
- Type 4 – Fully wrapped container with a non-metallic liner.

The test procedures specified for containers in Regulation (EC) No. 79/2009 (and described in Regulation (EU) No. 406/2010) apply according to the type of hydrogen container. Some tests apply to all types, but others apply to particular types only. This is illustrated in Table 1. This approach presupposes that some tests are unnecessary for certain types of container. For example, the European legislation specifies a permeation test (and performance limits) for Type 4 containers only; it is not required for Types 1, 2 or 3. However, metallic containers, or containers with metallic liners (i.e. Types 1, 2 and 3), are considered to have a negligible permeation rate, whereas containers with non-metallic liners (i.e. Type 4) are known to be susceptible to permeation (Adams *et al.*, 2011).

Table 1: Applicable test procedures for containers designed to use compressed (gaseous) hydrogen

Type of test	Applicable to container type			
	1	2	3	4
Burst test	✓	✓	✓	✓
Ambient temperature pressure cycle test	✓	✓	✓	✓
Leak before burst test	✓	✓	✓	✓
Bonfire test	✓	✓	✓	✓
Penetration test	✓	✓	✓	✓
Chemical exposure test		✓	✓	✓
Composite flaw tolerance test		✓	✓	✓
Accelerated stress rupture test		✓	✓	✓
Extreme temperature pressure cycle test		✓	✓	✓
Impact damage test			✓	✓
Leak test				✓
Permeation test				✓
Boss torque test				✓
Hydrogen gas cycle test				✓

There is no classification of container type in the draft global technical regulation. The container tests (and the system-level tests) specified in the global regulation are intended for all compressed hydrogen storage systems, regardless of container materials or construction. The draft global technical regulation (if adopted and transposed) would require some containers to undergo tests that are not currently required by the European legislation. Leaving aside any differences there might be in the test procedures and performance limits; it could be argued that the draft global technical regulation specifies a higher level of stringency for such containers than the European legislation (all things being equal). However, it might also be argued that the global regulation requires tests to be performed that are unnecessary, because it requires all tests to be performed for all types of containers, regardless of the hazards and risks of the particular materials.

New container technologies that cannot be classified according to the "types" listed in the European legislation would be unable to gain type-approval in Europe. However, the draft global technical regulation would apply to any container technology. The container tests are intended to reproduce worst-case on-road conditions, rather than test known failure mechanisms associated with specific types of container (Sloan, 2009). This approach assumes that the worst-case on-road conditions are not influenced in any way by the container materials and construction. While this may be the case, it does seem to contrast with the way working pressure is dealt with in the global technical regulation: the nominal working pressure of compressed hydrogen storage systems is limited to 70 MPa. The technical rationale states that "in the future, if there is interest in qualifying systems to higher nominal working pressure, the tests for qualification will be re-examined". It is unclear why this principle does not apply to the (seemingly) equally important characteristics of container materials and construction.

In summary, there are two potential safety implications of transposing these aspects of the global technical regulation into the European legislation. Firstly, some containers will be required to undergo test conditions that were not previously specified for their type. This might increase the level of safety for these containers, or at least do nothing if the tests are essentially unnecessary. Secondly, any type of container that meets the performance requirements will be able to gain type-approval, including containers that feature new materials or construction methods. Hence there would be no means of validating the performance tests and requirements for a new technology before permitting it to enter service. This relies very much on the tests to reproduce the worst-case on-road conditions, regardless of the container materials and construction.

4.3.2 *Service life and number of filling cycles*

Commission Regulation (EU) No. 406/2010 specifies a limit of 20 years for the service life of hydrogen containers. The regulation also specifies the number of filling cycles for hydrogen components to be 5,000 cycles (based on 20 years of service life). A reduced number of filling cycles is permitted if usage monitoring and control systems are installed or if components are replaced before exceeding their specified service life. This is shown in Table 2, with the corresponding requirements for the draft global technical regulation.

Table 2: Comparison of service life and number of filling cycle requirements

	Regulation (EU) No. 406/2010	Draft global technical regulation
Service life	20 years	15 years
Filling cycles	5,000 cycles	#Cycles: 5,500, 7,500 or 11,000 cycles

The draft global technical regulation specifies a service life limit of 15 years for compressed hydrogen storage systems (comprising the container, thermally-activated pressure relied device, check valve and shut-off valve). Each contracting party is allowed to set their own number of filling cycles (named #Cycles in the global regulation), which is assessed by a baseline pressure cycle life test. The value of #Cycles can be 5,500, 7,500 or 11,000 cycles.

Several test procedures in the European regulation refer to multiples of the number of filling cycles when specifying a number of pressure cycles to be carried out, but principally, the regulation requires that containers are capable of reaching 15,000 cycles (i.e. 3 x 5,000 cycles) without failure, for 20 years of service life. This is assessed by the ambient temperature pressure cycle test. The test is summarised in Table 3 with the corresponding test in the draft global technical regulation. The global regulation sets a minimum number of cycles to be achieved without leakage (#Cycles) with additional assurance regarding rupture.

Table 3: Comparison of filling cycle tests and requirements

	Regulation (EU) No. 406/2010	Draft global technical regulation
Test	Ambient temperature pressure cycle	Baseline initial pressure cycle life
Procedure	Pressure cycle: ≤2 MPa and ≥1.25 x NWP for 15,000 cycles; continue until failure, or up to 45,000 cycles	Pressure cycle: ≤2 MPa and ≥1.25 x NWP for 22,000 cycles
Requirement	No failure for 45,000 cycles: leak-before-burst test not required	No rupture for [22,000] cycles and no leakage within #Cycles
	Failure by leakage permitted, but further leak-before-burst test is required	[At the time of writing, 22,000 cycles is written in square brackets, indicating that the value is under discussion]
	Leak-before-burst test: pressure cycle; ≤2 MPa and ≥1.5 x NWP for 15,000 cycles; container to fail by leakage, or to exceed 15,000 cycles without failure	

All European cycle numbers are based on service life of 5,000 cycles

There are unlikely to be significant implications for safety if these aspects of the draft global technical regulation are transposed into the European legislation: the requirements are broadly comparable (if #Cycles is set at 11,000 cycles), given the differences in service life, and might be more stringent in the draft global regulation in certain circumstances.

Contracting parties to the 1998 Agreement are drawn from different regions of the world. In these regions, there are differences in the expected worst-case lifetime vehicle range and the worst-case fuelling frequency. These were taken into account when specifying #Cycles in the draft global technical regulation. Although the draft global technical regulation does not specify conditions under which a monitoring or control systems must be used, or specify when components should be replaced, contracting parties could specify further usage constraints on vehicles in their territories (i.e. if #Cycles is specified at 5,500).

4.3.3 *Inertial loading in a crash*

Commission Regulation (EU) No. 406/2010 requires that the container mounting system is capable of withstanding certain accelerations, which are specified according to vehicle category and impact direction. The requirements are summarised in Table 4. These can be verified by testing or by calculation and are consistent with similar requirements in UNECE Regulation 110 for compressed natural gas vehicles. These requirements do not apply to vehicles that have been approved to the EC directives for frontal and side impact (96/79/EC and 96/27/EC respectively), or the equivalent UNECE regulations (UNECE Regulation 94 and 95 respectively).

The draft global technical regulation specifies requirements and tests for the integrity of the fuel system following a collision. The main impact test procedures that already apply in each jurisdiction are used, but the draft global regulation specifies limits and test procedures for the leakage of fuel from the hydrogen system and concentration in enclosed spaces. However, there are no further requirements for vehicles that are exempt from full-scale crash testing legislation that would assess the capacity of the container mounting system to withstand certain levels of acceleration.

Table 4: Accelerations specified in the Regulation (EU) No. 406/2010

Vehicle category	Acceleration	
	In the direction of travel	Perpendicular to direction of travel
M_1 and N_1	± 20 g	± 8 g
M_2 and N_2	± 10 g	± 5 g
M_3 and N_3	± 6.6 g	± 5 g

Given that there are no requirements in the draft global technical regulation on this topic, the global requirements could be transposed into the European legislation without affecting the current European requirements. Maintaining the European requirements in Table 4 might give a measure of confidence in the integrity of the container mounting system and its capacity to withstand these levels of acceleration in the event of a collision.

4.3.4 *Burst pressure*

Commission Regulation (EU) No. 406/2010 specifies burst pressure ratios for hydrogen containers according to material and container type. The burst pressure ratio is defined as the minimum actual burst pressure of the container divided by its nominal working pressure. The ratios are shown in Table 5.

Table 5: Burst pressure ratios in Regulation (EU) No. 406/2010

Construction		Container type			
		Type 1	Type 2	Type 3	Type 4
All metal		2.25			
Overwrap	Glass		2.4	3.4	3.5
	Aramid		2.25	2.9	3.0
	Carbon		2.25	2.25	2.25
	Hybrid			(i)	

(i) Consideration given to load share between different fibres based on the different elastic moduli of the fibres. Calculated stress ratios for each individual structural fibre type shall conform to the specified values.

These ratios are the main requirement for the container burst test (carried out with a new, unused vessel). The principle behind these (European) requirements is that different materials have different stress characteristics and hence the safety factor is adjusted accordingly.

The draft global technical regulation also specifies an initial burst test with a new container. In fact, three new containers are selected at random from the design qualification batch. The purpose of the test is to verify the repeatability of containers presented for design qualification and to establish the midpoint initial burst pressure, which is used during other performance tests. All containers tested must have a burst pressure within ±10% of the midpoint burst pressure and greater than or equal to 200%[2] of the nominal working pressure of the container (which corresponds to a burst pressure ratio of 2.0, regardless of the material or container type).

[2] At the time of writing, 200% is written in square brackets, indicating that the value is under discussion.

The burst pressure ratio specified in the global technical regulation is lower than all of the ratios in the European regulation. The global technical regulation is therefore less stringent than the European regulation in terms of this burst pressure requirement for new, untested containers. However, Sloan (2009) questioned the capacity of the initial burst pressure requirements to safeguard against stress rupture and fatigue throughout the service life of the container.

Burst requirements are also specified after several container tests in the European regulation and at the end of each sequential test series in the draft global technical regulation. In the European regulation, the burst pressure requirements after these container tests are relaxed compared with the requirements for new, untested, containers. This is illustrated in Table 6. A burst test is required after three container tests: the chemical exposure test; accelerated stress rupture test; and extreme temperature pressure cycle test. The requirement for the chemical exposure test corresponds to a burst pressure ratio of 1.8, regardless of container type. The requirement for the accelerated stress rupture test and the extreme temperature pressure cycle test depend on the container type and materials. For example, the ratio would be in the order of 1.9 for all carbon-wrapped containers, but would be in the order of 3 for glass-wrapped Type 4 containers.

Table 6: Container tests with burst pressure requirements in Regulation (EU) No. 406/2010

Test	Procedure	Requirement
Chemical exposure test	Pendulum impact pre-conditioning Chemical exposure Pressure cycling (≤2 MPa and ≥1.25 x NWP for 5,000 cycles) Pressure hold (1.25 x NWP for min. 24 hours until 48 hours total elapsed time) Burst test	Burst pressure ≥ 1.8 x NWP
Accelerated stress rupture test	Pressure hold (1.25x NWP for 1,000 hours at 85°C) Burst test	Burst pressure ≥ 0.85 x NWP x BPR
Extreme temperature pressure cycle test	Temperature pre-conditioning (48 hours ≥ 85°C) Pressure cycling (≤2 MPa and 1.25 x cNWP for 7,500 cycles at ≥85°C) Stabilise and temperature conditioning (48 hours ≤ -40°C) Pressure cycling (≤2 MPa and ≥NWP for 7,500 cycles at ≤-40°C) Leak test Burst test	Burst pressure ≥ 0.85 x NWP x BPR (i.e. ≥1.9125 x NWP for Carbon; ≥2.975 x NWP for Glass, Type 4; etc)

NWP is nominal working pressure and BPR is burst pressure ratio

The draft global technical regulation requires that the residual burst pressures at the end of the hydraulic and pneumatic sequential test series are within 20% of the midpoint initial burst pressure. However, both test sequences also specify a residual pressure test whereby the container must withstand 180% of the nominal working pressure for 4 minutes, before the burst test is carried out. The burst pressure measured at the end of each sequence must therefore be greater than 180% of the nominal working pressure (which corresponds to a burst pressure ratio of 1.8).

Transposing these aspects of the global technical regulation into the European legislation would result in a significant change in the approach to container burst strength. It would mean that the same burst pressure requirement is applied regardless of container materials and type, and more crucially, the requirement for the initial burst pressure of new, untested containers would be reduced compared to the current level (although the degree to which would depend on the container materials and type). If the initial burst pressure is a useful indicator of the likely strength and durability of a container during its service life, this change might reduce the long-term reliability of hydrogen containers. However, the value of the initial burst pressure level was questioned by Sloan (2009) and by participants of the subgroup on safety responsible for developing the draft global technical regulation. They emphasised the importance of container strength at the end of its service life, which the sequential tests and residual burst test are intended to evaluate.

Evidence to support or justify either approach is very limited. Hydrogen-fuelled cars are not on the road in sufficient numbers to investigate container performance. The requirements in the European regulation are part of an historical approach to container burst strength, which began many years ago with compressed natural gas containers. The draft global technical regulation specifies a new approach, but there has been very little research to validate it. This is discussed further in the next section.

Prior to the 11th meeting of the subgroup on safety a new test procedure was proposed for the draft global technical regulation to reduce the risk of long-term stress rupture. Agreement was not reached; hence the new procedure was included as an option for further development in a later phase of the global regulation. This new procedure specifies additional static pressure tests at elevated temperature. Containers constructed from carbon fibre and/or metal alloys would be excused from the test along with glass fibre composite containers with an initial burst pressure greater than 330% of the nominal working pressure.

Some materials are prone to failure if they are exposed to stresses (below their yield strength) for long periods of time. Both the European regulation and the draft global technical regulation include a time-accelerated performance test for stress rupture at high pressure. However, traditional container standards have also specified the stress ratio (for Type 2, 3 and 4 containers), defined as the stress in the fibre at burst pressure divided by the stress in the fibre at working pressure. A higher stress ratio is typically specified for materials with poorer stress rupture performance (such as glass fibre).

Neither the European regulation nor the draft global regulation specify stress ratio requirements. The European regulation specifies the burst pressure ratio as a means of capturing the stress rupture requirement (although the stress ratio and the burst pressure ratio of some containers are not the same). The draft global regulation specifies lower initial burst pressures than the European regulation for some materials and (until this new proposal) relies on the stress rupture test at elevated temperature and the general principles of sequential stress exposures to deal with stress rupture. Some participants and observers of the subgroup on safety have expressed concerns about the ability of the requirements in the global regulation to deal with stress rupture. Adopting the new test procedure may satisfy some of those concerns.

4.3.5 *Hydraulic container tests – parallel or sequential testing*

Commission Regulation (EU) No. 406/2010 includes several test procedures for hydrogen containers that are performed hydraulically. These are presented as discrete tests that can be carried out in parallel, and with a new container for each test. The requirements for each test are typically based around the prevention of leak or rupture (within a certain number of filling cycles) or the burst pressure. These are summarised in Table 7.

Table 7: Hydraulic container tests in Regulation (EU) No. 406/2010

Test	Procedure	Requirement
Impact damage test	Drop tests Pressure cycling (≤2 MPa and ≥1.25 x NWP for 15,000 cycles)	No leak or rupture within 3,000 cycles, but failure by leakage permitted in remaining cycles
Composite flaw tolerance test	Flaws cut into over-wrap Pressure cycling (≤2 MPa and ≥1.25 x NWP for 15,000 cycles)	No leak or rupture within 3,000 cycles, but failure by leakage permitted in remaining cycles
Chemical exposure test	Pendulum impact pre-conditioning Chemical exposure Pressure cycling (≤2 MPa and ≥1.25 x NWP for 5,000 cycles) Pressure hold (1.25 x NWP for min. 24 hours until 48 hours total elapsed time) Burst test	Burst pressure ≥ 1.8 x NWP
Accelerated stress rupture test	Pressure hold (1.25 x NWP for 1,000 hours at 85°C) Burst test	Burst pressure ≥ 0.85 x NWP x BPR
Extreme temperature pressure cycle test	Temperature pre-conditioning (48 hours ≥85°C) Pressure cycling (≤2 MPa and 1.25 x NWP for 7,500 cycles at ≥85°C) Stabilise and temperature conditioning (48 hours ≤-40°C) Pressure cycling (≤2 MPa and ≥NWP for 7,500 cycles at ≤-40°C) Leak test Burst test	Burst pressure ≥ 0.85 x NWP x BPR

All cycle numbers are based on service life of 5,000 cycles

The draft global technical regulation specifies a sequence of hydraulic tests performed with the same container. The container must not leak during the sequence or during a residual proof pressure test. The residual burst pressure must be within 20% of the baseline initial burst pressure. The hydraulic test sequence is shown in Table 8.

Table 8: Hydraulic container tests in draft global technical regulation

Test	Procedure	Requirement
Performance durability (Hydraulic sequential tests)	Drop tests Flaws cut into surface Pendulum impact pre-conditioning Chemical exposure Pressure hold (1.25 x NWP for 48 hours) Pressure cycling (≤2 MPa and ≥1.25 x NWP for 6,600 cycles – final 10 cycles at 1.5 x NWP with no chemicals) Pressure hold (1.25 x NWP for 1,000 hours at 85°C) Stabilise and temperature conditioning (24 hours ≤-40°C) Pressure cycling (≤2 MPa and ≥0.8 x NWP for 2,200 cycles at ≤-40°C) Stabilise and temperature conditioning (24 hours ≥85°C) Pressure cycling (≤2 MPa and 1.25 x NWP for 2,200 cycles at ≥85°C) Residual pressure test (1.8 x NWP for 4 minutes) Burst test	No leakage during the sequence Residual burst pressure within 20% baseline initial burst pressure

All cycle numbers are based on maximum permitted #Cycles: 11,000 cycles

Sequential testing is, in principle, more stringent than parallel testing (assuming that the test procedures are identical) because the stresses are compounded. The sequential test procedures in the draft global technical regulation are generally the same as the corresponding parallel tests in the European regulation, although, there are some differences in the number of pressure cycles carried out. Most notably, the European regulation specifies more pressure cycles at extreme temperatures than the draft global technical regulation. However, the container has, of course, been subjected to a range of phenomena by this point in the sequence specified in the global regulation.

Sequential testing is a relatively new method of qualifying hydrogen storage containers and there is very little published research on the outcome of such tests. The study by McDougall (2009), therefore, is an important contribution[3]. McDougall performed a programme of tests to validate SAE TIR J2579, which included hydraulic and pneumatic test sequences. However, the hydraulic test sequence in SAE TIR J2579 differs from that in the draft global technical regulation (or it did at the time of McDougall's study). For instance, it did not include a high temperature static pressure hold or any extreme temperature pressure cycling. This study cannot, therefore, be used to validate the hydraulic test sequence in the draft global technical regulation. Nevertheless, it provides a useful insight into the effects of hydraulic sequential testing on some hydrogen containers.

[3] This study is sometimes mentioned during meetings of the subgroup on safety and is usually referred to as "the Powertech report".

McDougall (2009) performed the hydraulic test sequence on a Type 3 container with a nominal working pressure of 25 MPa. Photographs showed that the container was suitable for compressed natural gas only and that it was qualified to NGV2, the American National Standard for compressed natural gas vehicle fuel containers. McDougall noted that there had been "numerous failures of this tank design in both vehicle service and in routine testing". The container failed after 42 hours of the period of ambient temperature static pressure performed after chemical exposure. This illustrates that this hydraulic sequence was capable of picking out a particularly poor container. Up to the point of this failure, the SAE TIR J2579 sequence was identical to the global regulation.

McDougall (2009) also described hydraulic sequential tests on a Type 3 hydrogen container with a nominal working pressure of 70 MPa and on a Type 4 hydrogen container with a nominal working pressure of 35 MPa. Both containers completed the test series without leakage. However, the burst pressure of each container increased with respect to the baseline following the sequential testing. The burst pressure of the Type 3 container was approximately 7 MPa above the initial burst value and the corresponding figure for the Type 4 container was 10 MPa. The actual burst pressure values were not presented in the report. In a subsequent communication, McDougall (2011) explained that these increases were due to variability in the containers, rather than any stress-relieving effects of the test.

Transposing the draft global technical regulation into the European legislation will change the nature of the hydraulic container tests in Regulation (EU) No. 406/2010. Above all, they will be carried out in sequence on a single container, but there are other differences. For instance, the number of pressure cycles at extreme temperatures would be reduced, although these cycles would be carried out on a container that had undergone various other tests. At present, there is insufficient test or real-world data to determine with certainty, which approach is more stringent, but on balance, it would appear that the global technical regulation is a greater test of a container's durability.

The hydraulic sequential test procedure in the draft global technical regulation has not been validated. That said, a similar point could be made about the discrete tests in the European legislation. These have, however, been used for many years to qualify a range of compressed gaseous storage containers. A new test procedure can be validated by checking that it displays three important characteristics:

i) The capacity to deliver repeatable results with identical products (in the same laboratory);

ii) The capacity to deliver reproducible results with identical products (in different laboratories);

iii) The capacity to distinguish between products of different quality (and particularly to eliminate those that are at risk of failing in service).

4.3.6 *Penetration test*

The European legislation specifies a penetration test (for all container types). The purpose of the test is to provide evidence that the container does not rupture when penetrated by a bullet. The container is pressurised to its nominal working pressure (±1 MPa) and penetrated by an armour piercing bullet, or impactor, with a diameter of at least 7.62 mm. It must impact the sidewall of the container at approximately 45°.

The draft global technical regulation does not include a penetration test. It was included in earlier drafts but was subsequently removed. Documents from the time suggest that it was removed from the global regulation because a justification for the test could not be found. It was reasoned that a container in service would be unlikely to be subjected to gunfire, and that there was no direct correlation to crash safety.

It seems reasonable to assume that a container is unlikely to be subjected to gunfire in normal use. That said, it would be undesirable for it to become known that hydrogen containers are at risk of rupture following gunfire (which future designs might be if a penetration test is not mandatory). In these circumstances, hydrogen vehicles might become targets for vandalism or terrorism.

The penetration test should ensure that a small puncture of the container wall will not result in catastrophic rupture. While evidence is limited at the present time, it is conceivable that a sharp object might puncture the container in a collision. If the penetration test does not deal with this crash scenario (which was suggested during the global regulation discussions), it could be amended. For instance, a larger, non-symmetrical piece of metal, rather than a bullet, could be used to penetrate the sidewall. This would increase the likelihood of rupture and hence the stringency of the test, but might better reflect the conditions in a collision.

Transposing the broader global requirements into the European legislation, while keeping the penetration test, would ensure that containers continue to prevent catastrophic rupture when penetrated by a bullet (or similar sized object). Removing the penetration test from the European legislation would improve harmonisation with other regions that do not specify this test, but might expose future containers to the risk of rupture during unforeseen punctures.

4.3.7 *Boss torque test*

The European legislation specifies a boss torque test (for Type 4 containers). A torque of twice the valve or pressure relief device installation torque specified by the manufacturer is applied to each end boss of the container; first in the direction to tighten the threaded connection, then in the direction to loosen, and finally again in the direction to tighten. A leak test, and then a burst test are carried out.

The draft global technical regulation does not include a boss torque test. A rationale for not including the test is provided, which states that over-torque of the boss is a maintenance error, which should be dealt with by training procedures, the use of appropriate tools and fail safe designs.

Transposing the broader global requirements into the European legislation, while keeping the boss torque test, would ensure that containers continue to resist the torque specified in the regulation. Removing the boss torque test from the European legislation would improve harmonisation with other regions that do not specify this test.

4.3.8 *Pressure cycling with hydrogen*

The European legislation specifies a hydrogen gas cycling test (for Type 4 containers and Type 3 with welded metal liners). The purpose of the test is to provide evidence that the hydrogen container is capable of resisting high variations of pressure when hydrogen gas is used. The container is subjected to 1,000 pressure cycles and tested for leakage. It is then sectioned, and inspected for evidence of deterioration. The European legislation also specifies a hydrogen compatibility test (for Type 1, 2 and 3 containers). The test is described in the materials testing part of the Regulation (EU) No. 406/2010, but is carried out on containers or liners. The purpose of the test is to provide evidence that containers and liners are not susceptible to hydrogen embrittlement. It is not required if the metals conform to certain ISO standards. During the test, the container is subjected to 15,000 cycles (assuming 5,000 cycles for the service life) and must not fail. These tests are summarised in Table 9.

Table 9: Pressure cycling tests with hydrogen in Regulation (EU) No. 406/2010

Test	Procedure	Requirement
Hydrogen gas cycling test	Pressure cycling (≤2 MPa and ≥NWP for 1,000 cycles) Leak test Section container and inspect liner and liner/boss interface	No leakage Liner and liner/boss interface free of any deterioration, such as fatigue cracking or electrostatic discharge
Hydrogen compatibility test	Pressure cycling (≤2 MPa and ≥1.25 x NWP for 15,000 cycles or equivalent for liners)	No failure

15,000 cycles is based on service life of 5,000 cycles

The pressure cycling tests with hydrogen gas in Table 9 apply to hydrogen containers only. The European legislation specifies separate tests for hydrogen components. However, none of the component tests require hydrogen to be used. These include an endurance test that examines whether hydrogen components (i.e. other than containers) are capable of continuous, reliable operation. A specific number of test cycles must be carried out on each component under specific temperature and pressure conditions. Hydrogen may be used in this test, but it is not mandatory and dry air, nitrogen or helium could be used instead. There are also material tests for hydrogen components, which include a hydrogen compatibility test, but this is carried out on material samples only.

The draft global technical regulation specifies a sequence of tests with hydrogen gas. The pneumatic sequential tests are performed on a hydrogen storage system comprising the container, the thermally-activated pressure relief device, the check valve and the shut-off valve. It includes two groups of 250 cycles of ambient and extreme temperature pressure cycling. The system must not leak during the sequence or during a residual proof pressure test. The residual burst pressure must be within 20% of the baseline initial burst pressure. The pneumatic test sequence is shown in Table 10.

Table 10: Pneumatic test sequence in draft global technical regulation

Test	Procedure	Requirement
Expected on-road performance (Pneumatic sequential tests)	Ambient and extreme temperature cycling (250 cycles, including 25 cycles to 1.25 x NWP at 50°C, then 25 cycles to 0.8 x NWP at -40°C and remaining 200 cycles to 1.25 x NWP at 20 (±5)°C) Extreme temperature static pressure leak/permeation test (1.15 x NWP at 55°C until steady-state permeation or 30 hours) Ambient and extreme temperature cycling (as above) Extreme temperature static pressure leak/permeation test (as above) Residual pressure test (1.8 x NWP for 4 minutes) Burst test	No leakage during the sequence Residual burst pressure within 20% baseline initial burst pressure

The main pneumatic test in the European legislation (the hydrogen gas cycling test) specifies 1,000 pressure cycles, which is twice the number of cycles in the pneumatic sequential tests in the draft global technical regulation. However, the global regulation is potentially more stringent in other ways. For instance:

- It includes 100 cycles at extreme temperatures (-40°C or 50°C) with temperature equilibrium;
- The ambient temperature cycles are performed at 125% of the nominal working pressure (compared with nominal working pressure in the European regulation);
- Fuelling must take place within 3 minutes (compared with 5 minutes in the European regulation);
- The stresses on the system are compounded with an extreme temperature static pressure leak/permeation test (which is performed separately in the European regulation)
- It examines the residual strength of the container with hydraulic proof pressure and burst tests;

Regulation (EU) No. 406/2010 also specifies a hydrogen compatibility test for containers and liners, which requires many more pressure cycles than the pneumatic test sequence in the global regulation. However, it is a material test to check for embrittlement and applies in certain circumstances only.

The pneumatic sequential tests in the draft global technical regulation are performed on the container and the main components that form the primary pressure boundary. This is a fundamental difference from the European legislation, which specifies separate tests for the container and all of the components of the system. There are also various installation requirements in the European legislation, but no tests at the system level. The draft global regulation, therefore, checks for leakage at the primary interfaces of the high-pressure system directly, whereas the European legislation relies on tested components and their correct installation to prevent such leaks.

McDougall (2009) attempted to perform the pneumatic test sequence (in SAE TIR J2579) on a Type 3 container with a nominal working pressure of 70 MPa and with an in-tank solenoid valve, pressure relief device and check valve. However, leakage was detected during the initial cool-down to reach the starting conditions for the -40°C pressure cycles. This was attributed to an internal seal failure on the "tank valve". Another system was tested with the "same component types". Once settled at -40°C, with no leakage detected, the in-tank solenoid valve failed to operate.

Both systems failed very early in the test; during the initial cool-down or just after. McDougall (2009) concluded that the temperature was the cause in both cases. He noted that the systems that failed were certified to -40°C, with no mention of process temperature limitations. The specific standards that the components were certified to were not included in the report, but McDougall (2010) reported later that the tank valve was qualified to a draft UNECE regulation on compressed gaseous hydrogen (Revision 12b, dated 2003).This document was prepared by an informal working group of UNECE WP.29 GRPE and was based on proposals developed by the partners of the European Integrated Hydrogen Project – Phase II. The draft UNECE regulation was not completed, but it was used as a basis for Commission Regulation (EU) No. 406/2010. This implies that the tank valve that failed would have been subjected to extreme temperature testing (during the endurance test), although this may not have been carried out with hydrogen.

A 35 MPa Type 4 system was also tested by McDougall (2009). The system was cycled 125 times at 50°C and 125 times at -40°C. The container then underwent a 500 hour parking performance test at 85°C and 125% nominal working pressure followed by a permeation test. This test sequence (from SAE TIR J2579) is more stringent than that specified in the draft global technical regulation (shown in Table 10). For instance, the global regulation requires fewer extreme temperature pressure cycles, and specifies ambient temperature cycles instead. Furthermore, the extreme temperature static pressure test in the global regulation is carried out at a lower temperature and pressure (55°C and 115% of the nominal working pressure) and for a shorter period (until steady-state permeation or 30 hours). The system failed during the test. The overall permeation rate exceeded the performance limit and a hydrogen leak was discovered (from a single location on the container). The failure was attributed to the high-temperature pneumatic cycling.

Transposing the draft global technical regulation into the European legislation would mean that hydrogen gas pressure cycle tests are carried out on an assembly of the main high-pressure parts of the system (comprising the container, thermally-activated pressure relief device, shut-off valve and check valve). Hydrogen pressure cycle tests are currently specified for the container only and appear to be less stringent than those proposed in the draft global regulation. Separate pneumatic pressure cycle tests are currently specified for the other components of the system, but these do not have to be performed with hydrogen. While the draft global technical regulation appears to be more stringent that the European legislation in this respect, there is insufficient test or real-world data to confirm this. Furthermore, the sequential pneumatic tests in the draft global technical regulation have not been validated. As noted in section 4.3.5, a new test procedure can be validated by checking that it displays three important characteristics:

i) The capacity to deliver repeatable results with identical products (in the same laboratory);

ii) The capacity to deliver reproducible results with identical products (in different laboratories);

iii) The capacity to distinguish between products of different quality (and particularly to eliminate those that are at risk of failing in service).

4.3.9 *Material requirements*

Commission Regulation (EU) No. 406/2010 includes material-specific requirements for containers and liners that typically refer to EN or ISO standards. For example, steels must conform to the material requirements of sections 6.1 to 6.4 of ISO 9809-1 or sections 6.1 to 6.3 of ISO 9809-2, as appropriate. Similar requirements are made for aluminium alloy, plastic liner materials, fibres and resins. The regulation also specifies various material tests for hydrogen containers (which are usually performed on a sample of container material). These are shown in Table 11. Material tests are also specified for other components of the hydrogen system. These comprise: a hydrogen compatibility test; ageing test; and ozone compatibility test.

During the 11th meeting of the hydrogen and fuel cell vehicles subgroup on safety it was agreed that the material requirements and test procedures that were, at the time, specified in the global regulation would be moved to Part A (and would therefore become recommendations only). These were subsequently removed altogether. Section A.8 in the global regulation explains that agreement could not be reached on material compatibility and hydrogen embrittlement requirements and contracting parties should continue to use their national provisions. Transposing the broader requirements of the draft global technical regulation should not, therefore, affect the material requirements and test procedures in the European legislation. However, it is likely that material compatibility and hydrogen embrittlement requirements will be developed further in a second phase of activity on the draft global technical regulation.

Table 11: Applicable material tests in Regulation (EU) No. 406/2010

Material tests	Applicable to material					
	Steel	Alum-inium alloy	Plastic liner	Fibre	Resin	Coat-ing
Tensile test	✓	✓	✓			
Charpy impact test	✓					
Bend test	✓	✓				
Macroscopic examination	✓					
Corrosion test		✓				
Sustained load cracking test		✓				
Softening temperature test			✓			
Glass transition temperature test					✓	
Resin shear strength test					✓	
Coating test						✓
Hydrogen compatibility test	✓	✓	✓	✓	✓	

Various references to international standards are provided for test procedures, also certain exemptions are specified

4.3.10 *Bonfire test*

The bonfire test in Regulation (EU) No. 406/2010 is an engulfing fire test, which requires that the container vents through the pressure relief device(s) without rupture. The container is pressurised to its nominal working pressure with hydrogen or "a gas with a higher thermal pressure build up". It is placed horizontally approximately 100 mm above a uniform fire source with a length of 1.65 m. Further instructions are given depending on the length of the container with respect to the length of the fire source. Within 5 minutes of ignition, and for the duration of the test, the temperature of at least one of the thermocouples must be at least 590°C.

The draft global technical regulation specifies a period of localised fire before the fire source is extended to produce an engulfing fire. The localised fire test was introduced because localised fires have been shown to weaken the container before the pressure relief device(s) activate (Webster, 2010). Two temperature profiles are being considered by the subgroup on safety. Figure 3 shows the original temperature profile in the draft global technical regulation and Figure 4 shows a new profile proposed by the National Highway Traffic Safety Administration (NHTSA) during the 12th meeting of the subgroup on safety. This aspect of the global regulation will be agreed at a future meeting of the subgroup on safety.

The global technical regulation requires that hydrogen is used as the test gas during the fire test. However, it also states that contracting parties under the 1998 Agreement may choose to use compressed air as an alternative test gas for certification of containers for use only within their countries or regions. Two methods of positioning the system over the initial (localised) fire source are permitted:

- Method 1 – Qualification for a generic vehicle installation

  This method is used when the hydrogen storage system is not limited to a particular vehicle. The area farthest from the thermally-activated pressure relief device is exposed to the localised fire. Only thermal shielding or other mitigation devices that are fixed directly to the container and intended for all vehicles may be used in the test.

- Method 2 – Qualification for a specific vehicle installation

  This method is used when the hydrogen storage system is intended for a specific vehicle. Vehicle components including shielding and barriers that are permanently attached to the vehicle structure may be used. However, in these circumstances, the area farthest from the thermally-activated pressure relief device is not necessarily the worst-case. The specific-vehicle worst-case must be identified, therefore, and exposed to the localised fire in this test. In addition, the container is subjected to an engulfing fire without any shielding components.

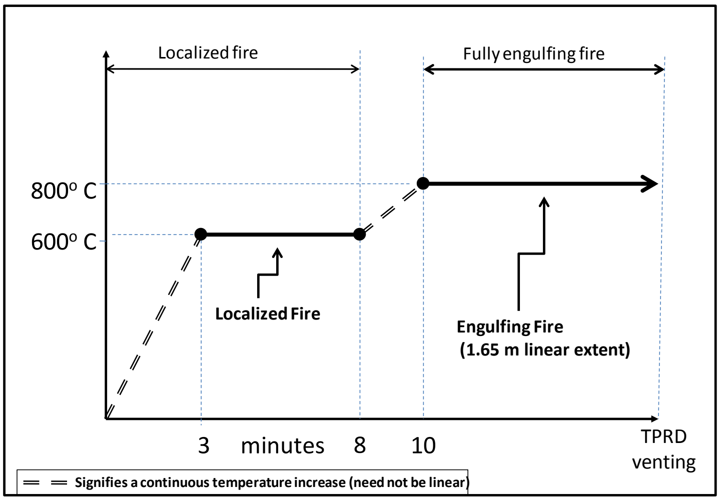

Figure 3: Fire test in the draft global technical regulation – original profile

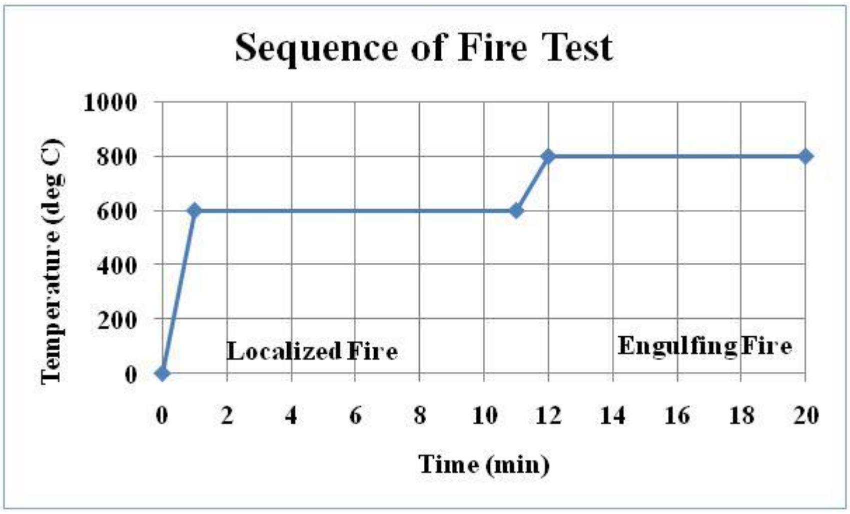

Figure 4: Fire test in the draft global technical regulation – NHTSA proposal

In the event of a fire, thermally-activated pressure relief devices are designed to release hydrogen from the storage container (in a controlled way). However, real-world failures with compressed natural gas vehicles and experiments with hydrogen containers have demonstrated that a relatively small fire can weaken container materials to the point of rupture before the temperature of the gas reaches the level needed to activate the safety device (Webster, 2010). Similar findings have been reported in vehicle-level fire tests (Scheffler, 2010).

The fire test in the draft global technical regulation is more stringent than the bonfire test in the European regulation because it includes a period of localised fire. Transposing these global requirements into the European legislation (regardless of the temperature profile that is agreed) would be likely to improve the safety of hydrogen storage systems because it would deal with a potential worst-case that is not currently examined by the (engulfing-only) bonfire test in Regulation (EU) 406/2010.

4.3.11 *Permeation test*

Commission Regulation (EU) No. 406/2010 specifies a static pressure and permeation test on a new container at 15(±2)°C. The container is pressurised to its nominal working pressure with hydrogen gas and monitored for 500 hours, or until the steady-state behaviour has lasted for 48 hours. The steady-state permeation rate must be less than 6 Ncm^3 per hour per litre internal volume of the container (Ncm^3/hr/L volume).

The draft global technical regulation specifies a sequence of tests with hydrogen gas, which includes two phases of static pressure and permeation testing. These pneumatic sequential tests are carried out on a hydrogen storage system comprising the container(s), thermally-activated pressure relief device, shut-off valve and check valve, and are summarised in Table 10 in Section 4.3.8. The static pressure and permeation tests are carried out at 55°C. In each test, the container is pressurised to 115% of the nominal working pressure and monitored until steady-state permeation, or for at least 30 hours. The maximum allowable hydrogen discharge from the storage system is either:

- R*150 mL/min where R = (Vehicle width+1)*(Vehicle height+0.5)*(Vehicle length+1)/30.4 m^3; or
- 46 mL/hr/L water capacity (provided the total capacity is less than 330L).

The pneumatic sequential tests in the draft global technical regulation replicate the worst-case service conditions that are expected for a hydrogen storage system over its service life. One of the periods of static pressure and permeation testing is carried out near the end of this sequence. It follows, therefore, that the maximum allowable permeation rate in the global regulation applies to a storage system that is in a similar condition to a system at the end if its service life. Table 12 compares the test conditions and permeation rates between the European regulation and the draft global technical regulation.

Table 12: Comparison of test conditions and allowable permeation rates

	Regulation (EU) No. 406/2010	Draft global technical regulation
Applicable vehicles	M_1, M_2 and M_3	M_1
Test piece	Container only	Storage system
Test piece condition	New	Simulated end-of-life
Testing temperature	15°C	55°C
Testing pressure	NWP	115%NWP
Testing period	500 hours or until steady-state behavior is kept for at least 48 hours	Until steady-state permeation or at least 30 hours
Maximum allowable permeation rate	<6.0 Ncm^3/hr/L internal volume of the container	R*150 mL/min where R = (Vehicle width+1)*(Vehicle height+0.5)*(Vehicle length+1)/30.4 m^3 or 46 Ncm^3/hr/L internal volume of the container

There are fundamental differences between the permeation tests in Commission Regulation (EU) No. 406/2010 compared with the draft global technical regulation. Most notably, the European regulation specifies a discrete test on a new container, whereas the global regulation specifies tests within a broader sequence of tests that are expected to simulate the worst-case service conditions for a hydrogen storage system. Very different maximum allowable permeation rates are specified, therefore, to take account of the condition of the container.

The maximum allowable permeation rate in the European regulation was derived from the findings of the HySafe permeation study[4]. The limit is essentially based on a calculation of the "safe" permeation rate at the end-of-life condition of the container. This approach and the assumptions made are described by Adams *et al.* (2011). The maximum allowable permeation rates in the draft global technical regulation were also derived largely from the findings of the HySafe study. However, the tests in the global regulation simulate the end-of-life condition of the storage system and this is reflected in the permeation rates.

The maximum allowable permeation rate in the European regulation is based on robust scientific studies. The performance limit is set at a relatively low level because the test is performed with a new container; hence it must ensure that permeation levels near the end-of-life of the container are also likely to be acceptable, given the stressful service conditions that it would be expected to be exposed to. However, there are risks with such an approach. Transposing the global requirements into the European regulation would eliminate some of the uncertainties and risks associated with the use of a new container to safeguard against permeation towards the end-of-life.

[4] HySafe: Safety of Hydrogen as an Energy Carrier (European 6th Framework Programme Network of Excellence, Contract No. SES6-CT-2004-502630)

4.3.12 *Hydrogen component tests (i.e. other than containers)*

Commission Regulation (EU) No. 406/2010 specifies detailed requirements and test procedures for the full range of hydrogen system components (such as pressure relief devices, valves, heat exchangers, refuelling connections or receptacles, pressure regulators, sensors and flexible fuel lines, etc). These are shown in Table 13.

Table 13: Applicable test procedures for components in the European legislation

	Type of test					
Hydrogen component	**Material tests**	**Corrosion resistance tests**	**Endurance test**	**Pressure cycle test**	**Internal leakage test**	**External leakage test**
Pressure relief devices	✓	✓	✓	✓	✓	✓
Automatic valves	✓	✓	✓	✓	✓	✓
Manual valves	✓	✓	✓	✓	✓	✓
Non-return valves	✓	✓	✓	✓	✓	✓
Pressure relief valves	✓	✓	✓	✓	✓	✓
Heat exchangers	✓	✓	✓	✓		✓
Refueling connections or receptacles	✓	✓	✓	✓	✓	✓
Pressure regulators	✓	✓	✓	✓	✓	✓
Sensors for hydrogen systems	✓	✓	✓	✓		✓
Flexible fuel lines	✓	✓	✓	✓		✓
Fittings	✓	✓	✓	✓		✓
Hydrogen filters	✓	✓		✓		✓
Removable storage system connectors	✓	✓	✓	✓		✓

Component tests are also specified in the draft global technical regulation, but they apply only to components that isolate the hydrogen container from the rest of the storage system (i.e. pressure relief devices, check valves and the shut off valves).

Table 14: Applicable test procedures for components in the draft global technical regulation

Tests for thermally-activated pressure relief devices	Tests for check valves and automatic shut-off valves
Pressure cycling test	Hydrostatic strength test
Accelerated life test	Leak test
Temperature cycling test	Extreme temperature pressure cycling test
Salt corrosion resistance test	Salt corrosion resistance test
Vehicle environment test	Vehicle environment test
Stress corrosion cracking test	Atmospheric exposure test
Drop and vibration test	Electrical test
Leak test	Vibration test
Bench top activation test	Stress corrosion cracking test
Flow rate test	Pre-cooled hydrogen exposure test

The component tests specified in the draft global technical regulation (for pressure relief devices, check valves and the shut off valves) are different from the European legislation, although there are some overlaps. The tests in the draft global regulation appear, on the whole, to be more comprehensive; however, they have not been validated. TRL understands that testing to validate these procedures is underway and the results will be made available to the hydrogen and fuel cell vehicles subgroup on safety.

Transposing the global requirements would have a significant effect on the component tests in the European legislation. The test procedures for pressure relief devices, check valves and the shut off valves are different, and in some cases altogether different types of tests are required. At present, there is insufficient information available to determine, with confidence, which approach is more stringent. However, the tests in the global technical regulation cover a broader range of conditions.

The European legislation currently requires various other components to undergo similar testing. These other components were not included in the global regulation because they were not thought to be “safety-critical”. Nevertheless, retaining tests on these components in the European legislation would ensure that they have met a minimum level of performance.

4.4 Liquefied hydrogen systems

A comprehensive table comparing the requirements for liquefied hydrogen systems in Regulation (EU) No. 406/2010 with those in the draft global technical regulation is presented in Appendix B. The remainder of this section discusses the key differences and their potential implications.

At present, the requirements for vehicles with liquefied hydrogen storage systems in the draft global technical regulation are optional. The contracting parties will not be obliged to transpose these requirements into their local legislation. Nevertheless, these optional requirements may be developed further during a second phase of activity on the draft global technical regulation and may be adopted as full requirements in future.

4.4.1 *Inertial loading in a crash*

The main points in the discussion in Section 4.3.3 for compressed hydrogen systems also apply here to liquefied hydrogen systems.

4.4.2 *Boil-off management system*

Commission Regulation (EU) No. 406/2010 specifies high-level requirements for boil-off under normal conditions. Namely, the boil-off gases must be rendered harmless by the boil-off management system, the system must accept the boil-off rate of the container and finally, the driver must be warned in the event of a failure of the boil-off management system.

There is no particular test of the boil-off management system, although one of the requirements of the maximum filling level test is that the filling process does not lead to any operating conditions that the boil-off management system is not designed for and cannot handle. The test is carried out by filling the container 10 times with liquid hydrogen at equilibrium with its vapour. At least one quarter of the liquid hydrogen must be emptied between each filling.

In contrast, the draft global technical regulation specifies a boil-off test. The test examines whether, during normal operation, the boil-off management system will limit the pressure in the inner storage container to the maximum allowable working pressure. After pre-conditioning, the container is filled and allowed to pressurise until the boil-off pressure is reached. The test must last for at least another 48 hours after the boil-off started and cannot be terminated before the pressure stabilises. Transposing the global requirements into the European legislation would ensure that the boil-off system is tested directly.

4.4.3 *Vacuum loss*

Commission Regulation (EU) No. 406/2010 requires that the primary pressure relief device for the inner tank limits the pressure inside the tank to no more than 110% of the maximum allowable working pressure, "even in the case of a sudden vacuum loss". Similar pressure limits are specified for the secondary pressure relief device, which vary depending on the inner tank material and type of device. However, there is no system-level test of this particular safety function.

A vacuum loss test is specified in the draft global technical regulation. The test assesses the operation of the pressure relief devices and capacity of the system to stay within its pressure limits in the event of a sudden vacuum loss due to air inflow in the vacuum jacket. This is considered to be a "worst-case" failure condition, which can result in significantly higher heat input to the inner container.

The pressure limits and performance aspects of the vacuum loss test are essentially the same as the (design) requirements specified in the European regulation. Transposing this part of the global technical regulation into the European legislation would ensure that the operation of the pressure relief devices (in the event of a sudden vacuum loss) is tested directly.

4.4.4 *Bonfire test*

The bonfire test in Regulation (EU) No. 406/2010 is an engulfing fire test, which requires that the container vents through the pressure relief device(s) without rupture. The bonfire test for liquefied hydrogen storage systems in the draft global technical regulation is essentially the same as that in the European regulation. However, during the 11th meeting of the hydrogen and fuel cell vehicles subgroup on safety, the possibility was raised of amending the test procedure to include a period of localised fire (similar to that specified for gaseous storage systems). At the time of writing, discussions were still on-going and no such amendment had been made.

4.4.5 *Material requirements*

Commission Regulation (EU) No. 406/2010 states that materials for the container and its equipment must be compatible with hydrogen, the atmosphere, and any other media they are in contact with. The regulation does not specify how these requirements must be met, but a section on materials sets out various requirements for the characteristics of materials, the certificates and proofs needed and the design calculation.

There are no material requirements for liquefied hydrogen storage systems in the draft global technical regulation. During the 11th meeting of the hydrogen and fuel cell vehicles subgroup on safety it was agreed that material requirements and test procedures would be included in Part A of the global regulation only (and would therefore become recommendations only). They were subsequently removed completely from the document. Transposing the broader requirements of the draft global technical regulation should not, therefore, affect the material requirements and test procedures in the European legislation. Material requirements for liquefied hydrogen storage systems may be developed in a second phase of activity on the draft global technical regulation.

4.4.6 *Hydrogen component tests (i.e. other than containers)*

The European legislation specifies several tests for the components of a liquefied hydrogen system, including pressure relief devices, valves, heat exchangers, refuelling connections or receptacles, pressure regulators, sensors and flexible fuel lines. These are shown in Table 15.

Table 15: Applicable test procedures for hydrogen components, other than containers

	Type of test								
Hydrogen component	**Pressure test**	**External leakage test**	**Endurance test**	**Operation-al test**	**Corrosion resistance test**	**Resistance to dry-heat test**	**Ozone ageing test**	**Temp. cycle test**	**Seat leakage test**
Pressure relief devices	✓	✓		✓	✓			✓	
Valves	✓	✓	✓		✓	✓	✓	✓	✓
Heat exchangers	✓	✓			✓	✓	✓	✓	
Refueling connections or receptacles	✓	✓	✓		✓	✓	✓	✓	✓
Pressure regulators	✓	✓	✓		✓	✓	✓	✓	✓
Sensors	✓	✓			✓	✓	✓	✓	
Flexible fuel lines	✓	✓			✓	✓	✓	✓	

Flexible fuel lines must also undergo a pressure cycle test

Component-level tests are also specified in the draft global technical regulation, but they apply only to components that isolate the hydrogen container from the rest of the storage system (i.e. the pressure relief devices and the shut off valves). The global regulation specifies the same tests as the European legislation for these components (i.e. the tests set out in Table 15), and the test procedures are identical.

Transposing the global requirements would have no effect on the component tests for pressure relief devices and shut-off valves (because they are already the same). However, the European legislation currently requires various other components to undergo similar testing. These other components were not included in the global regulation because they were not thought to be “safety-critical”. Nevertheless, retaining tests on these components in the European legislation would ensure that they have met a minimum level of performance.

4.5 Summary

Table 16 summarises the key findings from the comparative analysis of the European legislation and draft global technical regulation on hydrogen-powered vehicles.

Table 16: Comparison between the European (EU) legislation and draft UNECE global technical regulation (GTR) on hydrogen-powered vehicles

Topic	European legislation	Draft global technical regulation	Remark
Overall philosophy and approach	Specifies design and performance requirements All components tested (& in some cases specific material samples)	Some design requirements, but predominantly performance-based Tests on containers and certain safety-critical components only, with system-level tests (for gaseous systems)	EU legislation is more prescriptive, but GTR intended for all contracting parties, regardless of system
Compressed gaseous hydrogen systems			
Container classification and testing	All containers must be classified as one of four “types” defined in legislation New “types” of container unable to gain type-approval unless regulation is amended	No system of classification for containers	GTR is open to new container technologies, but relies on capability of tests to reproduce worst-case service conditions regardless of particular materials or manufacturing methods
	Performance tests applicable according to “type”	All performance tests apply to all containers	GTR requires some containers to undergo testing not required in EU legislation for their “type”
Service life and filling cycles	Service life limited to 20 years Number of filling cycles to be 5,000, but reduced number permitted if usage monitoring and control systems installed or if components are replaced Containers to be capable of reaching 15,000 pressure cycles (i.e. 3x5,000) without failure	Service life limited to 15 years Initial number of filling cycles (#Cycles) to be set by each contracting party at 5,500, 7,500 and 11,000 Containers not to leak within #Cycles for 15 years service life	Requirements are broadly comparable, given differences in service life and might be more stringent in GTR in certain circumstances GTR doesn’t specify conditions under which monitoring or control system must be used, or specify when components should be replaced, but contracting parties can

	for 20 years service life		specify usage constraints on vehicles
Inertial loading	Container mounting system must be capable of withstanding accelerations specified according to vehicle category and impact direction (unless vehicle approved to frontal and side impact directives)	Fuel system integrity requirements only, using crash tests in respective jurisdictions	Certain vehicles are exempt from frontal and side impact crash tests and hence there would be no means of assessing the integrity of the mounting system for these vehicles
Burst pressure	Burst pressure ratios specified for containers according to material and container type Ratios apply to tests on new containers, burst pressure requirements following certain container tests are relaxed slightly in comparison	Burst pressure ratio is the same, regardless of container material or type Burst pressure requirement at the end of sequential testing is 20% of initial baseline value	Burst pressure ratio in GTR is lower than all of the separate ratios in EU legislation Burst pressure requirements following exposure to container tests are broadly comparable (for certain materials and container types)
Hydraulic container tests	Several discrete hydraulic test procedures specified, carried out in parallel with new containers Requirements based around prevention of leak or rupture (within certain number of filling cycles) or the burst pressure	Sequence of hydraulic tests performed with same container Container must not leak or rupture during main sequence or residual proof pressure test and residual burst pressure to be within 20% of baseline	Sequential testing is, in principle, more stringent (assuming test procedures are identical) Sequential hydraulic test procedures in GTR are generally the same as EU legislation, although number of pressure cycles differs following chemical exposure test and during the extreme temperature pressure cycling test The sequential hydraulic test procedures have not been validated fully
Penetration test	Penetration test specified for all container types featuring 7.62mm armour piercing bullet into container at NWP	No penetration test	A container is unlikely to be exposed to gunfire, but test ensures that a small puncture of container wall does not result in catastrophic failure
Boss torque test	Boss torque test specified for Type 4 containers	No boss torque test	Boss torque test not included in GTR on basis that over-torque is a maintenance error

Pressure cycling with hydrogen	Hydrogen gas cycling test specified for Type 4 containers and Type 3 with metal liners, comprising 1,000 cycles to NWP and leak test Hydrogen compatibility test specified for Type 1, 2 and 3 containers comprising 15,000 cycles to 1.25xNWP (assuming 5,000 cycles for service life); however, test not required if certain ISO standards are met Other components required to conform to various ISO standards for hydrogen compatibility or manufacturers to perform material qualification tests	A sequence of system-level tests is specified with hydrogen gas, including two groups of 250 cycles of ambient and extreme temperature pressure cycling Ambient cycles are performed at 1.15xNWP, extreme temperature cycles at 1.15xNWP for 50°C and 0.8xNWP for -40°C	EU regulation requires more hydrogen pressure cycles, but they are performed on container only Hydrogen pressure cycles in GTR are performed on storage system comprising container and the primary closures of openings into the container, such as the TPRD, check valve, shut-off valve, etc GTR cycles include 20% at extreme temperatures The sequential pneumatic test procedures have not been validated fully
Material requirements	Material-specific requirements included for containers and liners, typically referring to EN or ISO standards Various material tests also specified for containers (usually on a material sample) and for other components	Material test procedures and requirements have not been finalised	Material test requirements in GTR will be added in a later phase
Bonfire test	Engulfing fire only	Period of localised fire is specified before fire source extended to produce engulfing fire	Localised period was introduced because localised fires can weaken container before PRD activates
Permeation test	Discrete static pressure and permeation test is specified at 15°C with container at NWP Monitoring for 500 hours or until steady-state permeation has lasted for 48 hours Limit for steady-state permeation is 6.0 $Ncm^3/hr/L$ volume of container	A sequence of system-level tests is specified with hydrogen gas, including two phases of static pressure and permeation testing at 55°C and 115%NWP Monitoring for 30 hours or until steady-state permeation (no minimum period) Maximum allowable discharge set using formula depending on vehicle dimensions; or 46 $Ncm^3/hr/L$ volume	EU test carried out on new container with allowable permeation rate set to safeguard against permeation near end-of-life GTR testing simulates condition of hydrogen storage system near end-of-life and hence permeation rates is set accordingly

Hydrogen component tests	Detailed requirements and test procedures for full range of hydrogen system components	Component tests for PRDs, check valves and shut-off valves only	GTR tests for PRDs, check valves and shut-off valves are generally more comprehensive than EU tests GTR tests have not been validated EU legislation requires some components to undergo testing that would not be required by GTR
Liquefied hydrogen systems			
Inertial loading	Container mounting system must be capable of withstanding accelerations specified according to vehicle category and impact direction (unless vehicle approved to frontal and side impact directives)	Fuel system integrity requirements only, using crash tests in respective jurisdictions	Certain vehicles are exempt from frontal and side impact crash tests and hence there would be no means of assessing the integrity of the mounting system for these vehicles
Boil-off management system (BMS)	Specifies high-level requirements for operation of BMS under normal conditions No specific test of BMS, but max filling level test requirements include that filling operation does not lead to conditions that BMS cannot handle	Boil-off test is specified to examine whether BMS will limit pressure in inner storage container to MAWP	Only the GTR tests the operation of the BMS directly
Vacuum loss	Specifies high-level requirements for PRDs to limit pressure, "even in case of a sudden vacuum loss" No vacuum loss test	Vacuum loss test is specified to assess the function of the PRDs in the event of sudden vacuum loss due to air inflow in the vacuum jacket	Only the GTR tests directly the operation of the PRDs in the event of sudden vacuum loss
Material requirements	Materials of container and its equipment to be compatible with hydrogen, the atmosphere and any other media, if they are in contact No specific material tests, but manufacturer is responsible for ensuring products show required properties and resist thermal, chemical and mechanical stresses	No material requirements	Material test requirements in GTR will be added in a later phase

Hydrogen component tests	Component-level tests are specified for PRDs, valves, heat exchangers, refuelling connections or receptacles, pressure regulators, sensors and flexible fuel lines	Closures that isolate liquid hydrogen from the rest of the system (PRDs and shut-off valves) are subjected to same tests as Regulation 406/2010	Several hydrogen components would be outside the scope of the GTR (but they may not be safety-critical)

5 Conclusions and further work

1. A comprehensive analysis was carried out to compare the European legislation for hydrogen-powered vehicles (Regulations (EC) No. 79/2009 and (EU) No. 406/2010) with the draft UNECE global technical regulation. This report presented the findings of the work and included:
    a. Detailed tables (in the appendices) comparing each technical requirement in Regulation (EU) No. 406/2010 with the corresponding requirement in the draft global regulation (where available);
    b. A discussion of the key differences and potential implications summarised in a table (in Section 4.5).
2. Overall, the work showed that there are fundamental differences between the European legislation and the draft global technical regulation. There are insufficient tests or real-world data to determine, with certainty, which is more stringent. There are aspects of a hydrogen storage system and its installation that are regulated in Europe, but are not included in the draft global technical regulation. However, the performance requirements in the global regulation appear, on balance, to be more stringent than those in the European legislation. That said, the penetration test is a potentially significant omission from the draft global technical regulation. Hydrogen containers may be unlikely to experience gunfire during their service life, but there could be implications for security if future containers were to become susceptible to rupture during gunfire. In these circumstances, hydrogen vehicles might become targets for vandalism or terrorism.
3. The performance tests in the draft global technical regulation (particularly those for compressed hydrogen storage systems) represent a new approach to the qualification of hydrogen storage systems. The test procedures were derived from similar tests in SAE TIR J2579; however, the specific procedures in the draft global technical regulation have not been validated.
4. The draft global technical regulation was developed by the UNECE Informal Group on Hydrogen and Fuel Cell Vehicles – Subgroup on Safety. This subgroup included several European stakeholders. Nevertheless, further consultation with European stakeholders would give them the opportunity to comment on the differences between the European legislation and the draft global technical regulation highlighted in this report.
5. A programme of experiments to validate the test procedures in the draft global technical regulation would develop the knowledge on the testing of hydrogen storage systems and would improve the understanding of the potential implications of transposing these procedures into the European legislation.
6. A new test procedure can be validated by checking that it displays three important characteristics:
    a. The capacity to deliver repeatable results with identical products (in the same laboratory);
    b. The capacity to deliver reproducible results with identical products (in different laboratories);
    c. The capacity to distinguish between products of different quality (and particularly to eliminate those that are at risk of failing in service).
7. The co-chairs, co-sponsors, European Commission and other stakeholders have expressed a strong interest in initiating a new programme of validation to further assess the draft global technical regulation and to provide a robust rationale for the requirements.

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Appendix A Compressed (gaseous) hydrogen systems

This appendix compares Annex IV in Regulation (EU) No. 406/2010 with equivalent requirements in the draft global technical regulation.

A.1 Part 0 - General

(EU) No. 406/2010 (Annex IV)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
2.	GENERAL REQUIREMENTS			
2.1.	Components to be kept to a minimum compatible with safety and correct functioning of system		No similar requirement in draft GTR	
2.2.	Manufacturer to ensure materials used in hydrogen component or system are compatible with hydrogen			There is no high-level, basic requirement for materials to be compatible with hydrogen in the draft GTR; material requirements have been deferred to a later phase of GTR activity
2.3.	Material compatibility with service conditions to be ensured and demonstrated by material tests in Parts 2 and 3 [of Annex IV of EU regulation]			See above
2.4.	Hydrogen components to be classified with regard to NWP and function according to definitions in Article 1 [i.e. Class 0, Class 1 or Class 2]		No requirement for pressure classification in draft GTR	
2.5.	Temperature range to be in accordance with section 2.7.5 [see below]		No requirement for temperature range in draft GTR	
2.6.	Documentation and test reports to be sufficiently detailed to allow third party facility to reproduce results		No similar requirement in draft GTR	

2.7.	**Service conditions** Service life to be specified by manufacturer and not to exceed 20 years	B.5.1	**Compressed hydrogen storage system** Service life to be 15 years or less	The EU regulation specifies a longer service life than the draft GTR
2.7.1.	*Service life* Service life to be specified by manufacturer and not to exceed 20 years		See above	
2.7.2.	*Working pressure* NWP to be specified for hydrogen components and systems and MAWP specified for components downstream of first pressure regulator MAWP to be equal to or exceed set pressure of overpressure protection specified in section 1.8. of Part 1 [of Annex IV].	B.5.1	**Compressed hydrogen storage system** All new compressed hydrogen storage systems to have NWP of 70 MPa or less	The EU regulation does not specify a limit for the NWP There is no high-level requirement for manufacturers to specify the NWP in the draft GTR, but it must be included on the container label
		B.5.1.6	**Labelling** Label to include NWP [amongst other information]	
		B.5.2.1.2	**Overpressure protection for low pressure system** Hydrogen system downstream of pressure regulator to be protected against overpressure due to failure of pressure regulator Pressure of overpressure protection device to be lower than or equal to MAWP for appropriate section of hydrogen system	The GTR specifies a test procedure (B.6.1.6), whereby the system is visually inspected for compliance
2.7.3.	*External surfaces* Effects of various materials, substances or environmental conditions on external surfaces of hydrogen components to be considered		No similar requirement in draft GTR	

2.7.4.	*Gas composition* Compressed hydrogen gas for testing to comply with, or be of greater purity than Type 1, Grade A gas in ISO/TS 14687-2		No specific requirement for composition of test gas in draft GTR	This might affect reproducibility between laboratories
2.7.5.	*Temperatures* Normal operating temperature for materials used and also average gas temperature to be in range -40°C to +85°C [certain exceptions are specified]		No similar requirements for material temperatures or for gas temperatures in draft GTR, but extreme temperature cycling is included in the performance tests	
2.7.6.	*Filling cycles* 5,000 cycles [A reduced number may be specified if usage monitoring/control installed or if service life is reduced]	B.5.1.1.2	**Baseline initial pressure cycle life** Leakage shall not occur within #Cycles, where #Cycles is set individually by each contracting party at 5,500, 7,500 or 11,000 cycles for a 15 year service life	The number of filling cycles that are specified is used to determine the number of cycles used in test procedures Principally, the EU regulation requires that containers are capable of reaching 15,000 cycles (i.e. 3 x 5,000 cycles) without failure, for 20 years of service life The GTR allows contracting parties to specify 11,000 cycles for 15 years service life and is, therefore, broadly comparable
2.7.7.	*Duty cycles* 50,000 [A reduced number may be specified if usage monitoring/control installed or if service life is reduced]		No similar requirement in draft GTR	A duty cycle means one start up and shut down cycle of the hydrogen conversion system, there are no references to duty cycle in the GTR

A.2 Part 1 – Requirements for the installation of hydrogen components and systems designed to use compressed (gaseous) hydrogen

(EU) No. 406/2010 (Annex IV)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
1.	GENERAL REQUIREMENTS			
1.1.	Reasonable precautions taken to avoid failure of other circuits affecting hydrogen system		No similar requirement in draft GTR	
1.2.	Hydrogen system pressurised to NWP using 100% hydrogen and tested for leakage for 3 minutes [“Hydrogen system” is not defined and there is no reference to a test procedure]	B.5.1.3.1	**Proof pressure test (Pneumatic sequential tests)** System pressurised to 150%NWP according to procedure in B.6.2.3.1	B.6.2.3.1 (proof pressure test) in draft GTR specifies non-corrosive fluid rather than hydrogen, target pressure is held for at least 30 seconds only However, hydrogen storage system (comprising container, PRDs and all components, fittings and fuel lines that isolate hydrogen from remainder of fuel system and the environment) must not leak during a sequence of tests performed with hydrogen gas, including ambient and extreme temperature gas pressure cycling and extreme temperature static pressure tests
		B.5.2.1.5	**Fuel system leakage** The hydrogen fuelling line and the hydrogen system(s) downstream of the main shut off valve(s) shall not leak, compliance to be verified at NWP (B.6.1.5 test procedure)	B.6.1.5 specifies a vehicle-level test procedure for fuel line leakage at accessible sections of fuel lines. However, the draft GTR does not specify a test period for the fuel line leakage test – if a gas leak detector is used (rather than leak detecting liquid), the detector must be operated for at least 10 s

1.3.	No hydrogen allowed in enclosed or semi-enclosed spaces in the event of leaking or venting	B.5.2.1.3.1	**Pressure relief systems** Hydrogen gas from TPRDs not to be directed into enclosed or semi-enclosed spaces (or to wheel housings, gas containers, or forwards from vehicle, or horizontally from back or sides) Other PRDs not to be directed towards electrical terminals, to passenger or luggage compartments, wheel housing or gas containers	The GTR specifies a test procedure (B.6.1.6), whereby the system is visually inspected for compliance
		B.5.2.1.4.1	**Protection against flammable conditions: single failure conditions** Hydrogen leakage and/or permeation from hydrogen storage system not to directly vent to the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within vehicle that contain unprotected ignition sources	Further requirements are specified in the draft GTR to limit hydrogen concentration in air in the event of any single failure downstream of the main shut off valve and for the provision of warnings
1.4.	Any hydrogen components mounted in the passenger or luggage compartment that could leak to be enclosed in gas tight housing in accordance with section 10		No requirement for gas tight housing in draft GTR	The draft GTR does not require gas tight housing to be installed; however, requirements are specified to limit hydrogen concentration in the event of a single failure of the system
1.5.	Minimum pressure of 0.2 MPa to be maintained at ambient temperature		No requirement for minimum pressure to be maintained by the system in draft GTR	
1.6.	All PRDs, safety components, etc to be protected against unauthorised interference		No requirement for protection against unauthorised use in draft GTR	
1.7.	Automatic valve to switch to safest mode if activation fails		No requirement for automatic valve to switch to safest mode in draft GTR	
1.8.	Hydrogen system downstream to be protected against overpressure If overpressure protection device used,	B.5.2.1.2	**Overpressure protection for low pressure system** Hydrogen system downstream of pressure	The GTR specifies a test procedure (B.6.1.6), whereby the system is visually inspected for compliance

	pressure to be set lower than or equal to MAWP for appropriate section of hydrogen system		regulator to be protected against overpressure due to failure of pressure regulator Pressure of overpressure protection device to be set lower than or equal to MAWP for appropriate section of hydrogen system	
1.9.	System provided to detect failure in either circuit of heat exchanger		No requirement for such a system in draft GTR	
2.	INSTALLATION OF CONTAINER			
2.1.	Integrated function and container function requirements fulfilled for container or container assembly			
2.2.	Container or assembly to be mounted to absorb accelerations specified, depending on vehicle category (demonstrated by testing or calculation)		No similar requirement to assess mechanical integrity of container mountings in draft GTR	The draft GTR specifies crash tests already applied in respective jurisdictions (for fuel system integrity), but there are certain vehicles that are exempt from such tests
2.3.	2.2 does not apply if vehicle is approved to 96/27/EC and 96/79/EC			
2.4.	Fire protection to be formed of PRDs	B.5.1.4	**Verification test for service terminating performance in fire** Fire test procedures (B.6.2.5) specified with TPRD required to activate [See below for section 5]	There is no separate requirement in the draft GTR to fit a PRD for fire protection, but the requirements for the fire test state that a TPRD must activate and release the gases
2.5.	No installation of containers with non-metallic liners in poorly ventilated areas unless integrated into system that vents permeated hydrogen (e.g. gas tight housing)		No similar requirement in draft GTR	
3.3.	REMOVAL OF STORAGE SYSTEM			
3.1. to 3.14.	Requirements for removable storage systems		No similar requirements [Part A states that GTR applies only to	EU regulation includes design requirements but does not specify any particular test

			storage systems securely attached within a vehicle throughout its service life and does not apply to storage systems intended to be exchanged in refuelling]	procedures for removable storage systems (except in Part 3 of Annex IV, which specifies test cycles for removable storage system connectors)
4.	AUTOMATIC VALVE(S) OR NON-RETURN VALVE(S) FOR ISOLATING A CONTAINER OR CONTAINER ASSEMBLY OR PROPULSION SYSTEM			
4.1. to 4.7.	Refer to (design) requirements in Regulation (EC) No. 79/2009 and also specify certain (design) requirements for various automatic valves		No similar requirements in draft GTR	
5.	PRESSURE RELIEF DEVICE(S)			
5.1.	Non-reclosing TPRDs required for compressed gaseous hydrogen containers [This is a design requirement for the fitment of a TPRD – the regulation specifies later a bonfire test and performance requirement]	B.5.1.4	**Verification test for service terminating performance in fire** Fire test procedures (B.6.2.5) specified with TPRD required to activate: “A TPRD must release the contained gases in a controlled manner without rupture”	There is no separate requirement in the draft GTR to fit a TPRD, but the requirements for the fire test state that a TPRD must activate and release the gases
5.2.	PRD to be installed such that hydrogen discharges into an atmospheric outlet that vents outside the vehicle		No basic requirement to discharge hydrogen into an outlet that vents outside the vehicle, but requirements prohibit discharges in certain directions or towards certain components [see below]	
5.3.	Not possible to isolate PRD from container due to normal operation or failure of another component		No requirement regarding the isolation of PRD in draft GTR	
5.4.	Hydrogen gas discharge not be directed to: electrical terminals, switches or ignition sources; towards any class 0 (i.e. high pressure) component; forward from the vehicle, or horizontally from the back or sides	B.5.2.1.3.1	**Pressure relief systems** Hydrogen gas from TPRDs not to be directed into enclosed or semi-enclosed spaces (or to wheel housings, gas containers, or forwards from vehicle, or	Visual inspection test procedure applies (B.6.1.6)

	of the vehicle		horizontally from back or sides); Other PRDs not to be directed towards electrical terminals, passenger or luggage compartments, wheel housing or containers	
5.5.	Internal dimensions of vent cannot impede function of PRD		No similar requirement in draft GTR regarding dimensions of PRD	
5.6.	Vent of PRD to be protected against blockage	B.5.2.1.3.1	**Pressure relief systems** Outlet of vent line, if present, to be protected, e.g. by a cap	Visual inspection test procedure applies (B.6.1.6)
5.7.	Outlet of PRD to be oriented such that gas flow does not impinge on other containers if vent becomes detached from PRD	B.5.2.1.3.1	TPRDs and PRDs not allowed to discharge towards hydrogen gas containers	GTR does not mention detachment of vent from PRD
6.	PRESSURE RELIEF VALVE(S)			
6.1. to 6.4.	6.1. to 6.3. same requirements as 5.2. to 5.3. for PRDs (i.e. hydrogen to be discharged outside vehicle, no possibility to isolate PRV and discharge not to be directed towards electrical terminals, passenger or luggage compartment, wheel housing or any high pressure component) 6.4. same as 5.6. (i.e. vent protected from blockage)	B.5.2.1.3.1	**Pressure relief systems** Other PRDs (i.e. not TPRDs) not to be directed towards electrical terminals, to passenger or luggage compartments, wheel housing or gas containers	Visual inspection test procedure applies (B.6.1.6)
7.	RIGID AND FLEXIBLE FUEL LINES			
7.1. to 7.7.	Various design requirements specified for the installation of rigid and flexible fuel lines		No similar requirements for fuel lines in draft GTR	
8.	FITTINGS BETWEEN HYDROGEN COMPONENTS			
8.1. to 8.3.	Various design requirements specified for the fittings and joints between hydrogen		No similar requirements for fittings and joints in draft GTR	

	components			
9.	REFILLING SYSTEM			
9.1.	Receptacle to be secured against maladjustment and rotation and protected from unauthorised interference, dirt and water and safe against foreseeable handling errors	B.5.2.1.1.3	**Fuelling receptacle requirements** Receptacle to be mounted to vehicle to ensure positive locking of the fueling nozzle and receptacle to be protected from tampering and ingress of dirt and water	Compliance determined by visual inspection for both EU regulation and GTR
9.2.	Receptacle to be installed such that access for refilling not required in any unventilated compartment	B.5.2.1.1.4	**Fuelling receptacle requirements** Receptacle not to be installed in passenger and luggage compartment and other places where hydrogen gas could accumulate and where ventilation is not sufficient	See above
9.3.	Receptacle not to be mounted in energy absorbing parts	B.5.2.1.1.4	**Fuelling receptacle requirements** Receptacle not to be mounted in energy absorbing parts	See above
9.4.	NWP of receptacle equal to NWP of Class 0 (i.e. high pressure) hydrogen components upstream of and including first pressure regulator		No similar requirement in draft GTR	
9.5.	Propulsion system or energy conversion system excluding safety devices no to operate during refuelling and vehicle to be immobilized		No similar requirement for operation of vehicle during refueling	
9.6.	Label(s) to be provided close to receptacle showing: H_2 gas 'xx' MPa	B.5.2.1.1.2	**Fuelling receptacle requirements** Label to be provided close to receptacle showing: Fuel type, NWP, date of removal from service of containers	EU regulation does not require date of removal from service of containers to be shown on fuelling port label

	No similar requirement in EU No. 406/2010, but EC No. 79/2009 requires non-return valve (or valve with same function) integrated into refuelling connection or receptacle	B.5.2.1.1.1	**Fuelling receptacle requirements** Fuelling receptacle to prevent reverse flow to the atmosphere	
10.	GAS TIGHT HOUSING			
10.1. to 10.5.	Various design requirements specified		No requirements for gas tight housing in draft GTR	
11.	ELECTRICAL INSTALLATION			
11.1. and 11.2.	Protection against overloads to be provided and power line connections to be tight against ingress of hydrogen		No requirements for electrical installation in draft GTR	
12.	SAFETY INSTRUMENTED SYSTEMS			
12.1. and 12.2.	Systems shall be fail-safe or redundant and special requirements in Annex VI (Safety requirements of complex electronic vehicle control systems) to apply if fail-safe of self-monitoring electronic systems		No requirements for safety instrumented systems in draft GTR	
13.	REQUIREMENTS FOR INSPECTION OF HYDROGEN SYSTEM			
13.1.	Each system inspected at least every 48 months after date of entry into service and at time of any re-installation		No similar requirement for inspection in draft GTR	Section A of GTR includes an ‘advisory’ which states that regulatory agencies and manufacturers are expected to monitor condition and performance of storage systems during service life
13.2.	Inspection to be performed by a technical service		No similar requirement in draft GTR	

A.3 Part 2 – Requirements for hydrogen containers designed to use compressed (gaseous) hydrogen

(EU) No. 406/2010 (Annex IV)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
1.	INTRODUCTION			
1.1.	Containers to be classified to types specified in Regulation (EC) No. 79/2009 (i.e. Types 1, 2, 3 or 4)		No requirement for container classification in draft GTR	Performance-based approach of GTR does not distinguish between container types
2.	GENERAL REQUIREMENTS			
2.1.	Manufacturer is free to design the shape of container provided that it meets the technical requirements		No requirement for container shape	Implies that any shape possible provided that performance requirements are met
2.2.	**Container assembly**			
2.2.1.	Assembly to be type-approved as one container if both the assembly and the constituent containers meet section 3 (technical requirements) and section 4 (tests procedures)		No similar requirement	There are no specific instructions for assemblies in draft GTR B.5.1 refers to the hydrogen storage system, defined as "high pressure storage container(s) and primary closure devices for openings into the high pressure storage container(s)" The baseline initial burst pressure test (B.5.1.1.1), the baseline initial pressure cycle life test (B.5.1.1.2) and the verification tests for performance durability (B.5.1.2) refer to containers, while the verification test for expected on-road performance (B.5.1.3) refers to the hydrogen storage system
2.2.2.	Alternatively, assembly to be type-approved as one container if the assembly meets sections 3 and 4 (the constituent containers need not fulfil all of the provisions in section 3 and 4 provided that the assembly does)		No similar requirement	
2.2.3.	Assembly to fulfil the requirements of sections 4.2.4. (bonfire), 4.2.10. (impact damage) and 4.2.11. (leak), notwithstanding the above		No similar requirement	

2.2.4.	Maximum four containers per assembly		No similar requirement	No limits are specified in the draft GTR for the number of containers in a hydrogen storage system
2.2.5.	Flexible fuel lines not to be used as integral interconnecting fuel lines in an assembly		No similar requirement	
3.	TECHNICAL REQUIREMENTS			
3.2.	**Fire protection** Container to be protected from rupture when exposed to fire and arrangement of fire protection system to be specified	B.5.1.4	**Verification test for service terminating performance in fire** Fire test (B.6.2.5.) specified with TPRD required to activate [No equivalent high-level requirement]	The EU regulation also requires a bonfire test, although it is not specified here
3.3.	**Opening threads** Openings with tapered or straight threads may be used and threads to comply with recognised international or national standard		No thread requirements	
3.4.	**Exterior environmental protection** Application process (of coatings) shall not adversely affect the mechanical properties Coating to facilitate in-service inspection Manufacturer shall provide guidance on coating treatment during such inspection		No similar requirement	
3.5.	**Material requirements**			
3.5.1.	Materials to be suitable for service conditions in section 2.7 (i.e. in Part 0) and no incompatible materials to be in contact [Material tests are specified in Section 4]		No similar requirement	All material compatibility and hydrogen embrittlement requirements have been deferred until Phase 2 of the GTR activity

3.5.2.	*Steel* Steels for containers and liners to conform to material requirements of sections 6.1 to 6.4 of ISO 9809-1 or sections 6.1 to 6.3 of ISO 9809-2 as appropriate Stainless steels for containers and liners shall conform to sections 4.1 to 4.4 of EN 1964-3 Welded stainless steels for liners of type 3 containers shall conform to sections 4.1. to 4.3. of EN 13322-2 as appropriate		No similar requirement	
3.5.3.	*Aluminium alloy* Aluminium alloys for containers and liners to conform to material requirements of sections 6.1. and 6.2. of ISO 7866. Welded aluminium alloys for liners of type 3 containers to conform to sections 4.2. and 4.3. of EN 12862.		No similar requirement	
3.5.4.	*Plastic liner materials* The material may be thermosetting or thermoplastic		No similar requirement	
3.5.5.	*Fibres* Published specifications for composite materials including principle test results and recommendations for storage, conditions and shelf life to be kept on file by manufacturer for intended life of container Fibre manufacturer’s certification that each shipment conforms to product specifications to be kept on file for intended life of each batch		No similar requirements	

<table>
<tr><td>3.5.6.</td><td>Resins

Polymeric material for impregnation of fibres may be thermosetting or thermoplastic resin</td><td></td><td>No similar requirement</td><td></td></tr>
<tr><td>3.6.</td><td>Burst pressure ratios

The minimum burst pressure ratios, i.e. the minimum actual burst pressure of the container divided by its nominal working pressure shall not be less than the values in Table IV.3.6

<table>
<tr><td colspan="2"></td><td colspan="4">Container type</td></tr>
<tr><td colspan="2">Construction</td><td>Type 1</td><td>Type 2</td><td>Type 3</td><td>Type 4</td></tr>
<tr><td colspan="2">All metal</td><td>2.25</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Overwrap</td><td>Glass</td><td></td><td>2.4</td><td>3.4</td><td>3.5</td></tr>
<tr><td>Aramid</td><td></td><td>2.25</td><td>2.9</td><td>3.0</td></tr>
<tr><td>Carbon</td><td></td><td>2.25</td><td>2.25</td><td>2.25</td></tr>
<tr><td>Hybrid</td><td></td><td colspan="3">(i)</td></tr>
</table>
(i) Consideration given to load share between different fibres based on the different elastic moduli of the fibres. Calculated stress ratios for each individual structural fibre type shall conform to the specified values</td><td>B.5.1.1.1</td><td>Baseline initial burst pressure

Three new containers randomly selected from design qualification batch of at least 10 containers

Manufacturer to supply documentation (measurements and statistical analyses) that establishes the midpoint burst pressure of new storage containers, BP_o

All containers tested must have burst pressure within ±10% of BP_o and ≥ 200% NWP

[At the time of writing, the 200%NWP value was in square brackets and designated an “open item” for further discussion at a future meeting]</td><td>The EU regulation specifies burst pressure ratios according to material and container type whereas the draft GTR sets a burst pressure limit that is applicable for all materials and types

The draft GTR appears to be less stringent, particularly for some materials, although the requirements for metal and carbon are closer to the EU requirement

This refers to the initial burst pressure only; burst pressure is also assessed during/after container testing</td></tr>
<tr><td>3.7.</td><td>Container manufacturing requirements

Various container manufacturing requirements to be met depending on container type (i.e. type 1 or type 2, 3 and 4)</td><td></td><td>No similar requirements</td><td></td></tr>
<tr><td>3.8.</td><td>Container markings

Manufacturer to provide permanent markings with font 6mm or greater on each container (or outer surface of permanently encapsulated containers)

Markings can be labels incorporated into resin coatings, adhesive labels, low stress</td><td>B.5.1.6</td><td>Labelling

Label to be permanently affixed on each container with at least the following: name of manufacturer, serial number, date of manufacture, NWP, type of fuel, and date of removal from service

Label to remain in place and be legible for</td><td>The draft GTR does not specify a font size for the label

The EU regulation requires the number of filling cycles to be included on the label

GTR implies that contracting parties may specify additional labeling requirements</td></tr>
</table>

	stamps or any combination Adhesive labels to conform to ISO 7225, or equivalent Multiple labels allowed but not obscured by mounting brackets Marking should show EC type-approval mark and: name of manufacturer; serial number; label as section 3.2 of Annex V; NWP at 15°C; year and month of manufacturer, do not use after yyyy/mm; and number of filling cycles xxxxxx		duration of recommended service life of container	
3.9.	**Batch test requirements**			
3.9.1. and 3.9.1	Detailed specifications for frequency of batch tests and instructions in the event of any failure to meet requirements		No batch test requirements in the draft GTR	
3.10.	**Production examination and test requirements** Detailed requirements for production examinations and tests		No production examination and test requirements	
3.11.	**Modifications** May be approved to reduce test programme specified in Table IV.3.11 Major changes not covered by table to be subjected to full approval testing		No similar requirements regarding modifications in draft GTR	
4.	TEST PROCEDURES			
4.1	**Material tests** Material tests to be carried out according to test procedures in Table IV.4.1 [11 tests are listed and a tick indicates		No material tests or requirements	All material compatibility and hydrogen embrittlement requirements have been deferred until Phase 2 of the GTR activity

	whether each test is applicable to each of the 6 materials that are also listed]			
4.1.1.	*Tensile test*			
4.1.1.1.	Sampling Applies to type 4 containers only Applies to plastic liner materials only Type-approval testing: 2 liners			
4.1.1.2.	Procedure Mechanical properties of materials tested at -40°C to ISO 527-2			
4.1.1.3.	Requirement Test results to be within range specified by manufacturer in appendix to information document			
4.1.1.4.	Results Tensile yield strength and ultimate elongation of plastic liner materials to be presented in test summary			
4.1.2.	*Softening temperature test*			
4.1.2.1.	Sampling Applies to type 4 containers only Applies to polymeric materials only Type-approval testing: 1 liner Batch testing: 1 liner			
4.1.2.2.	Procedure			

	Softening temperature of polymeric materials form finished liners to be determined based on A50 method in ISO 306			
4.1.2.3.	Requirement Softening temperature to be ≥100°C			
4.1.2.4.	Results Softening temperature to be presented in test summary			
4.1.3.	*Glass transition temperature test*			
4.1.3.1.	Sampling Applies to type 2, 3 and 4 containers only Applies to composite resin materials only Type-approval testing: 3 samples			
4.1.3.2.	Procedure Glass transition temperature of resin materials determined with ASTM D3418			
4.1.3.3.	Requirements Test results to be within range indicated by manufacturer in appendix to information document set out in Part 1 to Annex II			
4.1.3.4.	Results To be documented in test report and presented in test summary Glass transition temperature presented to be the minimum measured value			

4.1.4.	*Resin shear strength test*			
4.1.4.1.	Sampling Applies to type 2, 3 and 4 containers only Applies to composite resin materials only Type-approval testing: 3 samples			
4.1.4.2.	Procedure Resin materials to be tested on sample coupon representative of the over-wrap to ASTM D2344/D2344M			
4.1.4.3.	Requirement After boiling in water for 24 hours the minimum shear strength of the composite shall be 13.8 MPa			
4.1.4.4.	Results Minimum resin shear strength to be presented in a test summary			
4.1.5.	*Coating test*			
4.1.5.1.	Sampling Applies to all container types where exterior environmental protective coating used Number of samples to be tested for type-approval as specified in appropriate standards			
4.1.5.2.	Procedure and Requirement a) Adhesion strength to ISO 4624, using method A or B, coating to exhibit			

	adhesion rating of 4 b) Flexibility to ASTM D522, using method B with 12.7 mm mandrel at specified thickness at -20°C, no visible cracks on coating c) Impact resistance to ASTM D2794, coating at room temperature to pass a forward impact test of 18 J d) Chemical resistance to ASTM D1308, using open spot test method and 100 hours exposure to a 30% sulphuric acid solution and 24 hours exposure to a polyalkalene glycol, with no evidence of lifting, blistering or softening of coating Adhesion to meet rating of 3 when tested to ASTM D3359, but test not necessary of test to section 4.2.6 carried out e) Light and water exposure to ASTM G154 for exposure of 1,000 hours, with no evidence of blistering Adhesion to meet rating of 3 when tested to ISO 4624, and 20% maximum gloss allowed f) Salt spray exposure to ASTM B117, for exposure of 500 hours, undercutting not to exceed 3mm at scribe mark, no evidence of blistering Adhesion to meet rating of 3 when tested to ASTM D3359 g) Resistance to chipping at room temperature to ASTM D3170, coating to have rating of 7A or better and no			

	exposure of substrate			
4.1.5.3.	Results To be presented in test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.1.6.	*Coating batch test*			
4.1.6.1.	Sampling Applies to all container types where exterior environmental protective coating used Number of samples to be batch tested according to section 3.9.1			
4.1.6.2.	Procedure and Requirement a) Coating thickness measurement to ISO 2808 with thickness meeting design requirements b) Adhesion strength to ISO 4624 using Method A or B with coating adhesion rating of 4			
4.1.6.3.	Results To be presented in test summary and manufacturer to keep coating thickness and adhesion strength values on file for service life of container			
4.1.7.	*Hydrogen compatibility test*	B.5.1.3.2	Ambient and Extreme Temperature Gas Pressure Cycling Test	
4.1.7.1.	Sampling Applies to type 1, 2 and 3 containers Type-approval testing: 3 containers or		No sampling requirements	The EU regulation requires hydrogen compatibility testing for Type 1,2, and 3 containers only whereas the draft GTR requirements apply to all container types; however, the EU regulation also specifies a

	liners			"hydrogen gas cycle test" (section 4.2.14) applicable to Type 4 containers and Type 3 with welded metal liners Some "material tests" in EU regulation are carried out on complete containers
4.1.7.2.	Procedure At ambient temperature, hydrogen used to pressure cycle for 3x number of filling cycles (according to section 2.7.6), either: a) The container between ≤2.0 MPa and ≥1.25x NWP; or b) The liner between pressure levels that provide equivalent liner wall stress present at ≤2.0 MPa and ≥1.25x NWP for the container	B.5.1.3.2	The system will be pressure cycled using hydrogen gas for 500 cycles in accordance with B.6.2.4.1 test procedure • Pressure cycles divided into two groups: half of the cycles (250) performed before exposure to static pressure and remaining half (250) will be performed after initial exposure to static pressure • In each group, 25 cycles to be performed to 125%NWP at 50°C and 95% relative humidity, then 25 cycles to 80%NWP at -40°C and remaining 200 cycles to 125%NWP at 20(±5)°C • Hydrogen gas fuel temperature to be -40(±5)°C • During first group of 250 pressure cycles, 5 cycles to be performed after temperature equilibrium of the system at 50°C and 95% humidity; 5 cycles after equilibrium at -40°C; and 5 cycles with fuel temperature of 20°C after equilibrium at -40°C • Fifty pressure cycles to be performed using a defueling rate greater than or equal to the maintenance defueling rate	The EU regulation specifies a discrete hydrogen compatibility test for Type 1, 2 and 3 **containers** that requires 15,000 cycles (assuming 5,000 filling cycles specified for the system) In contrast, the draft GTR specifies a sequence of **system** tests with hydrogen gas, which include two groups of 250 cycles of ambient and extreme temperature gas pressure cycling As well as this difference of approach, there are technical differences in the procedures: the EU regulation specifies ambient temperature, whereas the draft GTR specifies periods of ambient and extreme temperatures
4.1.7.3.	Requirement Containers not to fail before reaching 3x number of filling cycles (according to	B.5.1.3	**Verification test for expected on-road performance (pneumatic sequential tests)**	

	section 2.7.6)		Hydrogen storage system must not leak during the following sequence of tests	
4.1.7.4	Results To be documented in test report and presented in a test summary and manufacturer to keep results on file throughout service life			
4.1.8.	*Hardness test*			
4.1.8.1	Sampling Applies to all containers and to liners of type 1, 2 and 3 containers Applies to metallic materials only Production testing: all containers or liners Test carried out after final heat treatment		No similar requirement	Production testing is not included in the draft GTR
4.1.8.2.	Procedure Hardness test to be carried to ISO 6506-1 on parallel wall at centre and at one of domed ends of each container or liner			
4.1.8.3.	Requirement Hardness value to be in range specified for the design			
4.1.8.4.	Results Hardness value to be presented in test summary with manufacturer to keep results on file throughout service life			
4.2.	**Container tests**			

4.2.1.	*Burst test*	B.5.1.1.1	**Baseline initial burst pressure**	
4.2.1.1.	Sampling Applies to all container types Type-approval testing: 3 finished containers Type-approval testing: 1 liner (additional test for type 2 containers only) Batch testing: number of containers tested according to section 3.9.1.	B.5.1.1.1	Three new containers randomly selected from design qualification batch to be hydraulically pressurised until burst	
4.2.1.2.	Procedure Container to be hydraulically burst tested at ambient temperature Rate or pressurisation ≤1.4 MPa/s for pressures above 80%NWP x burst pressure ratio in section 3.6. If rate exceeds 0.35 MPa/s at pressures higher than 80%NWP x burst pressure ratio, container placed in series between pressure source and pressure measurement device, or the time at pressure above the NWP x burst pressure ratio shall exceed 5s	B.6.2.2.1	Burst test (hydraulic) Burst test conducted at 20(±5)°C using non-corrosive fluid Rate of pressurisation ≤1.4 MPa/s for pressures above 150%NWP If rate exceeds 0.35 MPa/s at pressures higher than 150%NWP, container placed in series between pressure source and pressure measurement device, or the time at pressure above target burst pressure ratio shall exceed 5s	The instructions relating to the rate of pressurisation depend on the container materials and type in the EU regulation whereas the draft GTR specifies ≤1.4 MPa/s for pressures above 150%NWP irrespective of material and container type The EU regulation corresponds to ≤1.4 MPa/s for pressures above 180%NWP for metal and carbon
4.2.1.3.	Requirement Burst pressure to exceed NWP x burst pressure ratio in section 3.6. For type 2 containers, the burst pressure of liner to exceed 1.25xNWP	B.5.1.1.1	All containers tested must have burst pressure within ±10% of BP_o and ≥200%NWP. [200%NWP value is an "open item"]	The requirement depends on the container materials and type in the EU regulation, and appears to be less stringent in the draft GTR EU requirement corresponds to 225%NWP for metal or carbon containers, higher for others
4.2.1.4.	Results Burst pressure to be presented in test summary and kept by manufacturer	B.6.2.2.1	Burst pressure shall be recorded	

	throughout service life of container			
4.2.2.	*Ambient temperature pressure cycle test*	B.5.1.1.2	**Baseline initial pressure cycle life**	
4.2.2.1.	Sampling Applies to all container types Type-approval testing: 2 finished containers Batch testing: number of containers tested according to section 3.9.1.	B.5.1.1.2	Three randomly selected new containers hydraulically pressure cycled to 125%NWP without rupture for 22,000 cycles or until leak occurs [At the time of writing, the 22,000 cycles value was an "open item" for discussion at a future meeting"]	
4.2.2.2.	Procedure a) Fill container with non-corrosive fluid b) Pressure cycle for 3 x number of filling cycles in section 2.7.6., from ≤2.0 MPa and ≥1.25xNWP at a rate not exceeding 10 cycles/min For type-approval, containers cycled until failure occurs or up to 9x number of filling cycles For batch testing follow section 3.9.1	B.6.2.2.2	Pressure cycling test (hydraulic) a) Fill container with non-corrosive fluid b) Stabilise temperature of container and fluid at specified temperature and relative humidity at start of testing; maintain environment, fuelling fluid and container skin at specified temperature for duration of testing. But container temperature may vary from environmental temperature c) Pressure cycle between <2MPa and target pressure at a rate not exceeding 10 cycles/min d) Maintain and monitor temperature of hydraulic fluid within container at specified temperature	Draft GTR also specifies ambient temperature pressure cycling during a series of sequential hydraulic tests; 125%NWP for 60%#Cycles (#Cycles cannot be greater than 11,000 and could be set at a lower number by the contracting party, but not lower than 5,500 cycles
4.2.2.3.	Requirement For type-approval containers shall either reach 9x number of filling cycles without failure, in which case the LBB test is section 4.2.3 is not required, or they shall fail by leakage and not rupture	B.5.1.1.2	**Baseline initial pressure cycle life** Cycling to continue without rupture for 22,000 cycles or until leak occurs Leakage not to occur within initial number of cycles (#Cycles); #Cycles not to exceed 11,000 but could be set lower by a	The EU regulation does not specify a minimum number of cycles to be reached before leakage can occur, but requires a further test (at a higher pressure) if the container leaks during this test

	For batch testing, containers shall not fail before reaching 3x number of filling cycles		contracting party, but not lower than 5,500 cycles	
4.2.2.4.	Results The number of cycles to failure, along with location and description to be documented and presented in test summary and manufacturer to keep results on file throughout service life			
4.2.3.	*Leak-before-burst performance test*		No corresponding test in draft GTR	
4.2.3.1.	Sampling Applies to all container types Not required if container proven to exceed 9x number of filling cycles when tested to 4.2.2. Type-approval testing: 3 finished containers			The intention of this test seems to be covered by the baseline initial pressure cycle life test in draft GTR
4.2.3.2.	Procedure a) Fill container with non-corrosive fluid b) Pressure cycle between ≤2.0 MPa and ≥1.5 NWP at a rate of≤10 cycles/min to 3x number of filling cycles			
4.2.3.3.	Requirement Container to fail by leakage or to exceed 3x number of filling cycles without failure			
4.2.3.4.	Results The number of cycles to failure, along with location and description to be documented and presented in test summary and manufacturer to keep results on file			

	throughout service life			
4.2.4.	*Bonfire test*	B.5.1.4	**Verification test for service terminating performance in fire**	
4.2.4.1.	Sampling Applies to all container types Type-approval testing: 1 finished container	B.5.1.4	No similar requirement	
4.2.4.2.	Procedure Container pressurised to NWP with hydrogen or a gas with higher thermal pressure build up [Detailed procedure included]	B.6.2.5.1	Fire test (pneumatic) [Offers two methods: qualification for generic installation and qualification for specific vehicle followed by detailed procedure]	There are significant differences between the EU regulation and draft GTR, most notably, GTR specifies localised and engulfing fires, while EU regulation specifies engulfing fire only
4.2.4.3.	Requirement Container shall vent through PRD(s) and not rupture	B.5.1.4	TPRD to release the gases in controlled manner without rupture	
4.2.4.4.	Results To be presented in test summary and to include elapsed time from ignition to start of venting and maximum pressure and time of evacuation until pressure ≤1MPa reached		No requirement	
4.2.5.	*Penetration test*			
4.2.5.1.	Sampling Applies to all container types Type-approval testing: 1 finished container		No similar test or requirements	The draft GTR does not require a penetration test
4.2.5.2.	Procedure a) Pressurise with compressed gas to NWP ±1 MPa			

	b) Penetrate at least one sidewall with 7.62 mm or greater armour piercing bullet, or impactor, with at approximate angle of 45°			
4.2.5.3.	Requirement Container not to rupture			
4.2.5.4.	Results Approximate size of entrance and exit openings and locations to be specified in test summary			
4.2.6.	*Chemical exposure test*	B.5.1.2.4	Chemical exposure and ambient pressure cycling test	
4.2.6.1.	Sampling Test applies to type 2, 3 and 4 containers Type-approval testing: 1 finished container	B.5.1.2	At least one system to be tested to demonstrate performance capability	The EU regulation requires chemical exposure testing for Type 2,3, and 4 containers only whereas the draft GTR requirements apply to all container types
4.2.6.2.	Procedure a) Upper section to be divided into 5 areas (100 mm in diameter) and marked for pendulum impact and fluid exposure, areas do not need to be in straight line but cannot overlap	B.6.2.3.3	Surface damage test (unpressured) b) Pendulum impacts Upper section of horizontal storage container to be divided into five (not overlapping areas) 100 mm in diameter	The EU regulation specifies a discrete chemical exposure test (including pressure cycling, static pressure and a container burst); however, the draft GTR specifies a sequence of tests, which include chemical exposure and ambient temperature pressure cycling, alongside other tests Prior to the chemical exposure, the draft GTR specifies the generation of a surface flaw as part of this sequence (two longitudinal saw cuts are made on the surface of the cylinder), whereas it is part of a separate test in the EU regulation
	b) Approximate centre of each of five areas to be preconditioned by impact of steel pendulum body with shape of	B.6.2.3.3	After 12 hours preconditioning at -40°C in environmental chamber, centre of each of five areas to sustain an impact of pendulum	No reference to temperature preconditioning in EU regulation

	pyramid with equilateral triangle faces and square base, summit and edges rounded to radius of 3 mm Centre of percussion of pendulum to coincide with centre of gravity of pyramid; its distance from axis of rotation of pendulum to be 1 m and total mass referred to centre of percussion to be 15 kg Energy of pendulum at moment of impact not to be less than 30 J Container to be held in position by end bosses or by intended mounting brackets Container to be unpressurised		with pyramid with equilateral faces and square base, summit and edges rounded to radius of 3 mm Centre of impact of pendulum to coincide with centre of gravity of pyramid Energy of pendulum at moment of impact should be 30 J Container to be secured in place and not under pressure	EU regulation specifies more pendulum characteristics than the draft GTR
	c) Each of 5 preconditioned areas to be exposed to one of five solutions: i) Sulphuric acid (19% vol. in water) ii) Sodium hydroxide (25% wt. in water) iii) Methanol/gasoline (5/95% conc.) iv) Ammonium nitrate (28% wt. in water) v) Windshield washer fluid (50% vol. in methyl alcohol & water)	B.6.2.3.4	Chemical exposure and ambient pressure cycling test Each of five areas of unpressured container preconditioned by pendulum impact to be exposed to one of five solutions: 1. Sulphuric acid (19% vol. in water) 2. Sodium hydroxide (25% wt. in water) 3. Methanol (5% vol. in gasoline) 4. Ammonium nitrate (28% wt. in water) 5. Windshield washer fluid (50% vol. methyl alcohol in water)	
	d) During exposure, orient container with fluid areas uppermost Place pad of glass wool 0.5 mm thick and 100 mm diameter on each	B.6.2.3.4	Orient container with fluid exposure areas on top Place pad of glass wool 0.5 mm thick and	

	exposure area Apply an amount to ensure pad is wetted evenly across surface and through thickness for test duration		100 mm diameter on each exposure area Apply an amount to ensure pad is wetted evenly across surface and through thickness for test duration	
	[Different test order in EU regulation, see below]	B.6.2.3.4	Exposure to be maintained for 48 hrs with container held at 125%NWP (applied hydraulically) and 20±5°C before subject to further tests	
	e) Pressure cycle between ≤ 2 MPa and 1.25xNWP for number of filling cycles in section 2.7 at max rate of 2.75 MPa/s	B.6.2.3.4	Perform pressure cycling to specified target pressures to B.6.2.2.2 at 20±5°C for specified number of cycles	The EU regulation requires the number of filling cycles to be that specified for the container (i.e. 5,000 cycles), whereas the draft GTR specifies 60% #Cycles for the container (i.e. 60% of 5,500, 7,500 or 11,000)
		B.5.1.2.4	Chemical exposure and ambient pressure cycling test Storage container exposed to chemicals and pressure cycled to 125%NWP at 20±5°C for 60% #Cycles pressure cycles Chemical exposure to be discontinued before last 10 cycles, which are conducted at 150% NWP	
	f) Pressurise to 1.25xNWP and hold for minimum of 24 hrs until elapsed exposure time (pressure cycling and pressure hold) to environmental fluids is at least 48 hrs		[Different test order in draft GTR, see above]	
	g) Burst test to section 4.2.1.2		No burst test carried out at this point in the draft GTR	The draft GTR specifies a different test sequence; the burst test is performed after further testing
4.2.6.3.	Requirement Container to have burst pressure of ≥ 1.8xNWP			
4.2.6.4.	Results			

	To be presented in test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.2.7.	*Composite flaw tolerance test*	B.6.2.3.3	Surface damage test	
4.2.7.1.	Sampling Applies to type 2, 3 and 4 containers Type-approval testing: 1 finished container	B.5.1.2	At least one system to be tested to demonstrate performance capability	The EU regulation requires composite flaw tolerance testing for Type 2,3, and 4 containers only, whereas the draft GTR requirements apply to all container types
4.2.7.2.	Procedure a) Flaws in longitudinal direction to be cut into over-wrap, greater than visual inspection limits specified by manufacturer and at least the following to be cut into longitudinal direction of container sidewall: i) 25 mm long by 1.25 mm deep ii) 200 mm long by 0.75 mm deep b) Pressure cycle flawed container between ≤ 2 MPa and 1.25x NWP at ambient temperature for 3x filling cycles according to section 2.7.6	B.6.2.3.3	a) Surface flaw generation Two longitudinal saw cuts made on bottom outer surface of unpressurised container along cylindrical zone close to, but not in, shoulder area First cut to be at least 25 mm long, 1.25 mm deep and towards valve end Second cut to be 200 mm long and 0.75 mm deep and towards opposite end to valve	Surface flaw generation in draft GTR follows broadly the same procedure as the EU regulation; however it is carried out before the chemical exposure and is part of a sequence of tests In contrast, the composite flaw tolerance test in the EU regulation is a discrete test procedure
4.2.7.3.	Requirement Container not to leak or rupture within 0.6xfilling cycles according to section 2.7.6., but may fail by leakage in remaining test cycles			
4.2.7.4.	Results Number of cycles to failure and location and description presented in test summary, as specified in addendum to EC type-approval			

	certificate in Part 2 to Annex II			
4.2.8.	*Accelerated stress rupture test*	B.5.1.2.5	High temperature static pressure test	
4.2.8.1.	Sampling Applies to type 2, 3 and 4 containers Type-approval testing: 1 finished container	B.5.1.2	At least one system to be tested	The EU regulation requires accelerated stress rupture testing for Type 2,3, and 4 containers only whereas the draft GTR requirements apply to all container types
4.2.8.2.	Procedure a) Pressurise to 1.25xNWP for 1,000 hours at 85°C b) Burst test according to section 4.2.1.2.	B.5.1.2.5	Storage container to pressurised to 125% NWP at 85°C for 1,000 hrs No burst test carried out at this point in the draft GTR	The draft GTR specifies the high temperature static pressure test as part of a sequence of tests, whereas the accelerated stress rupture test in the EU regulation is a discrete test
4.2.8.3.	Requirement Container to achieve burst pressure of ≥ 0.85xNWP x burst pressure ratio given in section 3.6			
4.2.8.4	Results Burst pressure to be presented in test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.2.9.	*Extreme temperature pressure cycling test*	B.5.1.2.6	Extreme temperature pressure cycling	
4.2.9.1.	Sampling Applies to type 2, 3 and 4 containers Type-approval testing: 1 finished container	B.5.1.2	At least one system to be tested	The EU regulation requires extreme temperature pressure cycling for Type 2,3, and 4 containers only whereas the draft GTR requirements apply to all container types

4.2.9.2.	Procedure a) Condition for 48 hrs with temperature ≥85°C and relative humidity ≥95% b) Pressure cycle between ≤2 MPa and 1.25xNWP at temperature ≥85°C and relative humidity ≥95% for 1.5 x filling cycles according to section 2.7.6. c) Stabilise at ambient conditions d) Condition the container and test fluid to temperature ≤-40°C as measured on container surface and in fluid e) Pressure cycle at ≤-40°C and between ≤2 MPa and ≥NWP for 1.5xfilling cycles f) Leak test type 4 containers and type 3 with welded metal liners to section 4.2.11. g) Burst test to section 4.2.1.2.	B.5.1.2.6	Storage system to be pressure cycled at -40°C to 80%NWP for 20%#Cycles and at 85°C to 125%NWP for 20%#Cycles according to procedure B.6.2.2.2	During the 85°C part of the test, the EU regulation specifies 1.5xfilling cycles (i.e. 7,500 cycles) to be performed, whereas the draft GTR specifies 20%#Cycles (i.e. 1,100 to 2,200 cycles) During the -40°C part of the test, the EU regulation specifies 1.5x filling cycles (i.e. 7,500 cycles) to be performed, whereas the draft GTR specifies 20%#Cycles (i.e. 1,100 to 2,200 cycles) also the EU regulation specifies that the cycling is performed to NWP whereas the draft GTR specifies 80%NWP The EU regulation specifies 95% humidity
		B.6.2.2.2	Pressure cycling test (hydraulic) a) Fill container with non-corrosive fluid b) Stabilise temperature of container and fluid at specified temperature and relative humidity at start of testing; maintain environment, fuelling fluid and container skin at specified temperature for duration of testing. But container temperature may vary from environmental temperature c) Pressure cycle between <2MPa and target pressure at a rate not exceeding 10 cycles/min d) Maintain and monitor temperature of hydraulic fluid within container at specified temperature	
4.2.9.3.	Requirement Container to by cycle tested without evidence of rupture, leakage or fibre unravelling If leak test required, leak test requirements to be met Container not to burst at less than 85% of NWP x burst pressure ratio in section 3.6.			The extreme temperature pressure cycling test takes places towards the end of the hydraulic sequential tests in the draft GTR; a residual pressure test (180%NWP for 30 secs) is then performed followed by a residual burst strength test The residual burst pressure test at the end of the sequence requires that the burst pressure is within 20% of the baseline initial burst pressure

4.2.9.4.	Results Burst pressure to be presented in test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.2.10.	*Impact damage test*	B.5.1.2.2	Drop (impact) test	
4.2.10.1.	Sampling Applies to type 3 and 4 containers Type-approval testing: 1 container All impacts on 1 container or individual impacts on maximum of 3	B.5.1.2 B.6.2.3.2	At least one system to be tested Drop specifications may be executed with a single container, or as many as three containers may be used	The EU regulation requires the impact damage (i.e. drop) test for types 3 and 4 containers only whereas the draft GTR requirements apply to all container types
4.2.10.2.	Procedure To be performed at ambient temperature without pressurisation or valves, plug may be inserted in threaded ports 1) Drop once from horizontal position with bottom 1.8 m above ground 2) Drop once onto each end from vertical position with potential energy ≥ 488J, with bottom ≤ 1.8m above ground 3) Drop once at 45° and then for non-symmetrical or non-cylindrical containers, rotate through 90° along longitudinal axis and drop again at 45° with cog 1.8m above ground; but drop angle to be changed if necessary so bottom ≥ 0.6 m and cog 1.8 m above ground 4) Pressure cycle between ≤ 2 MPa and ≥	B.6.2.3.2	To be drop tested at ambient temperature without pressurisation or valves Container to be dropped onto smooth, horizontal concrete pad or similar 1) Drop once from horizontal position with bottom 1.8 m above ground 2) Drop once onto each end from vertical position with potential energy ≥ 488J, with bottom ≤ 1.8m above ground 3) Drop once at 45° and then for non-symmetrical or non-cylindrical containers, rotate through 90° along longitudinal axis and drop again at 45° with cog 1.8m above ground; but drop angle to be changed if necessary so bottom ≥ 0.6 m and cog 1.8 m above ground No attempt to be made to prevent bouncing, but containers may be prevented from falling	The drop impact test specified in the draft GTR takes place at the beginning of the hydraulic sequential tests, whereas it is a discrete test in the EU regulation

	1.25x NWP for 3x filling cycles (according to section 2.7.6.) Containers with specific coating which indicates that the container was dropped, drop height and potential energy to be half values above		over If a single container is subjected to all three drop specifications, and leakage does not occur within #Cycles, then that container undergoes further testing in B.5.1.2 If more than one container used, then those containers to undergo pressure cycling to B.6.2.2.2 until leakage or [22,000 cycles]; the new container to undergo further testing to B.5.1.2 is identified as follows: a) If all reach [22,000] without leakage, a new container is subjected to drop specification 3) before further testing in B.5.1.2 b) If any container does not reach [22,000] without leakage, a new container is subjected to drop specification that resulted in lowest number of cycles to leakage before further testing in B.5.1.2	
4.2.10.3.	Requirements Container not to leak or rupture within 0.6x filling cycles, but may fail by leakage during remaining test cycles Containers with specific coating to show visible deformations			
4.2.10.4.	Results Number of cycles to failure, and location and description, to be presented in test summary			
4.2.11.	*Leak test*			

4.2.11.1.	Sampling Applies to type 4 containers and type 3 with welded metal liners Type approval testing: 1 finished container Batch testing: according to section 3.9.1. Production testing: all finished containers		No corresponding test in draft GTR	The EU regulation specifies a discrete leak test for type-approval, for batch testing and also for production testing (i.e. all finished containers to undergo a leak test) The EU regulation also refers to the leak test and/or the leak test requirements during other test procedures The GTR specifies a leak test only if the permeation rate exceeds a certain limit during the pneumatic sequential tests (B.5.1.3)
4.2.11.2.	Procedure Dry container thoroughly and pressurise for at least 3 minutes to NWP with leak test gas For batch testing follow test sequence in note 6 to Table IV			
4.2.11.3.	Requirement Container to be rejected if any leakage through cracks, pores, unbonds or similar defects Permeation through wall according to section 4.2.12 is not considered to be leakage			
4.2.11.4.	Results Test results to be presented in a test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II Leakage rate applicable to tests carried out with 100% hydrogen only, leakage rates for other gases or mixtures shall be converted			

	to an equivalent rate			
4.2.12.	*Permeation test*	B.5.1.3.3	Extreme Temperature Static Pressure Leak/Permeation Test	
4.2.12.1.	Sampling Applies to type 4 containers only Type-approval testing: 1 finished container	B.5.1.3.3	Test will be performed after each group of 250 pneumatic pressure cycles in B.5.1.3.2 (Ambient and Extreme Temperature Gas Pressure Cycling Test)	The EU regulation requires hydrogen gas cycling for type 4 containers and type 3 with metal liners whereas the draft GTR requirements apply to all container types [Number of containers to be tested not specified for pneumatic sequential tests – at least one system to be tested for hydraulic sequential testing and for service terminating performance tests]
4.2.12.2.	Procedure a) Pressurise with hydrogen gas to NWP b) Place in enclosed sealed chamber at 15°C±2°C and monitor permeation for 500 hours or until steady state behaviour is kept for at least 48 hours	B.5.1.3.3	The system will be held at 115%NWP and 55°C with hydrogen gas until steady-state permeation or 30 hours, whichever is longer in accordance with B.6.2.4.2	The EU regulation specifies a discrete permeation test at 15°C whereby the container is pressurised to NWP with hydrogen gas and monitored for 500 hours or until the steady-state permeation rate has lasted for 48 hours In contrast, the draft GTR specifies a sequence of tests with hydrogen gas (to replicate worst-case service conditions), which include two phases of a static pressure and permeation testing at 55°C, which follow on from ambient and extreme temperature gas pressure cycling
		B.6.2.4.2	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°C in a sealed container Total steady-state discharge rate due to leakage and permeation from storage system shall be measured	
4.2.12.3.	Requirements Steady state permeation rate shall be less than 6.0 $Ncm^3/hr/L$ internal volume of the container	B.5.1.3.3	Extreme Temperature Static Pressure Leak/Permeation Test The maximum allowable hydrogen discharge from compressed hydrogen storage system is R*150ml/min where $R=(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4\ m^3$ and V_{width}, V_{height} and V_{length} are vehicle	The test in the EU regulation is carried out on a new container, but the allowable permeation rate is set at a level intended to safeguard against permeation near the end-of-life The GTR testing simulates the condition of hydrogen storage system near its end-of-

			width, height and length in meters Alternatively, maximum allowable hydrogen discharge for system with a total water capacity of less than 330 L is 46 $Ncm^3/hr/L$ water capacity of the storage system If permeation rate is greater than 0.005 mg/sec (3.6 cc/min), then a localised leak test shall be performed according to test procedure B.6.2.4.3 to ensure no point of localised external leakage is greater than 0.005 mg/sec (3.6 cc/min)	life and hence the permeation rates are set accordingly
4.2.12.4.	Results Steady state permeation rate to be presented in a test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.2.13.	*Boss torque test*			
4.2.13.1.	Sampling Applies to type 4 containers only Type-approval testing: 1 finished container Batch testing: number of containers tested according to section 3.9.1.		No comparable test or requirements	The EU regulation specifies a boss torque test whereas no similar test or requirements are in the draft GTR
4.2.13.2.	Procedure a) Restrain body of container against rotation b) Apply a torque of 2x valve or PRD installation torque specified by manufacturer to each end boss of the container; first in the direction to tighten the threaded connection, then in the direction to loosen, and finally again			

	in the direction to tighten c) For type-approval, the following tests shall also be conducted: i) Leak test (4.2.11) ii) Burst test (4.2.1.2. and 4.2.1.3) For batch testing follow test sequence given in explanatory note (6) to Table IV.3.9			
4.2.13.3.	Requirement For type-approval, container shall meet leak and burst test requirements For batch testing, container shall meet leak test requirements			
4.2.13.4.	Results Applied torque, leakage and burst pressure to be presented in a test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II Leakage rate applicable to tests carried out with 100% hydrogen only, leakage rates for other gases or mixtures shall be converted to an equivalent rate			
4.2.14.	*Hydrogen gas cycling test*	B.5.1.3.2	Ambient and Extreme Temperature Gas Pressure Cycling Test	
4.2.14.1.	Sampling Applies to type 4 containers and type 3 with welded metal liners Type-approval testing: 1 finished container		Number of systems not specified [Number of containers to be tested not specified for pneumatic sequential tests – at least one system to be tested for hydraulic sequential testing]	The EU regulation requires hydrogen gas cycling for Type 4 containers and Type 3 with metal liners whereas the draft GTR requirements apply to all container types

4.2.14.2.	Procedure a) Use hydrogen gas to pressure cycle container between ≤2 MPa and ≥NWP for 1,000 cycles, filling time not to exceed 5 minutes, temperatures during venting not to exceed values in section 2.7.5 b) Leak test to section 4.2.11. Section the container and inspect liner and liner/end boss interface for evidence of deterioration such as fatigue cracking or electrostatic discharge	B.5.1.3.2	The system will be pressure cycled using hydrogen gas for 500 cycles in accordance with B.6.2.4.1 test procedure • Pressure cycles divided into two groups: half of the cycles (250) performed before exposure to static pressure and remaining half (250) will be performed after initial exposure to static pressure • In each group, 25 cycles to be performed to 125%NWP at 50°C and 95% relative humidity, then 25 cycles to 80%NWP at -40°C and remaining 200 cycles to 125%NWP at 20(±5)°C • Hydrogen gas fuel temperature to be -40(±5)°C • During first group of 250 pressure cycles, 5 cycles to be performed after temperature equilibrium of the system at 50°C and 95% humidity; 5 cycles after equilibrium at -40°C; and 5 cycles with fuel temperature of 20°C after equilibrium at -40°C • Fifty pressure cycles to be performed using a defueling rate greater than or equal to the maintenance defueling rate	The EU regulation specifies a discrete gas cycling test whereby the **container** is cycled to NWP for 1,000 cycles followed by a leak test and inspection In contrast, the draft GTR specifies a sequence of **system** tests with hydrogen gas, which include two groups of 250 cycles of ambient and extreme temperature gas pressure cycling As well as this difference of approach, there are technical differences in the procedures: the EU regulation does not specify a temperature and hence the test is (presumably) performed at ambient temperature, whereas the draft GTR specifies periods of ambient and extreme temperatures
4.2.14.3.	Requirement Container shall meet the leak test requirements Liner and liner/end boss interface shall be free of any deterioration, such as fatigue cracking or electrostatic discharge			
4.2.14.4.	Results			

	Total leakage value to be presented in a test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II			
4.2.15.	*Hydraulic test*			
4.2.15.1.	Sampling Test applies to all container types Production testing: all finished containers		No corresponding test in draft GTR	The EU regulation requires all finished containers to undergo a hydraulic test as part of a suite of production tests whereas no production tests are specified in the draft GTR
4.2.15.2.	Procedure and Requirement a) Container shall be pressurised to ≥1.5x NMP, pressure may not exceed auto-frettage pressure b) Pressure shall be maintained for at least 30s to ensure complete expansion, if pressure cannot be maintained due to failure of test apparatus, permissible to repeat test at a pressure increased by 0.7 Mpa but no more than two such repeats are permitted c) For type 1, 2 or 3 containers, manufacturer to define appropriate limit of permanent volumetric expansion for test pressure used, but not to exceed 5% of total volumetric expansion measured under test pressure (permanent expansion is residual volumetric expansion after pressure released) d) For type 4 containers, manufacturer to define appropriate limit of elastic expansion for test pressure used, but not to exceed average batch value by more than 10% (elastic expansion is			

	total expansion less permanent expansion) e) Any container that does not meet defined expansion limit to be rejected, but may still be used for batch test purposes			
4.2.15.3.	Results Results to be presented in a test summary, as specified in addendum to EC type-approval certificate in Part 2 to Annex II Manufacturer to keep results on file throughout container service life			

A.4 Part 3 – Requirements for hydrogen components other than containers designed to use compressed (gaseous) hydrogen

(EU) No. 406/2010 (Annex IV)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
2.	GENERAL REQUIREMENTS			
2.1.	Components other than containers to be type-approved to this Part	B.5.1.5	**Verification test for performance durability of primary closures** Closures that isolate the high pressure storage system (the TPRD(s), check valve(s) and shut-off valve(s) to meet the requirements in this section	The EU regulation specifies component-level requirements for a range of components, whereas the draft GTR specifies requirements for TPRDs, check valves and shut-off valves only
2.2.	Unless stated, parts of removable storage system connector to be treated as separate components		No similar requirement	
2.3.	Electrical part of a component in contact with ignitable hydrogen-air mixtures shall: • be insulated such that no current passes through hydrogen containing parts • be insulated from the body of the component and the container or container assembly		No similar requirement	
2.4.	Welded connections upstream of first pressure regulator to be hydraulically pressure tested to 3xNWP without rupture, welded connections downstream of first pressure regulator to be hydraulically		No similar requirement	B.5.1.5 specifies qualification tests for closures that isolate the hydrogen storage system, but there is no specific reference in the draft GTR to welded connections

	pressure tested to 3xMAWP without rupture			
3.	TECHNICAL REQUIREMENTS			
3.1	**General requirements**			
3.1.1.	All tests at ambient temperature (unless stated otherwise)	B.6.2.6.1	TPRD Qualification performance tests All tests at ambient temperature 20(±5)°C unless otherwise specified	The draft GTR specifies separate component-level tests for TPRDs and for check valves and shut-off valves
		B.6.2.6.2	Qualification performance tests for check valve and shut-off valve All tests at ambient temperature 20(±5)°C unless otherwise specified	
3.1.2.	Explosive gas mixtures to be prevented during testing		No similar requirement	
3.1.3.	Test period for leakage and pressure tests not less than 3 minutes		No general requirement [see test procedures below]	
3.1.4.	Test pressure measured at inlet of component under test (unless stated otherwise)		No similar requirement	
3.1.5.	Filling cycles used if component exposed to pressure during filling, duty cycles used if exposed to pressure during vehicle operation		No similar requirement	
3.1.6.	Manufacturer to complete all documents referred to in section 4 and to submit to competent authority		No similar requirement	
3.1.7.	Components to be subjected to applicable tests in Annex V to (EC) No. 79/2009 and tests conducted on representative components with manufacturer's	B.5.1.5	**Verification test for performance durability of primary closures** Closures that isolate the high pressure	

	identification marks		storage system (the TPRD(s), check valve(s) and shut-off valve(s) to meet the requirements in this section	
3.1.8.	Tests specified in section 4.2 to be conducted on same samples and sequence given in Annex V to (EC) No. 79/2009 unless otherwise indicated		No similar requirement	
3.2 (3.2.1. to 3.2.5.)	**Specific requirements** [Section specifies a series of design requirements for flexible fuel lines, including electrical resistance, receptacle profile dimensions and ductility of metallic pipes]		No similar requirements	Section B.5.2.1.1 of the draft GTR specifies fuelling receptacle requirements, but the profile of the receptacle is not defined
4.	TEST PROCEDURES			
4.1.	Material tests			
4.1.1.	*Hydrogen compatibility test*			
4.1.1.1.	Sampling Applies to materials used in a specific component where material in contact with hydrogen, except: a) Aluminium alloys that conform to ISO 7866 b) Steels that conform to ISO 9809 Number of samples to be tested: 3		No similar requirements	There are no material requirements for components in the draft GTR All material compatibility and hydrogen embrittlement requirements have been deferred until Phase 2 of the GTR activity

4.1.1.2.	Procedure and Requirements a) For metallic materials other than those above, hydrogen compatibility to be demonstrated in accordance with ISO 11114-1 and ISO 11114-4 or manufacturers to perform material qualification tests in hydrogen environments anticipated in service b) For non-metallic materials: hydrogen compatibility to be demonstrated			
4.1.1.3.	Results Results to be presented in a test summary			
4.1.2.	*Ageing test*			
4.1.2.1.	Sampling All non-metallic materials used in a component to be tested Number of samples to be tested: 3		No similar test or requirement	No ageing test requirements in draft GTR As noted above, there are no material requirements for components in the draft GTR
4.1.2.2.	Procedure and Requirements Test to in accordance with ASTM D572, sample exposed to oxygen at the maximum material temperature in accordance with section 2.7.5.1. at 2 MPa for 96 hours Tensile strength and elongation or the microhardness to comply with manufacturer's specifications, no visible cracking allowed			
4.1.2.3.	Results Results to be presented in a test summary			

4.1.3.	*Ozone compatibility test*			
4.1.3.1.	Sampling Applies to elastomer materials where: a) A sealing surface is exposed to air b) Used as a flexible fuel line cover Number of samples to be tested: 3		No similar test or requirement	No ozone compatibility test requirements for component materials in draft GTR
4.1.3.2.	Procedure and Requirements Test to in accordance with ISO 1431-1 Test samples stressed to 20% elongation and exposed to air at 40°C with ozone concentration of 0.5 parts per million for 120 hours No visible cracking allowed			
4.1.3.3.	Results Results to be presented in a test summary			
4.2.	**Component tests**	B.6.2.6	**Test procedures for primary closures in compressed hydrogen storage system**	
4.2.1.	*Corrosion resistance test*	B.6.2.6.1.4	Salt corrosion resistance test	The EU regulation specifies a corrosion resistance test that applies to all components The draft GTR specifies a salt corrosion test and a stress corrosion cracking test for TPRDs only, and separate salt corrosion and stress corrosion cracking tests for check valves and shut-off valves only
		B.6.2.6.1.6	Stress corrosion cracking test	
		B.6.2.6.2.4	Salt corrosion resistance test	
		B.6.2.6.2.9	Stress corrosion cracking test	
4.2.1.1.	Sampling Number of components to be tested: 3	B.6.2.6.1.4	Salt corrosion resistant test TPRD units to be tested: 2	

		B.6.2.6.1.6	Stress corrosion cracking test TPRD to be tested (when made from copper-based alloy, e.g. Brass): 1	
		B.6.2.6.2.4	Salt corrosion resistance test No sampling specified (AISI series 300 Austenitic stainless steels are exempt)	
		B.6.2.6.2.9	Stress corrosion cracking test No sampling specified (Brass valves with a history of satisfactory experience are exempt)	
4.2.1.2.	Procedure and Requirements Test a: Metallic components to be submitted to 144 hour salt spray test to ISO 9227 with all connections closed and meeting requirements therein Test b: A copper alloy component also to be submitted to 24 hours immersion in ammonia to ISO 6957 with all connections closed and meeting requirements therein	B.6.2.6.1.4	Salt corrosion resistance test TPRD to be pressurised to 125% service pressure and exposed for 150 hours to salt spray (fog) test as specified in ASTM B117 [Certain exceptions to this procedure are also specified] If component expected to operate in vehicle underbody, then exposed for 500 hours Following the tests, the PRD to meet requirements of leak test (B.6.2.6.1.8), flow rate test (B.6.2.6.1.10) and bench top activation test (B.6.2.6.1.9)	The corrosion resistance test in the EU regulation comprises two tests: a test with salt spray and a test with ammonia The draft GTR specifies these tests separately and in each case, does not refer to the ISO standards from the EU regulation
		B.6.2.6.1.6	Stress corrosion cracking test TPRD to be exposed for 10 days to moist ammonia-air mixture in a glass chamber [Further requirements are specified for characteristics of ammonia and position of sample in solution] Brass units not to exhibit cracking or delamination due to test	

		B.6.2.6.2.4	Salt corrosion resistance test Component to be exposed for 150 hours to salt spray test as specified in ASTM B117, unless it operates in vehicle underbody service conditions where it must be exposed for 500 hours Following the test, the sample is to comply with the requirements of leak test (B.6.2.6.2) and hydrostatic strength test (B.6.2.6.2.1)	
		B.6.2.6.2.9	Stress corrosion cracking test Component to be exposed for 10 days moist ammonia-air mixture in a glass chamber [Further requirements are specified, as noted above] Brass units not to exhibit cracking or delamination due to test	
4.2.1.3.	Results Results to be presented in a test summary	B.5.1.5	**Verification test for performance durability of primary closures** Manufacturers to maintain records that closures meet the requirements	
4.2.2.	*Endurance test*		No directly comparable test	
4.2.2.1.	Sampling Number of components to be tested: 3			
4.2.2.2.	Procedures and Requirements			
4.2.2.2.1.	Component to be tested according to: a) Pressurise component with dry air, nitrogen, helium or hydrogen to NWP and subject to 96% of total test cycles in Table 4.2.2. at ambient temperature			While there is no directly comparable endurance test in the draft GTR, TPRDs are subject to the following tests: • Pressure cycling test • Accelerated life test

<table>
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<td>A complete test cycle shall take place over a period of not less than 10 ± 2 s

When valve is in closed position, downstream pressure shall decay to 0.5 times the NWP of the component or lower

Component to fulfil requirements of internal and external leakage tests (sections 4.2.4. and 4.2.5. respectively) at this temperature

b) Component shall then be operated through 2% of total number of test cycles at the minimum material temperature in accordance with section 2.7.5.1. after sufficient conditioning time at this temperature to ensure thermal stability

Component to fulfil requirements of the internal and external leakage tests (sections 4.2.4. and 4.2.5. respectively) at this temperature

c) Component shall then be operated through 2% of total number of test cycles at maximum material temperature in accordance with section 2.7.5.1. after sufficient conditioning time at this temperature to ensure thermal stability and at 1.25xNWP

Component to fulfil requirements of the internal and external leakage tests (sections 4.2.4. and 4.2.5. respectively) at this temperature

<table><tr><th>Component</th><th>No. of test cycles</th></tr></table></td>
<td></td>
<td></td>
<td>• Temperature cycling test
• Salt corrosion resistance test
• Stress corrosion cracking test
• Drop and vibration test
• Leak test
• Bench top activation test
• Flow rate test

Check valves and shut-off valves are subject to:

• Hydrostatic strength test
• Leak test
• Extreme temperature pressure cycling test
• Salt corrosion resistance test
• Vehicle environment test
• Atmospheric exposure test
• Electrical test
• Vibration test
• Stress corrosion cracking test
• Pre-cooled hydrogen exposure test

These various tests include test cycles at pressures and temperatures specified in the endurance tests with similar leakage requirements</td>
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<tr>
<td></td>
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<tr><td>Automatic valve</td><td>1.5x duty or filling cycles in section 2.7.6. or 2.7.7 as appropriate to use of valve</td></tr>
<tr><td>Manual valve</td><td>100</td></tr>
<tr><td>Non-return valve</td><td>2x number of duty or filling cycles in section 2.7.6. or 2.7.7 as appropriate to use of valve</td></tr>
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<tr>
<td>4.2.2.2.2.</td>
<td>Fittings

Fittings to be subjected to 25 connection/disconnection cycles</td>
<td></td>
<td>No tests on fittings</td>
<td></td>
</tr>
<tr>
<td>4.2.2.2.3.</td>
<td>Flexible fuel lines

[Describes a detailed test procedure in which a calculated length of flexible part of fuel line attached to a test fixture and exposed to a defined number of duty or filling cycles]</td>
<td></td>
<td>No tests on flexible fuel lines</td>
<td></td>
</tr>
<tr>
<td>4.2.2.2.4.</td>
<td>Pressure regulators

[Describes a detailed test procedure for pressure cycling pressure regulator]</td>
<td></td>
<td>No tests on pressure regulators</td>
<td></td>
</tr>
<tr>
<td>4.2.2.2.5.</td>
<td>Pressure relief devices

[Describes a creep test (1.25NWP for 500 hours) and further increasing temperature cycling test to activation for pressure relief devices]</td>
<td rowspan="2"></td>
<td rowspan="2">No directly comparable creep test and temperature cycle to activation; however, TPRDs are exposed to similar conditions in tests listed above</td>
<td rowspan="2"></td>
</tr>
<tr>
<td>4.2.2.2.6.</td>
<td>Pressure relief valves

[Describes test cycles for pressure relief valves]</td>
</tr>
<tr>
<td>4.2.2.2.7.</td>
<td>Receptacles</td>
<td></td>
<td>No tests on receptacles</td>
<td></td>
</tr>
</table>

	Receptacles pressurised to 1.25xNWP and submitted to a number of connection/disconnection cycles equal to 3x number of filling cycles in section 2.7.6			
4.2.2.2.8.	*Sensors for hydrogen systems* Sensor to be subjected to same endurance test as hydrogen component into which it is installed		No tests on sensors for hydrogen systems	
4.2.2.2.9	*Removable storage system connector* [Describes test cycles for removable storage system connectors]		No tests on removable storage system connectors	
4.2.2.3.	Results Results to be presented in a test summary			
4.2.3.	*Hydraulic pressure cycle test*	B.6.2.6.1.1	Pressure cycling test	
4.2.3.1.	Sampling Number of components to be tested: 3	B.6.2.6.1.1	Five TPRD units to undergo testing	Test applies to TPRDs only
4.2.3.2.	Procedure and Requirements		TPRDs to undergo 11,000 internal pressure cycles with hydrogen gas First five pressure cycles to be between <2(±1) MPa and 150%NWP(±1MPa); the remaining to be between 2(±1) MPa and 125%NWP(±1MPa) First 1,500 pressure cycles to be conducted at TPRD temperature of 85(±5)°C and remaining at 55(±5)°C Max cycling rate is 10 cycles/min PRD to meet leak test (B.6.2.6.1.8), flow rate test (B.6.2.6.10) and bench activation test	
4.2.3.2.1.	*Pressure relief devices* PRDs to be subjected to 1.5x filling cycles in section 2.7.6. at both minimum and maximum material temperatures to section 2.7.5.1. Pressure shall periodically change from 2 MPa to 1.25xNWP at a rate not exceeding 6 cycles/min, except when tested at minimum material temperature when maximum test pressure shall be NWP			

			(B.6.2.6.1.9) following this test	
4.2.3.2.2.	*Components other than pressure relief devices* Before cycling test below, components to be subjected to hydraulic test pressure of 1.5xNWP or MAWP as applicable and shall not show signs of permanent deformation or failure or visible leaks Components shall be subjected to 3x filling cycles or duty cycles in sections 2.7.6. or 2.7.7. Pressure shall periodically change from 2 MPa to 1.25xNWP for components upstream of first pressure regulator, or from 0.1x MAWP to MAWP for components downstream of first pressure regulator, at a rate not exceeding 6 cycles/min Subsequently, the component shall fulfil requirements of internal and external leakage tests (sections 4.2.4 and 4.2.5.)	B.6.2.6.2.3	Extreme temperature continuous valve cycling test Total number of operational cycles is 50,000; Valve is installed in a test fixture corresponding to manufacturers specifications for installation Operation of unit is repeated continuously using hydrogen gas; one cycle is as follows: a) Check valve connected to test fixture and pressure applied in six pulses to valve inlet with outlet closed, pressure is then vented from valve inlet; pressure is lowered on outlet side to <60%NWP prior to next cycle b) Automatic shut-off valve connected to test fixture and pressure applied continuously to both inlet and outlet sides Testing performed on unit stabilised at following temperatures: a) Ambient temperature cycling: 125%NWP for 90% of cycles with part at 20(±5)°, then ambient leak test b) High temperature cycling: 125%NWP for 5% of cycles with part at +85(±5)°C, then high temperature leak test c) Low temperature cycling: 100%NWP for 5% of cycles with part at -40(±5)°C, then low temperature leak test Following 11,000 cycles and leak tests, check valve to be subject to 240 hours of chatter flow at a flow rate that causes most chatter	Test applies to check valves and shut-off valves only

			(valve flutter) On completion of test, check valve to comply with ambient temperature leak test (B.6.2.6.2.2) and hydrostatic strength test (B.6.2.6.2.1)	
4.2.3.3.	Results Results to be presented in a test summary	B.5.1.5	Manufacturers to maintain records that closures meet the requirements	
4.2.4.	*Internal leakage test*	B.6.2.6.1.8	Leak test	Draft GTR test applies to TPRDs only
		B.6.2.6.2.2	Leak test	Draft GTR test applies to check valves and shut-off valves only
4.2.4.1.	Sampling Number of components to be tested: 3	B.6.2.6.1.8	No sampling requirement	
		B.6.2.6.2.2	One unit to be tested at ambient temperature without being subjected to other design qualification tests	
4.2.4.2.	Procedure Components to be tested using leak test gas and pressurised at inlet of component when in its characteristic closed position and with corresponding outlet port open	B.6.2.6.1.8	TPRD unit to be held at 125%NWP with hydrogen gas for one hour at ambient temperature before leakage is measured Method for measuring is at the discretion of the test facility	
	Components to be tested at following conditions: a) At ambient temperature and at 0.02xNWP and at NWP. Where an external leakage test (section 4.2.5.) is also required at this temperature it may be undertaken before the next stage of this test; b) At minimum material temperature in accordance with section 2.7.5.1., after	B.6.2.6.2.2	Three temperature regimes: 1) Ambient temperature: condition at 20(±5)°C, test at 5%NWP and 150%NWP; 2) High temperature: condition at +85(±5)°C, test at 5%NWP and 150%NWP; 3) Low temperature: condition at -40(±5)°C, test at 5%NWP and 100%NWP	

	sufficient conditioning time at this temperature to ensure thermal stability and at 0.02xNWP and at NWP Where an external leakage test (section 4.2.5.) is also required at this temperature it may be undertaken before the next stage of this test; c) At maximum material temperature in accordance with section 2.7.5.1., after sufficient conditioning time at this temperature to ensure thermal stability and at 0.02xNWP and 1.25xNWP, except for components with a required material temperature of 120 ^{0}C where the higher test pressure shall be 1.37xNWP Component shall be observed for leakage with its outlet port open, leakage can be determined by a flowmeter installed on the inlet side of the component or by another test method demonstrated to be equivalent		Additional units to undergo leak testing as specified in subsequent tests with uninterrupted exposure to temperatures specified in those tests	
4.2.4.3.	Requirements When pressurised, component to stay bubble free for 3 min or shall not leak internally at a rate exceeding 10 Ncm^3 per hour	B.6.2.6.1.8	Total hydrogen leak rate to be less than 216 Nml/hr	
		B.6.2.6.2.2	Sample passes if no bubbles observed for specified time period If bubbles are detected, the leak rate shall not exceed 216 Nml/hr of hydrogen gas	
4.2.4.4.	Results Results to be presented in a test summary	B.5.1.5	Manufacturers to maintain records that closures meet the requirements	
4.2.5.	*External leakage test*		Leak test (described above) applies to both internal and external leakage	
4.2.5.1.	Sampling			

	Number of components to be tested: 3			
4.2.5.2.	Procedure Components to be tested using leak test gas at following conditions: a) At ambient temperature and at 0.02xNWP b) At ambient temperature and at NWP c) At minimum required material temperature, in accordance with section 2.7.5.1, after sufficient conditioning time at this temperature to ensure thermal stability and at 0.02xNWP and at NWP d) At maximum required material temperature, in accordance with section 2.7.5.1, after sufficient conditioning time at this temperature to ensure thermal stability and at 0.02xNWP and 1.25xNWP, except for components with a required material temperature of 120°C where the higher test pressure shall be 1.37xNWP For heat exchangers, this test shall only be undertaken on the hydrogen circuit			
4.2.5.3.	Requirements Throughout the test, the component shall be free from leakage through stem or body seals or other joints, and shall not show evidence of porosity in casting, demonstrated by a surface active agent without formation of bubbles for 3 minutes or measured with a combined leakage and permeation rate less than 10 Ncm^3 per hour			

	(for flexible fuel lines only 10 Ncm^3 per hour per meter) or it shall be tested by using a demonstrated equivalent test method The permitted leakage rate is applicable to tests with 100 per cent hydrogen only, permitted leakage rates for other gases or gas mixtures shall be converted to an equivalent leakage rate to that for 100 per cent hydrogen			
4.2.5.4.	Results Results to be presented in a test summary			

Appendix B Liquefied hydrogen systems

This appendix compares Annex III in Regulation (EU) No. 406/2010 with equivalent requirements in the draft global technical regulation.

B.1 Part 0 - General

(EU) No. 406/2010 (Annex III)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
2.	GENERAL REQUIREMENTS			
2.1.	The materials used in a hydrogen component or system shall be compatible with hydrogen in its liquid and/or gaseous state		No similar requirement	

B.2 Part 1 – Requirements for the installation of hydrogen components and systems designed to use liquid hydrogen

(EU) No. 406/2010 (Annex III)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
1.	GENERAL REQUIREMENTS			
1.1.	All hydrogen components and systems to be installed on the vehicle and connected in accordance with best practice.		No similar requirement in draft GTR	
1.2.	The hydrogen system(s) shall show no leaks other than the boil-off at MAWP, i.e. stay bubble-free if using leak-detecting spray	B.7.2.1.1	Proof pressure System to be pressurised to p_{test} ≥ 1.3(MAWP + 0.1 MPa) according to procedure in B.7.4.1.1	
		B.7.4.1.1	Proof pressure test Test passed when during at least 10 minutes after applying the proof pressure, no visible permanent deformation, no visible degradation in container pressure and no visible leakage detectable	
1.3.	Operating temperature for internal combustion engine compartment: -40°C to +120°C; and on board (all types of propulsion system): -40°C to +80°C		No similar requirement in draft GTR	
1.4.	Appropriate automatic measures to be adopted in coordination with the refuelling station to ensure that no uncontrolled hydrogen release occurs during the filling procedure		No specific requirement for coordination with refuelling station	B.5.2.1.1 in GTR requires that “a compressed hydrogen fuelling receptacle shall prevent reverse flow to the atmosphere” However, this applies to compressed (i.e. gaseous) systems only

1.5.	In the event of hydrogen leakage or venting, hydrogen shall not be allowed to accumulate in enclosed or semi-enclosed spaces of the vehicle	B.5.2.1.3.1	**Pressure relief systems** Hydrogen gas from TPRDs not to be directed into enclosed or semi-enclosed spaces (or to wheel housings, gas containers, or forwards from vehicle, or horizontally from back or sides) Other PRDs not to be directed towards electrical terminals, to passenger or luggage compartments, wheel housing or gas containers	The draft GTR is more explicit about type of pressure relief system and the direction of gas discharge, although the requirements were originally intended to apply to both liquefied and gaseous systems
2.	INSTALLATION OF THE HYDROGEN CONTAINER ON-BOARD OF A VEHICLE			
2.1.	Container can be integrated into the vehicle design to provide complementary functions, in such cases container to be designed to fulfil integrated function requirements and container requirements in Part 2		No requirements relating to complementary functions	
2.2.	When vehicle is ready for use, lowest part of hydrogen container not to reduce ground clearance of vehicle unless container is adequately protected, at the front and sides, and no part of the container is located lower than protective structure		No similar requirement for ground clearance or protection	
2.3.	Container(s), and safety devices to be mounted to absorb accelerations specified, depending on vehicle category (demonstrated by testing or calculation) Mass to be representative of fully equipped and filled container(s)		No similar requirement to assess mechanical integrity of container mountings in draft GTR	The GTR specifies crash tests already applied in respective jurisdictions (for fuel system integrity), but there are many vehicles that are exempt from such tests
2.4.	2.3 does not apply if vehicle is approved according to 96/27/EC and 96/79/EC			
3.	ACCESSORIES FITTED TO THE CONTAINER			

3.1. to 3.3.	Refer to (design) requirements in Regulation (EC) No. 79/2009 and also specify certain (design) requirements for various automatic valves		No similar requirements in draft GTR	
4.	RIGID AND FLEXIBLE FUEL LINES			
4.1. to 4.5.	Requirements for the installation of rigid and flexible fuel lines so that they are not subjected to abrasion, stress, corrosion, etc		No similar requirements	
5.	FITTINGS OR GAS CONNECTIONS			
5.1 to 5.4.	Specify various design requirements for the fittings and joints between hydrogen components		No similar requirements	
6.	REFUELLING CONNECTION OR RECEPTACLE			
6.1.	Refuelling connection or receptacle to be secured against maladjustment and protected from dirt and water and safe against handling errors	B.5.2.1.1.3	**Fuelling receptacle requirements** Receptacle to be mounted to the vehicle to ensure positive locking of the fuelling nozzle and to be protected from tampering and the ingres of dirt and water	In both the EU regulation and the draft GTR compliance is determined by visual inspection
6.2.	Refuelling connection or receptacle not to be installed in engine compartment, passenger compartment or in any other unventilated compartment	B.5.2.1.1.4	**Fuelling receptacle requirements** Receptacle not to be installed in passenger or luggage compartment or any other place where hydrogen gas could accumulate and where ventilation is not sufficient	Compliance determined by visual inspection
6.3.	Refuelling line to be secured at container as described in section 3.1.1. (shut-off valves to comply with section 6 of Annex VI to EC No. 79/2009)		No similar requirement	
6.4.	Refuelling connection or receptacle to have an isolating device according to section 3.1.2. (to comply with section 4 of Annex VI	B.5.2.1.1.1	**Fuelling receptacle requirements** Compressed hydrogen fuelling receptacle to prevent reverse flow to the atmosphere	

	to EC No. 79/2009			
6.5.	Propulsion system to be incapable of operating and vehicle incapable of moving while refuelling connection or receptacle connected to filling station		No similar requirement	
7.	ELECTRICAL INSTALLATION			
7.1.	Electrical components of hydrogen system to be protected against overloads		No similar requirement	
7.2.	Power supply connections to be tight against ingress of hydrogen where hydrogen components are present or hydrogen leaks are possible		No similar requirement	
8.	BOIL-OFF UNDER NORMAL CONDITIONS			
8.1 to 8.3.	Specify requirements for the boil-off management system		No comparable high-level requirements	There are no high-level boil-off system requirements in the draft GTR, but boil-off test requirements are specified (in B.7.3.2.1)
9.	OTHER REQUIREMENTS			
9.1 to 9.4.	Various requirements relating to protection against vandalism, adverse temperature effects, protection of flammable materials and failure of heating circuit		No similar requirements	
10.	SAFETY INSTRUMENTED SYSTEMS			
10.1. and 10.2.	Systems shall be fail-safe or redundant and special requirements in Annex VI (Safety requirements of complex electronic vehicle control systems) to apply if fail-safe or self-monitoring electronic systems		No requirements for safety instrumented systems in draft GTR	
11.	REQUIREMENTS FOR INSPECTION OF HYDROGEN SYSTEM			

11.1.	Each system inspected at least every 48 months after date of entry into service and at time of any re-installation		No similar requirement for inspection in GTR	
11.2.	Inspection to be performed by a technical service		No similar requirement	

B.3 Part 2 – Requirements for hydrogen containers designed to use liquid hydrogen

(EU) No. 406/2010 (Annex III)		Draft Global Technical Regulation		Remark
Para. No.	Text	Para. No.	Text	
1.	INTRODUCTION			
1.	This part sets out requirements and test procedures for hydrogen containers designed to use liquid hydrogen	B.7.1	This section specifies optional requirements for the integrity of a liquefied hydrogen storage system	
2.	TECHNICAL REQUIREMENTS			
2.1.	The design validation of the container by calculation shall be done in accordance with EN 1251-2		No similar requirement	
2.2.	**Mechanical stresses** Container parts to withstand following mechanical stresses			
2.2.1	*Inner tank*			
2.2.1.1.	Test pressure The inner tank shall resist the test pressure P_{test}: P_{test} = 1.3(MAWP+0.1 MPa)	B.7.4.1.1	Proof pressure test The test pressure p_{test} shall be defined by the manufacturer and fulfil the following requirements: $p_{test} \geq 1.3(MAWP + 0.1\ MPa)$ Further specifications made for metallic containers and for non-metallic	Draft GTR includes separate specifications for metallic and non-metallic containers; however, minimum value of p_{test} is same as EU regulation Both the EU regulation and the draft GTR specify a pressure test procedure (compared later), although the EU regulation does not refer to the test procedure here
2.2.1.2.	Outer pressure If an operating mode of the inner tank and		No similar requirement	

	its equipment under vacuum is possible, the inner tank and its equipment shall resist an outer pressure of 0.1 MPa			
2.2.2.	*Outer jacket*			
2.2.2.1.	Outer jacket to resist the MAWP, which is the set pressure of its safety device		No similar requirement	
2.2.2.2.	The outer jacket shall resist an outer pressure of 0.1 MPa		No similar requirement	
2.2.3.	*Outer supports* Outer supports of full container to resist accelerations in section 2.3 of Part 1, without rupture, and allowable stress in support elements not to exceed: $\sigma \leq 0.5$ Rm		No similar requirement to assess mechanical integrity of container supports in draft GTR	The GTR specifies crash tests already applied in respective jurisdictions (for fuel system integrity), but there are many vehicles that are exempt from such tests
2.2.4.	*Inner supports* inner supports of full container to resist accelerations in section 2.3 of Part 1, without rupture, allowable stress in the support elements calculated according to linear stress not exceed: $\sigma \leq 0.5$ Rm		No similar requirement to assess mechanical integrity of container supports in draft GTR	The GTR specifies crash tests already applied in respective jurisdictions (for fuel system integrity), but there are many vehicles that are exempt from such tests
2.2.5.	Requirements of 2.2.3. and 2.2.4. don’t apply if demonstrated that tank may support accelerations in section 2.3. of Part 1 without leak on inner tank and all pipes upstream of automatic safety devices, shut off valves and/or non-return valves			
2.2.6.	Proof of dimensioning of supports of container can be done by calculation or experiment			

2.3.	**Design temperature**			
2.3.1.	*Inner tank and outer jacket* Design temperature of inner tank and outer jacket to be 20°C		No similar requirement	
2.3.2.	For all other equipment not mentioned under section 2.3.1., design temperature is lowest respectively the highest possible operating temperature in section 1.3. of Part 1		No similar requirement	
2.3.3.	Thermal stresses by operating conditions like filling or withdrawal or during cooling down process to be considered		No similar requirement	
2.4.	**Chemical compatibility**			
2.4.1.	Materials of container and its equipment to be compatible with: a) hydrogen, if parts are in contact with it; b) the atmosphere, if parts are in contact with it; c) any other media parts are in contact with (i.e. coolant etc.).		No similar requirement	
3.	MATERIALS			
3.1.	Materials to be composed, manufactured and treated in a manner that: a) finished products show required mechanical properties; b) finished products used for pressurised components and in contact with hydrogen, resist thermal, chemical and mechanical stresses, and are		No similar requirements	

	compatible with cryogenic temperatures to EN 1252-1 (if in contact with cryogenic temperatures)			
3.2.	**Characteristics**			
3.2.1.	Materials used at low temperatures to follow toughness requirements of EN 1252-1; for non-metallic materials, low temperature suitability to be validated by an experimental method, taking service conditions into account		No similar requirement	
3.2.2.	Materials used for outer jacket to ensure integrity of insulation system, and their elongation at fracture in a tensile test to be at least 12% at liquid nitrogen temperature		No similar requirement	
3.2.3.	Corrosion allowance not required for inner tank, and not on other surfaces if adequately protected against corrosion		No similar requirement	
3.3. (3.3.1 to 3.3.5)	**Certificates and proofs of material characteristics** Various requirements covering filler materials, chemical cast analysis and mechanical properties certificates, instructions for technical services and manufacturers and markings on material sheets		No similar requirements	
3.4.	**Design calculation**			
3.4.1.	Provisions regarding the inner tank: Design of the inner tank to be to design rules of EN 1251-2	B.7.2.1.3	**Baseline pressure cycle life** When using metallic containers and/or metallic vacuum jackets, manufacturer must	Draft GTR includes separate specifications for metallic and non-metallic containers

3.4.2.	Provisions regarding the outer jacket: Design of the outer jacket to be to design rules of EN 1251-2.		either provide a calculation to demonstrate that tank is designed to current regional legislation or accepted standards for cryogenic pressure vessels (e.g. in US, ASME Boiler and Pressure Vessel Code, in Europe EN 1251-1 and EN 1251-2) or they must define and perform suitable tests (including B.7.4.1.3), which prove same level of safety For non-metallic containers and/or vacuum jackets, suitable test must be designed by the manufacturer to prove same safety as metallic container (as well as B.7.3.1.3)	
3.4.3.	The general tolerances of ISO 2768-1 to apply			
4.	MANUFACTURING AND MOUNTING OF THE CONTAINER			
4.1. to 4.8.	Various requirements for manufacturing and mounting of container, including welding quality systems, minimising number of joints, standards for manufacturing operations, etc		No similar requirements	
5.	OTHER REQUIREMENTS			
5.1.	**Protection of the outer jacket** Outer jacket to be protected by means of a device preventing bursting of outer jacket or collapsing of inner tank		No similar requirement high-level requirement for protection	
5.2.	**Provisions regarding insulation** Under no circumstances may ice be allowed to form on outer wall of container under normal operating conditions, but local ice formation allowed on outside of pressure relief pipe		No similar requirement	
5.3.	**Level gauge**			
5.3.1.	Measuring gauge in driver’s compartment to		No similar requirement	

	indicate level of liquid in container with accuracy of ± 10%			
5.3.2.	If system comprises a float, it shall withstand outside pressure greater than MAWP of inner tank with minimum coefficient of safety of 2 with respect to buckling failure criteria		No similar requirement	
5.4.	**Maximum filling level**			
5.4.1.	System to be provided for preventing container from being overfilled, it may work in conjunction with refuelling station, and shall bear a marking indicating container type and mounting position and orientation		No similar requirement	
5.4.2.	Filling process not to lead to any PRD coming into operation irrespective of time passed during/after filling process, and filling process not to lead to operating conditions the BMS is not designed to handle		No similar high-level requirement	Although not directly comparable, the draft GTR specifies a boil-off test that requires PRD not to activate during the whole test, which presumably includes the filling process.
5.5. (5.5.1 and 5.5.2)	**Marking** Detailed marking requirements are specified for inner tank and outer jacket	B.5.1.6	**Labelling** Label to be fixed permanently on each container with at least: Name of manufacturer, serial number, date of manufacture, NWP, type of fuel and date of removal from service	The EU regulation specifies separate requirements for the inner tank and outer jacket The EU regulation specifies more labelling requirements than the draft GTR
5.6.	**Inspection openings** Inspection openings not required in inner or outer jacket		No similar requirement	
6.	TESTS AND INSPECTION			
6.1.	**Tests and inspection for the approval** Technical service to perform tests and	B.7.1	Hydrogen storage system may be qualified to performance test requirements specified in this section	

	inspections to sections 6.3.1. to 6.3.6. on two samples of containers Samples of container to be subjected to tests according to 6.3.7. to 6.3.9. and to be witnessed by technical service			
6.2.	**Tests and inspection during production** Tests and inspections to sections 6.3.1. to 6.3.6. to be performed on each container	B.7.2	All liquefied hydrogen storage systems produced for on-road vehicle service must be capable of satisfying the requirements of this section	The draft GTR does not specify production tests (i.e. tests on all tanks), but requires that all systems in use must be capable of meeting the requirements
6.3.	**Testing procedures**			
6.3.1.	*Pressure test*	B.7.4.1.1	Proof pressure test	
6.3.1.1.	Inner tank and pipe work between inner tank and the outer jacket to withstand an inner pressure test at room temperature with any suitable media, according to the following requirements. The test pressure p_{test} shall be: $p_{test} = 1.3(MAWP + 0.1MPa)$	B.7.4.1.1	The test pressure p_{test} to be defined by manufacturer and to fulfil the following requirements: • $p_{test} \geq 1.3$ (MAWP + 0.1 MPa) • For metallic containers p_{test} to be either at least equal to maximum pressure of inner container during fault management (as determined in B.7.4.2.3) or manufacturer to prove by calculation that at maximum pressure of inner container during fault management no yield occurs • For other materials than metallic, p_{test} to be at least equal to the maximum pressure of the inner container during fault management (as determined in B.7.4.2.3)	The draft GTR contains additional specifications depending on container materials
6.3.1.2.	Pressure test to be performed before the outer jacket is mounted	B.7.4.1.1	a) Test to be done on inner storage container and interconnecting pipes between inner storage container and vacuum jacket before the outer jacket is mounted	

6.3.1.3.	Pressure in inner tank to be increased at a constant rate until the test pressure is reached	B.7.4.1.1	b) The test to be done either hydraulic with water or a glycol/water mixture or alternatively with gas; Container to be pressurised to test pressure p_{test} in an even rate and kept at that pressure for at least 10 minutes	
6.3.1.4.	The inner tank must remain under the test pressure at least for 10 minutes to establish that the pressure is not reducing			
6.3.1.5.	After the test the inner tank must not show any signs of visible permanent deformation or visible leaks	B.7.4.1.1	The test is passed when during at least 10 minutes after applying the proof pressure no visible permanent deformation, no visible degradation in the container pressure and no visible leakage are detectable	
6.3.1.6.	Any inner tank tested which does not pass the test because of permanent deformation shall be rejected and shall not be repaired			
6.3.1.7.	Any inner tank tested which does not pass the test because of leakage may be accepted after repair and retesting			
6.3.1.8.	In case of hydraulic test, upon completion of this test, container to be emptied and dried until the dew point inside the container is –40°C, according to EN 12300		No similar requirement	
6.3.1.9.	Test report to be drawn up and inner tank to be marked by inspection departments if accepted		No similar requirement	
6.3.2.	*Leak testing* After final assembly, hydrogen container to be leak tested with a gas mixture containing a minimum of 10 per cent of helium	B.7.2.2.2	Leak After boil-off test (with liquid hydrogen), system to be kept at boil-off pressure and total discharge rate due to leakage to be measured according to procedure in B.7.4.2.2 Maximum allowable discharge from the storage system: R*150 NmL/min where R = $(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4$ and V_{width}, V_{height} and V_{length} are the vehicle width, height, length (m) respectively	The EU regulation does not appear to specify a performance requirement

6.3.3.	*Verification of the dimensions* The following dimensions shall be verified: – for cylindrical container(s) roundness of the inner tank according to EN 1251-2:2000, 5.4 – departure from a straight line of the inner and outer jacket according to EN 1251-2, 5.4		No similar requirements	
6.3.4.	*Destructive and non-destructive tests of welding seams* The tests shall be performed according to EN 1251-2.		No similar requirement	
6.3.5.	*Visual inspection* Welding seams and inner and outer surfaces of inner and outer jackets of container to be inspected visually, surfaces not to show any critical damages or defaults		No similar requirement	
6.3.6.	*Marking* The marking shall be verified in accordance with section 5.5	B.5.1.6	**Labelling** Label to be fixed permanently on each container with at least: Name of manufacturer, serial number, date of manufacture, MAWP, type of fuel and date of removal from service	See earlier remarks for section 5.5
6.3.7.	*Burst test* The burst test shall be performed on one sample of the inner tank, not integrated in its outer jacket and not insulated	B.7.2.1.2	Baseline initial burst pressure Burst test to be performed on one sample of the inner container, not integrated in its outer jacket and not insulated (and to	

			procedure in B.7.4.1.2)	
6.3.7.1.	Criteria			
6.3.7.1.1.	Burst pressure to be at least equal to burst pressure used for the mechanical calculations. For steel tanks that is: a) either the MAWP (in MPa) plus 0.1 MPa multiplied by 3.25; b) or MAWP (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp, where Rm means minimum ultimate tensile strength and Rp means minimum yield strength	B.7.2.1.2	Burst pressure to be at least equal to burst pressure used for the mechanical calculations. For steel containers that is: • either the MAWP (in MPa) plus 0.1 MPa multiplied by 3.25; • or the MAWP (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp, where Rm means minimum ultimate tensile strength and Rp means minimum yield strength of the container material	
6.3.7.1.2.	Hydrogen containers made from materials other than steel to be demonstrated to perform as safely as containers complying with the requirements set out in points 6.3.7.1.1. and 6.3.7.1.2	B.7.3.1.2	For inner containers made out of an aluminium alloy or other material, a passing criterion to be defined which guarantees at least the same level of safety compared to steel inner containers	
6.3.7.2.	Procedure			
6.3.7.2.1.	Tested tank to be representative of the design and manufacturing of the type to be approved		No similar requirement	
6.3.7.2.2	The test shall be a hydraulic test	B.7.4.1.2	b) The test shall be done hydraulically with water or a water/glycol mixture	
6.3.7.2.3	Tube and piping may be modified to enable the test (purge of dead volume, introduction of the liquid, closing of non-used pipes, etc.)		No similar requirement	
6.3.7.2.4	The tank to be filled with water, pressure to be increased at a constant rate not exceeding 0.5 MPa/min until burst	B.7.4.1.2	b) The test shall be done hydraulically with water or a water/glycol mixture c) Pressure shall be increased at a constant	

	When MAWP is reached there shall be a wait period of at least 10 minutes at constant pressure so that the deformation of the tank shall be checked		rate not exceeding 0.5 MPa/min until burst or leakage of the container occurs d) When MAWP is reached there shall be a wait period of at least 10 minutes at constant pressure so that the deformation of the tank shall be checked	
6.3.7.2.5	A system shall enable to look at possible deformations		No similar requirement	
6.3.7.2.6	Pressure to be recorded or written during the entire test	B.7.4.1.2	e) Pressure to be recorded or written during the entire test	
6.3.7.3.	Results Test conditions and bursting pressure to be written in a test certificate signed by the manufacturer and the technical service		No similar requirement	
6.3.8.	*Bonfire test*			
6.3.8.1.	Criteria			
6.3.8.1.	Tank shall not burst and pressure inside inner tank shall not exceed permissible fault range of inner tank; in case of steel inner tanks, the secondary pressure relief device shall limit the pressure inside the tank to 136%MAWP of inner tank, if a safety valve is used as secondary pressure relief device In case of steel inner tanks, secondary pressure relief device shall limit pressure inside tank to 150%MAWP of inner tank, if a burst disk is used outside the vacuum area as secondary pressure relief device In case of steel inner tanks, secondary pressure relief device shall limit pressure inside tank to 150%(MAWP + 0.1 MPa) of inner tank, if a burst disk is used inside the	B.7.4.3	**Verification test for service-terminating performance due to fire** The test is passed when the following criteria are met: a) Secondary PRD not to operate below 110% of set pressure of primary PRD b) Tank shall not burst and pressure inside inner tank shall not exceed the permissible fault range of the inner tank Permissible fault range for steel tanks is as follows: If a safety valve is used as second PRD, the pressure inside the tank not to exceed	

	vacuum area as secondary pressure relief device For other materials, an equivalent level of safety shall be demonstrated The secondary pressure relief device shall not operate below 110% set pressure of the primary pressure relief device		136%MAWP of inner tank If a burst disk is used outside the vacuum area as second PRD, the pressure inside tank not to exceed 150%MAWP of inner tank If a burst disk is used inside the vacuum area as second PRD, the pressure inside tank not to exceed 150%(MAWP + 0.1 MPa) of inner tank For other materials, an equivalent level of safety shall be demonstrated	
6.3.8.2.	Procedure			
6.3.8.2.1.	Tested tank to be representative of design and manufacturing of the type to be approved	B.7.4.3	Tested liquid hydrogen storage system to be representative of design and the manufacturing of type to be homologated	
6.3.8.2.2.	Its manufacturing shall be completely finished and it shall be mounted with all its equipment	B.7.4.3	Its manufacturing shall be completely finished and it shall be mounted with all its equipment	
6.3.8.2.3.	The tank shall already be cooled down and the inner tank shall be at the same temperature as the liquid hydrogen The tank shall have contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner tank	B.7.4.3	a) The bonfire test is conducted with a completely cooled-down container (according to the procedure in B.7.4.2.1) b) The tank to have contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner tank	
6.3.8.2.3.1	The tank shall be filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system shall be half of the maximum allowed quantity that may be contained in the inner tank	B.7.4.3	c) The tank is filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system is half of the maximum allowed quantity that may be contained in the inner tank	
6.3.8.2.3.2	A fire shall burn 0.1 m underneath the tank; the length and the width of the fire	B.7.4.3	d) A fire burns 0.1 m underneath the tank; the length and the width of the fire	

	shall exceed the plan dimensions of the container by 0.1 m; the temperature of the fire shall be at least 590 °C; the fire shall continue to burn for the duration of the test		exceed the plan dimensions of the container by 0.1 m; the temperature of the fire is at least 590 ºC; the fire shall continue to burn for the duration of the test	
6.3.8.2.3.3	The pressure of the tank at the beginning of the test shall be between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner tank	B.7.4.3	e) The pressure of the tank at the beginning of the test is between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner tank	
6.3.8.2.3.4	Once safety device opens, test shall continue until the blow off of the safety device has finished; during the test the tank shall not burst and the pressure inside the inner tank shall not exceed the permissible fault range of the inner tank; in the case of steel inner tanks, the tank pressure shall not exceed 136%MAWP of the inner tank; for other materials, an equivalent level of safety shall be applied	B.7.4.3	f) The test shall continue until the storage pressure decreases to, or below, the pressure at beginning of test, or in case the first PRD is a reclosing type, the test continues until the safety device has opened for a second time	There have been several discussions within HFCV-SGS regarding the need to specify a clear end to this test, and to take account of systems in which the PRD could close, but reopen again, as well as systems in which the device is non-reclosing The requirement is intended to be comparable to the test with gaseous systems whereby the test is finished when the pressure fails below 1 MPa
6.3.8.3.	The test conditions and the maximum pressure reached within the tank during the test shall be recorded in a test certificate signed by the manufacturer and the technical service	B.7.4.3	g) The test conditions and the maximum pressure reached within the tank during the test are recorded in a test certificate signed by the manufacturer and the technical service	
6.3.9.	*Maximum filling level test*			
6.3.9.1.	Criteria During all tests necessary for approval, filling process shall not lead to any pressure relief device coming into operation irrespective of time passed during/after the filling process; the filling process shall not lead to operating conditions the BMS is not designed for and therefore cannot handle		No maximum filling level test	The draft GTR specifies a boil-off test, in which the PRDs are not allowed to open, but it is not directly comparable A boil-off test (to check that the boil-off management system limits the pressure to the MAWP) is not required in the EU regulation

6.3.9.2.1.	The tested tank shall be representative of the design and the manufacturing of the type to be approved			
6.3.9.2.2.	Its manufacturing shall be completely finished and it shall be fitted with all its equipment and particularly the level gauge			
6.3.9.2.3.	Tank to already be cooled down and inner tank to be at the same temperature as the liquid hydrogen; the tank shall have contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner tank			
6.3.9.2.4.	The mass of hydrogen or the mass flow rate at the inlet and the outlet of the tank shall be measured with an accuracy better than 1 per cent of the maximum filling mass of the tested container			
6.3.9.2.5.	The tank shall be completely filled 10 times with liquid hydrogen at equilibrium with its vapour, between each filling at least a quarter of the liquid hydrogen of the tank shall be emptied			
6.3.9.3.	Results The test conditions and the ten maximum level measured by the added system shall be written in a test certificate signed by the manufacturer and the technical service			

B.4 Part 3 – Requirements for hydrogen components other than containers designed to use liquid hydrogen

(EU) No. 406/2010 (Annex III)		Draft Global Technical Regulation		Remark
Para. No.	**Text**	**Para. No.**	**Text**	
2.	GENERAL REQUIREMENTS			
2.1.	Materials used in hydrogen components to be compatible with hydrogen in accordance with section 4.11		No similar requirement	
2.2.	Hydrogen system upstream of first pressure regulator, excluding the hydrogen container, to have MAWP equal to maximum pressure component is subjected to but at least 1.5 times set pressure of the primary safety relief device of the inner tank and a coefficient of safety not less than that of the inner tank		No similar requirement	
2.3.	Components downstream of pressure regulator(s) shall be protected against over-pressurisation and shall be designed for at least 1.5 times the outlet pressure (MAWP) of the first pressure regulator upstream		No similar requirement	
2.4.	Insulation of components to prevent liquefaction of air in contact with outer surfaces, unless system provided for collecting and vaporising liquefied air, then materials of components nearby to be compatible with atmosphere enriched with oxygen to EN 1797	B.7.3.2	Insulation of components to prevent liquefaction of air in contact with outer surfaces, unless system provided for collecting and vaporising liquefied air, then materials of components nearby to be compatible with atmosphere enriched with oxygen	
3.	TECHNICAL REQUIREMENTS			
3.1.	**Pressure relief devices**			

3.1.1.	*Pressure relief devices for the inner tank*			
3.1.1.1.	The primary pressure relief device for the inner tank shall limit the pressure inside the tank to not more than 110%MAWP, even in case of a sudden vacuum loss; this device shall be a safety valve or equivalent and shall be connected directly to the gaseous part under normal operating conditions		No similar high-level requirement	The draft GTR specifies performance tests for pressure relief devices (summarised below) The draft GTR also specifies a vacuum loss test, which requires that the PRD limits the pressure of the inner tank to not more than 110%MAWP
3.1.1.2.	The secondary pressure relief device for the inner tank shall be installed to ensure that the pressure in the tank cannot under any circumstances exceed the permissible fault range of the inner tank In the case of steel inner tanks, the secondary pressure relief device shall limit the pressure in the tank to 136%MAWP of the inner tank, if a safety valve is used as secondary pressure relief device In case of steel inner tanks, the secondary pressure relief device shall limit the pressure in the tank to 150%MAWP of the inner tank, if a burst disk is used outside the vacuum area as secondary pressure relief device In case of steel inner tanks, the secondary pressure relief device shall limit the pressure in the tank to 150%(MAWP + 0.1 MPa) of the inner tank, if a burst disk is used inside the vacuum area as secondary pressure relief device For other materials, an equivalent level of safety shall be demonstrated The secondary pressure relief device shall not operate below 110% of set pressure of		No similar high-level requirement	See above; these requirements are part of the vacuum loss test

	the primary pressure relief device			
3.1.1.3.	The sizing of the safety devices shall be done in accordance with EN 13648-3		No similar requirement	
3.1.1.4.	The two devices referred to in sections 3.1.1.1. and 3.1.1.2. may be connected to the inner tank by the same fuel line		No similar requirement	
3.1.1.5.	The rating of the pressure relief devices shall be clearly marked; Tampering with the devices shall be prevented by means of a lead seal or equivalent system		No similar requirement	
3.1.1.6.	Pressure relief valves shall, after discharge, close at a pressure higher than 90% of set pressure of the pressure relief valve; They shall remain closed at all lower pressures		No similar requirement	
3.1.1.7.	Pressure relief valves shall be installed on the gaseous fraction area of the hydrogen tank		No similar requirement	
3.1.2.	*Pressure relief devices for other components*			
3.1.2.1.	Whenever there is a risk of cryogenic liquid or vapour becoming trapped between two items of equipment on a line, a pressure relief device or a measure ensuring an equivalent level of safety shall be provided		No similar requirement	
3.1.2.2.	Upstream of the first pressure regulator the set pressure of the safety device which prevents over-pressurisation shall not exceed the MAWP of the lines and shall not be less than 120%MAWP of the tank, to prevent such valves opening instead of the pressure relief devices for the inner tank		No similar requirement	
3.1.2.3.	The rating of pressure relief devices downstream of the pressure regulator(s)		No similar requirement	

	shall not exceed the MAWP of the components downstream of the pressure regulator			
3.1.2.4.	Pressure relief valves shall, after discharge, close at a pressure higher than 90% of the set pressure of the pressure relief valve. They shall remain closed at all lower pressures		No similar requirement	
3.1.3.	*Provisions regarding the approval of pressure relief devices*			
3.1.3.1.	The design, manufacturing and control of the pressure relief devices shall be in accordance with EN 13648-1 and EN 13648-2		No similar requirement	
3.1.3.2.	In case of boil off system in parallel of the primary safety device, then the safety valve shall be a category B safety device otherwise it shall be a category A safety device according to EN 13648		No similar requirement	
3.1.3.3.	MAWP: 1.5×MAWP of the inner tank or maximum pressure the component is subjected to		No similar requirement	
3.1.3.4.	Set pressure			
3.1.3.4.1.	Primary devices of the inner tank: according to section 3.1.1.1		No similar requirement	
3.1.3.4.2.	Secondary device of the inner tank: according to section 3.1.1.2		No similar requirement	
3.1.3.4.3.	Pressure relief devices for components other than the tank: according to section 3.1.2		No similar requirement	
3.1.3.5.	Design temperature			

3.1.3.5.1.	External temperature: according to section 1.3 of Part 1.		No similar requirement	
3.1.3.5.2.	Internal temperature: – 253 °C to + 85 °C		No similar requirement	
3.1.3.6.	Applicable test procedures: Pressure test section 4.2 External leakage test section 4.3 Operational test section 4.5 Corrosion resistance section 4.6, only for metallic parts, only for equipment outside of the gas tight housing Temperature cycle test section 4.9, only for non-metallic parts	B.7.2.4.1	Pressure relief devices qualification requirements Design qualification testing to be conducted on finished PRDs which are representative of normal production: • Pressure test • External leakage test • Operational test • Corrosion resistance test • Temperature cycle test	
3.1.4.	*Lines incorporating pressure relief devices*			
3.1.4.1.	No isolating device shall be installed between the protected component and the pressure relief device		No similar requirement	
3.1.4.2.	The lines before and behind the pressure relief devices shall not impede their function and shall be compatible with the criteria defined in sections 3.1.1. to 3.1.3.		No similar requirement	
3.2.	**Valves**			
3.2.1.	*Provisions regarding the approval of hydrogen valves*			
3.2.1.1.	The design, manufacturing and checking of the cryogenic hydrogen valves shall be in accordance with EN 13648-1 and EN 13648-2		No similar requirement	

3.2.1.2.	MAWP: 1.5xMAWP of the inner tank or maximum pressure the valve is subjected to		No similar requirement	
3.2.1.3.1.	External temperature: according to section 1.3 of Part 1		No similar requirement	
3.2.1.3.2.	Internal temperature: – 253 °C to + 85 °C for valves before the heat exchanger – 40 °C to + 85 °C for valves after the heat exchanger		No similar requirement	
3.2.1.4.	Applicable test procedures: Pressure test section 4.2 External leakage test section 4.3 Endurance test section 4.4 (with 6,000 cycles for manual valves & 20,000 cycles for automatic valves) Corrosion resistance section 4.6, only for metallic parts, only for equipment outside of the gas tight housing Resistance to dry-heat section 4.7, only for non-metallic parts Ozone ageing section 4.8, only for non-metallic parts Temperature cycle test section 4.9, only for non-metallic parts Seat leakage test section 4.12	B.7.2.4.2	Shut-off valves qualification requirements Design qualification testing to be conducted on finished shut-off valves which are representative of normal production: • Pressure test • External leakage test • Endurance test • Corrosion resistance test • Resistance to dry-heat test • Ozone ageing test • Temperature cycle test • Flex line cycle test	
3.3.	**Heat exchangers**			

3.3.1.	Notwithstanding the provision of section 2.1. the Maximum Allowable Working Pressure (MAWP) of the heat exchanger shall be the highest Maximum Allowable Working Pressure (MAWP) of the different circuits		No similar requirement	
3.3.2.	The exhaust gases from the propulsion system shall not under any circumstances be used directly in the heat exchanger		No similar requirement	
3.3.3.	A safety system shall be provided to: prevent failure of the heat exchanger; and prevent any cryogenic liquid or gas from entering the other circuit and the system located downstream of it, if it has not been designed for this		No similar requirement	
3.3.4.	*Provisions regarding the approval of hydrogen valves*			The requirement refers to heat exchangers not hydrogen valves
3.3.4.1.	MAWP: 1.5×MAWP of the inner tank or maximum pressure the component is subjected to		No similar requirement	
3.3.4.2.	Design temperatures External temperature: according to section 1.3 of Part 1. Internal temperature: −253 °C to + 85 °C		No similar requirement	
3.3.4.3.	Applicable test procedures Pressure test section 4.2 External leakage test section 4.3 Corrosion resistance section 4.6, only for metallic parts Resistance to dry-heat section 4.7, only for		No similar requirement	

	non-metallic parts Ozone ageing section 4.8, only for non-metallic parts Temperature cycle test section 4.9, only for non-metallic parts			
3.3.4.4.	The manufacturing and mounting of the heat exchanger shall be certified according to sections 4.3. to 4.5 of Part 2		No similar requirement	
3.4.	**Refuelling connections or receptacles**			
3.4.1.	Refuelling connections or receptacles to be protected against contamination		No similar requirement	Fuelling receptacle requirements in B.5.2.1.1 do not apply to vehicles with liquid hydrogen systems (see B.7.3)
3.4.2	Specifies provisions, design temperatures and test procedures		No similar requirement	
3.5.	**Pressure regulators**			
3.5.1	Specifies provisions, design temperatures and test procedures		No similar requirement	
3.6.	**Sensors**			
3.6.1.	Specifies provisions, design temperatures and test procedures		No similar requirement	
3.7.	**Flexible fuel lines**			
3.7.1	Specifies provisions, design temperatures and test procedures		No similar requirement	
3.8.	**Provisions regarding electrical components of the hydrogen system**			

3.8.1.	To prevent electric sparks: a) electrically operated devices containing hydrogen shall be insulated in a manner that no current passes through hydrogen containing parts; b) the electrical system of the electrically operated device shall be insulated from the body of the vehicle; c) the electric circuit insulation resistance (batteries and fuel cells excluded), shall exceed 1 kΩ for each volt of the nominal voltage		No similar requirement	
3.8.2.	In case of power supply bushing to establish an isolated and tight electrical connection, the electric connection shall be of a hermetic sealed type		No similar requirement	
4.	TEST PROCEDURES			
4.1.	**General provisions**			
4.1.1.	Leakage tests shall be conducted with pressurised gas such as air or nitrogen containing at least 10 per cent helium	B.7.4.4	**Component verification tests** Testing shall be performed with hydrogen gas quality compliant with ISO 14687-2/SAE J2719	
4.1.2.	Water or another fluid may be used to obtain the required pressure for pressure test		No similar requirement	
4.1.3.	All test records shall indicate the type of test medium used, if applicable		No similar requirement	
4.1.4.	The test period for leakage and pressure tests shall be not less than 3 minutes more than the response time of the sensor		No similar requirement	

4.1.5.	All tests shall be performed at ambient temperature, unless otherwise stated	B.7.4.4	**Component verification tests** All tests to be performed at ambient temperature 20(±5)°C unless otherwise specified	
4.1.6.	The different components shall be correctly dried before leak test		No similar requirement	
4.2.	**Pressure test**	B.7.4.4.1	**Pressure test**	
4.2.1.	A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 1.5MAWP with the outlets of the high pressure part plugged, the pressure shall then be increased from 1.5 to 3 times the MAWP The component shall not show any visible evidence of rupture or cracks	B.7.4.4.1	A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 1.5MAWP with the outlets of the high pressure part plugged, the pressure shall then be increased from 1.5 to 3 times the MAWP The component shall not show any visible evidence of rupture or cracks	
4.2.2.	The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge, having a pressure range of not less than 1.5x nor more than 2x test pressure and the accuracy of the gauge shall be 1% of the pressure range	B.7.4.4.1	The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge, having a pressure range of not less than 1.5x nor more than 2x test pressure and the accuracy of the gauge shall be 1% of the pressure range	
4.2.3.	For components requiring a leakage test, this test shall be performed prior to the pressure test	B.7.4.4.1	For components requiring a leakage test, this test shall be performed prior to the pressure test	
4.3.	**External leakage test**	B.7.4.4.2	**External leakage test**	
4.3.1.	A component shall be free from leakage, and shall not show evidence of porosity in casting when tested as described in section 4.4.3. at any gas pressure between zero and its MAWP	B.7.4.4.2	A component shall be free from leakage, and shall not show evidence of porosity in casting when tested as described in section B.7.4.4.3.3 at any gas pressure between zero and its MAWP	

4.3.2.	The test shall be performed on the same equipment at the following conditions: at ambient temperature; at the minimum operating temperature or at liquid nitrogen temperature after sufficient conditioning time at this temperature to ensure thermal stability; at the maximum operating temperature after sufficient conditioning time at this temperature to ensure thermal stability	B.7.4.4.2	The test shall be performed on the same equipment at the following conditions: • at ambient temperature; • at the minimum operating temperature or at liquid nitrogen temperature after sufficient conditioning time at this temperature to ensure thermal stability; • at the maximum operating temperature after sufficient conditioning time at this temperature to ensure thermal stability	
4.3.3.	During this test the equipment under test shall be connected to a source of gas pressure. A positive shut-off valve and a pressure gauge having a pressure range of not less than 1.5x nor more than 2x test pressure shall be installed in the pressure supply piping and the accuracy of the gauge shall be 1% of the pressure range The pressure gauge shall be installed between the positive shut-off valve and the sample under test	B.7.4.4.2	During this test the equipment under test shall be connected to a source of gas pressure. A positive shut-off valve and a pressure gauge having a pressure range of not less than 1.5x nor more than 2x test pressure shall be installed in the pressure supply piping and the accuracy of the gauge shall be 1% of the pressure range The pressure gauge shall be installed between the positive shut-off valve and the sample under test	
4.3.4.	Throughout the test, the sample shall be tested for leakage, with a surface active agent without formation of bubbles or measured with a leakage rate less than 10 cm^3/hour	B.7.4.4.2	Throughout the test, the sample shall be tested for leakage, with a surface active agent without formation of bubbles or measured with a leakage rate less than 10 cm^3/hour	
4.4.	**Endurance test**	B.7.4.4.3	**Endurance test**	
4.4.1.	A hydrogen component shall be capable of conforming to the applicable leakage test requirements of sections 4.3. and 4.12., after being subjected to the number of operation cycles specified for component in sections 3.1. to 3.7. of Part 3	B.7.4.4.3.1	A hydrogen component shall be capable of conforming to the applicable leakage test requirements of sections B.7.3.4.2 and B.7.3.4.9., after being subjected to 20,000 operation cycles	

4.4.2.	The appropriate tests for external leakage and seat leakage, as described in sections 4.3. and 4.12. shall be carried out immediately following the endurance test	B.7.4.4.3.2	The appropriate tests for external leakage and seat leakage, as described in sections B.7.4.4.2 and B.7.4.4.9 shall be carried out immediately following the endurance test	
4.4.3.	The component shall be securely connected to a pressurised source of dry air or nitrogen and subjected to the number of cycles specified for that specific component in sections 3.1. to 3.7. of Part 3 A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds	B.7.4.4.3.3	The component shall be securely connected to a pressurised source of dry air or nitrogen and subjected to 20,000 operation cycles A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds	
4.4.4.	The component shall be operated through 96% of the number of specified cycles at ambient temperature and at the MAWP of the component During the off cycle the downstream pressure of the test fixture shall be allowed to decay to 50% of the MAWP of the component	B.7.4.4.3.4	The component shall be operated through 96% of the number of specified cycles at ambient temperature and at the MAWP of the component During the off cycle the downstream pressure of the test fixture shall be allowed to decay to 50% of the MAWP of the component	
4.4.5.	The component shall be operated through 2% of the total cycles at the maximum material temperature (according to section 1.3 of Part 1) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP The component shall comply with sections 4.3. and 4.12. at the appropriate maximum material temperature (according to section 1.3 of Part 1) at the completion of the high temperature cycles	B.7.4.4.3.5	The component shall be operated through 2% of the total cycles at the maximum material temperature (-40°C to +85°C) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP The component shall comply with sections B.7.4.4.2 and B.7.4.4.9 at the appropriate maximum material temperature (-40°C to +85°C) at the completion of the high temperature cycles	
4.4.6.	The component shall be operated through 2% of the total cycles at the minimum material temperature (according to section	B.7.4.4.3.6	The component shall be operated through 2% of the total cycles at the minimum material temperature (-40°C to +85°C) but not less	

	1.3 of Part 1) but not less than the temperature of liquid nitrogen after sufficient conditioning time at this temperature to ensure thermal stability and at the MAWP of the component The component shall comply with sections 4.3. and 4.12. at the appropriate minimum material temperature (according to section 1.3 of Part 1) at the completion of the low temperature cycles		than the temperature of liquid nitrogen after sufficient conditioning time at this temperature to ensure thermal stability and at the MAWP of the component The component shall comply with sections B.7.4.4.2 and B.7.4.4.9 at the appropriate minimum material temperature (-40°C to +85°C) at the completion of the low temperature cycles	
4.5.	**Operational test**	B.7.4.4.4	**Operational test**	
4.5.1.	The operational test shall be carried out in accordance with EN 13648-1 or EN 13648 2 The specific requirements of the standard are applicable	B.7.4.4.4	The operational test shall be carried out in accordance with EN 13648-1 or EN 13648 2 The specific requirements of the standard are applicable	
4.6.	**Corrosion resistance test**	B.7.4.4.5	**Corrosion resistance test**	
4.6.1.	Metallic hydrogen components shall comply with the leakage tests referred to in sections 4.3. and 4.12. after being submitted to 144 hours salt spray test according to ISO 9227 with all connections closed.	B.7.4.4.5	Metallic hydrogen components shall comply with the leakage tests referred to in sections B.7.4.4.2 and B.7.4.4.9 after being submitted to 144 hours salt spray test according to ISO 9227 with all connections closed	
4.6.2	A copper or brass hydrogen containing component shall comply with the leakage tests referred to in sections 4.3. and 4.12. and after being submitted to 24 hours immersion in ammonia according to ISO 6957 with all connections closed	B.7.4.4.5	A copper or brass hydrogen containing component shall comply with the leakage tests referred to in sections B.7.4.4.2 and B.7.4.4.9 and after being submitted to 24 hours immersion in ammonia according to ISO 6957 with all connections closed	
4.7.	**Resistance to dry-heat test** The test shall be carried out in compliance with ISO 188	B.7.4.4.6	**Resistance to dry-heat test** The test shall be carried out in compliance with ISO 188	

	The test piece shall be exposed to air at a temperature equal to the maximum operating temperature for 168 hours The change in tensile strength shall not exceed + 25% The change in ultimate elongation shall not exceed the following values: – maximum increase 10%; – maximum decrease 30%		The test piece shall be exposed to air at a temperature equal to the maximum operating temperature for 168 hours The change in tensile strength shall not exceed +25% The change in ultimate elongation shall not exceed the following values: • maximum increase 10%; • maximum decrease 30%	
4.8.	**Ozone ageing test**	B.7.4.4.7	**Ozone ageing test**	
4.8.1.	The test shall be in compliance with ISO 1431-1 The test piece, which shall be stressed to 20% elongation, shall be exposed to air at + 40 °C with an ozone concentration of 50 parts per hundred million during 120 hours	B.7.4.4.7	The test shall be in compliance with ISO 1431-1 The test piece, which shall be stressed to 20% elongation, shall be exposed to air at + 40 °C with an ozone concentration of 50 parts per hundred million during 120 hours	
4.8.2.	No cracking of the test piece is allowed	B.7.4.4.7	No cracking of the test piece is allowed	
4.9.	**Temperature cycle test** A non-metallic part containing hydrogen shall comply with the leakage tests referred to in sections 4.3. and 4.12. after having been submitted to a 96 hours temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP	B.7.4.4.8	**Temperature cycle test** A non-metallic part containing hydrogen shall comply with the leakage tests referred to in sections B.8.3.2 and B.8.3.9 after having been submitted to a 96 hours temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP	
4.10	**Pressure cycle test**	B.7.4.4.9	**Flex line cycle test**	

4.10.1	Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements referred to in section 4.3., after being subjected to 6,000 pressure cycles	B.7.4.4.9	Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements in section B.7.4.4.2 and B.7.4.4.9 after being subjected to 6,000 pressure cycles	
4.10.2	The pressure shall change from atmospheric pressure to the Maximum Allowable Working Pressure (MAWP) of the tank within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds	B.7.4.4.9	The pressure shall change from atmospheric pressure to the Maximum Allowable Working Pressure (MAWP) of the tank within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds	
4.10.3	The appropriate test for external leakage, as referred to in section 4.3. shall be carried out immediately following the endurance test	B.7.4.4.9	The appropriate test for external leakage, as referred to in section B.7.4.4.2 shall be carried out immediately following the endurance test	
4.11.	**Hydrogen compatibility test**			
4.11.1	The hydrogen compatibility shall be proved according to ISO 11114-4.		No similar requirement	
4.11.2	The materials of the components in contact with cryogenic temperatures shall be compatible with cryogenic temperatures according to EN 1252-1		No similar requirement	
4.12.	**Seat leakage test**			
4.12.1.	The seat leakage tests shall be carried out on samples which have previously been subjected to the external leakage test referred to in section 4.3		No similar requirement	
4.12.2.	Seat leakage tests shall be conducted with the inlet of the sample valve connected to a source of gas pressure, the valve in the closed position, and with the outlet open A positive shut-off valve and a pressure			

	gauge having a pressure range of not less than 1.5x and not more than 2x test pressure shall be installed in the pressure supply piping and the accuracy of the gauge shall be 1% of the pressure range The pressure gauge shall be installed between the positive shut-off valve and the sample under test While under the applied test pressure corresponding to the MAWP, observations for leakage shall be made with the open outlet submerged in water or by a flow meter installed on the inlet side of the valve under test The flow meter shall be capable of indicating, for the test fluid employed, the maximum leakage flow rates permitted within an accuracy of +/- 1%.			
4.12.3.	The seat of a shut-off valve, when in the closed position, shall not leak at a rate exceeding 10 cm^3/hour at any gas pressure between zero and the MAWP			
4.12.4.	A non-return valve, when in the closed position, shall not leak when subjected to any aerostatic pressure between 50 kPa and its MAWP			
4.12.5.	Non-return valves if used as a safety device or refuelling connections or receptacles shall not leak at a rate exceeding 10 cm^3/hour during the test			
4.12.6.	The pressure relief devices shall not leak at a rate exceeding 10 cm^3/hour at any gas pressure between zero and set pressure minus 10%			