Evaluation of Safety Standards for Fuel System and Fuel Container Integrity of Alternative Fuel Vehicles

Lauren A. Lynch,[1] Louis Browning,[2] and Amy Snelling[2]

1 National Renewable Energy Laboratory
2 ICF International

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List of Acronyms

ANSI	American National Standards Institute
CGA	Compressed Gas Association, Inc.
CMVSS	Canada Motor Vehicle Safety Regulations
CNG	compressed natural gas
CSA	CSA Group
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FMVSS	Federal Motor Vehicle Safety Standards
GTR	global technical regulation
GVWR	gross vehicle weight rating
ISO	International Organization for Standardization
JARI	Japan Automotive Research Institute
kg	kilograms
lbs.	pounds
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NFPA	National Fire Protection Association
NGV	natural gas vehicle
NGVTF	Natural Gas Vehicle Technology Forum
NHTSA	National Highway Traffic Safety Administration
NPGA	National Propane Gas Association
NREL	National Renewable Energy Laboratory
PRD	pressure relief device
RRC	Railroad Commission of Texas
UNECE	United Nations Economic Commission for Europe
U.S.	United States

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Executive Summary

The Federal Motor Vehicle Safety Standards (FMVSS) No. 303, "Fuel system integrity of compressed natural gas vehicles," and FMVSS No. 304, "Compressed natural gas fuel container integrity," specify requirements for the integrity of the fuel system and fuel containers on compressed natural gas (CNG) vehicles. FMVSS No. 303 applies to CNG vehicles that have a gross vehicle weight rating (GVWR) of 10,000 pounds or less and to all school buses. Currently, there are no FMVSSs for the fuel system and fuel container integrity of propane and liquefied natural gas (LNG) vehicles or fuel system and fuel container integrity requirements for heavy-duty CNG vehicles on the road.

The U.S. Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA) is researching fuel system and fuel container safety for medium- and heavy-duty CNG and propane vehicles to update FMVSS. NHTSA is also researching current best practices and standards for high pressure fuel tanks in motor vehicles as they may apply to FMVSS. The National Renewable Energy Laboratory (NREL) conducted and attended subject matter expert panel meetings and other meeting types to identify opportunities to improve fuel system and fuel container safety for CNG and propane fuel vehicles.

In addition, NREL completed a review of FMVSS No. 303 and No. 304 against the latest editions of natural gas and propane international and industry codes and standards for the purposes of identifying commonalities and differing technical approaches as they pertain to natural gas and propane vehicle fuel system and fuel container integrity requirements.

In this report, NREL offers considerations to reflect minimum safety standards, current industry best practices and existing standards for light-, medium-, and heavy-duty CNG and propane vehicle fuel system container integrity, fuel container integrity, and fuel container fire tests. The considerations for fuel system and fuel container integrity requirements are justified by literature review, relevant research, and technical forum feedback. In addition, this report provides relevant research, where available, and identifies test procedures to evaluate compliance with the performance requirements.

The considerations presented in this report are for:

- Fuel system integrity assessments of CNG medium- and heavy-duty vehicles
- Fuel system integrity assessments for propane vehicles and propane fuel tanks
- Additional CNG fuel tank integrity assessments
- More repeatable fire test procedure for CNG fuel tank integrity.

Detailed considerations are included in Section VII, and a summary of the line-by-line review of fuel system, fuel container integrity, and fuel container fire test procedures for natural gas and propane vehicles is provided in the appendices. This report also includes an overview of the regulatory landscape for natural gas and propane vehicles that NREL reviewed.

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1 Introduction

This section provides an overview of the agreement between the U.S. Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA) and the National Renewable Energy Laboratory (NREL) that resulted in this report.

1.1 Background

There are two Federal Motor Vehicle Safety Standards (FMVSS) in place that specify requirements for integrity of the fuel system and fuel container on compressed natural gas (CNG) fuel vehicles. These are FMVSS Nos. 303, "Fuel system integrity of compressed natural gas vehicles," and FMVSS No. 304, "CNG fuel container integrity." At this time, no FMVSS are defined for the fuel system and fuel container integrity of propane and liquefied natural gas (LNG) vehicles or fuel system integrity requirements for heavy-duty CNG vehicles on the road. However, there are voluntary industry design standards and best practices, as well as regulations defined in other countries.

FMVSS No. 303 specifies requirements for the integrity of the CNG fuel system of light-duty vehicles and school buses, and FMVSS No. 304 specifies requirements for fuel container integrity on all CNG vehicles. FMVSS No. 304 applies to containers used for vehicle propulsion, whereas containers used to transport CNG and transportation of CNG containers are regulated by the DOT Pipeline and Hazardous Materials Safety Administration. FMVSS Nos. 303 and 304 are performance-based standards to consistently test and validate equipment and are not design restrictive.

Despite the increasing number of natural gas and propane medium- and heavy-duty vehicles on the road, there are no FMVSS fuel system integrity requirements beyond light-duty and school buses for CNG vehicles and no FMVSS fuel system integrity requirements for propane vehicles. NHTSA is researching fuel system safety for medium- and heavy-duty natural gas and propane vehicles to update FMVSS Nos. 303 and 304. NHTSA is also researching current best practices and standards for high pressure fuel tanks in motor vehicles as they may apply to FMVSS No. 304.

1.2 Objective

The purpose of this report is to provide a review of federal, international, and industry codes and standards, and to summarize subject matter expert feedback and industry best practices to assess strategies for consideration that may achieve an industry-supported, common approach for natural gas and propane vehicle fuel system and fuel container integrity requirements.

The primary international standards included in this review are sourced from the United Nations Economic Commission for Europe (UNECE), International Organization for Standardization, and Canada Motor Vehicle Safety Regulations. The primary industry codes included in this review are sourced from CSA Group (CSA), as well as the American National Standards Institute (ANSI) and National Fire Protection Association (NFPA).

The considerations for fuel system and fuel container requirements are not design-restrictive and are justified by literature review, relevant research, and technical forum feedback. To evaluate

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compliance with performance requirements, the considerations reference test procedures. This report also includes an overview of the regulatory landscape for natural gas and propane vehicles.

In addition to the review findings, NREL gathered subject matter expert feedback and industry best practice information from multiple expert panel meetings and other meeting types. NREL conducted discussions at two annual Natural Gas Vehicle Technology Form (NGVTF) meetings, presented at the CSA Transportation Strategic Steering Committee meeting and the Natural Gas Transportation Technical Committee meeting in 2019, discussed with other members during regular Propane Autogas Advisory Council meetings, and presented to members of the National Propane Gas Association (NPGA) Technology, Standards and Safety Committee in 2019.

NREL then consolidated literature review and subject matter expert feedback to outline considerations that may be used to update FMVSS fuel system and fuel container integrity requirements of CNG and liquefied petroleum gas (LPG) light-, medium-, and heavy-duty vehicles.

2 Codes, Standards and Regulations

This section briefly discusses FMVSS for fuel system and fuel container integrity on natural gas and propane vehicles in the United States, as well as international and industry organizations and their relevant codes, standards, and best practices that were considered for this review.

2.1 U.S. Department of Transportation

DOT NHTSA promulgates and maintains the FMVSS for motor vehicles and motor vehicle equipment. Each FMVSS must be practicable and meet the need for motor vehicle safety. There are two distinct FMVSS for CNG fuel system and fuel container integrity. CNG fuel system requirements are defined in FMVSS No. 303 and CNG fuel container integrity requirements for those used for propulsion are defined in FMVSS No. 304.

FMVSS No. 303,[1] promulgated in 1994, specifies requirements for the integrity of the CNG fuel system of light-duty vehicles (vehicles with a GVWR less than or equal to 4,536 kg [10,000 lbs.]). This standard also applies to school buses, regardless of GVWR, that use CNG as a motor fuel. FMVSS No. 304,[2] promulgated in 1994, specifies requirements for fuel container integrity used for propulsion on all CNG fuel vehicles. The purpose of these standards is to reduce deaths and injuries occurring from fires that result from fuel leakage during and after motor vehicle crashes. Since the promulgation of FMVSS No. 304 in 1994, industry standards have been updated to address CNG container failures in the field. However, FMVSS No. 304 has remained largely unchanged.

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[1] Information on this regulation can be found online at https://www.ecfr.gov/cgi-bin/text-idx?SID=742c08d2854b8f047dcbc11ad5cb588b&mc=true&node=se49.6.571_1303&rgn=div8.
[2] Information on this regulation can be found online at https://www.ecfr.gov/cgi-bin/text-idx?SID=742c08d2854b8f047dcbc11ad5cb588b&mc=true&node=se49.6.571_1304&rgn=div8.

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Currently, there are no FMVSS for fuel system integrity requirements for heavy-duty CNG vehicles. In addition, there are no FMVSS for fuel system and fuel container integrity requirements for propane or LNG vehicles.

2.2 International Organizations

In 1958, several United Nations Economic Commission of Europe (UNECE) member states entered into an agreement to establish uniform type-approval standards for motor vehicles and their components. Among the standards adopted under the 1958 Agreement are ECE Regulation Nos. 67 (ECE R.67) and 110 (ECE R.110).

ECE R.67[3] provides uniform provisions concerning the approval of:

I. Specific equipment of passenger and goods vehicles using LPG in their propulsion system
II. Passenger and goods vehicles fitted with specific equipment for the use of LPG in their propulsion system with regard to the installation of such equipment.

ECE R.110[4] provides uniform provisions concerning the approval of:

I. Specific components of motor vehicles using CNG in their propulsion system
II. Vehicles with regard to the installation of specific components of an approved type for the use of CNG in their propulsion system.

In 1998, several UNECE member states entered into a new global agreement that established a process to jointly develop global technical regulations (GTRs) for the performance of motor vehicles, equipment, and parts. The 1998 Agreement operates in parallel with the 1958 Agreement, with vehicle standards continuing to be developed under both agreements. UN GTR No. 13[5] concerns hydrogen and fuel cell vehicles.

International Organization for Standardization (ISO) is an international standard-setting body. ISO standards are internationally agreed upon by public and private sector experts. For the purposes of this review, applicable ISO standards are:

- ISO 11439—Gas Cylinders – High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles
- ISO 15500-12—Road vehicles – CNG fuel system components – Part 12: Pressure relief valve
- ISO 15501-1—Road vehicles – CNG fuel systems – Part I: Safety requirements
- ISO 15501-2—Road vehicles – CNG fuel systems – Part II: Test methods.

[3] Information on this regulation can be found online at http://www.unece.org/trans/main/wp29/wp29regs61-80.html.
[4] Information on this regulation can be found online at http://www.unece.org/trans/main/wp29/wp29regs101-120.html.
[5] Information on this regulation can be found online at http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_registry.html.

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ISO 11439 specifies minimum requirements for light-weight refillable gas cylinders intended only for the on-board storage of high pressure CNG as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings that can arise from vehicle collisions.

ISO 15500-12 specifies tests and requirements for the pressure relief valve/pressure relief device (PRD), a CNG fuel system component. It is applicable to vehicles using natural gas in mono-fuel, bi-fuel, or dual-fuel applications.

ISO 15501-1 specifies the minimum safety requirements applicable for the functionality of CNG on-board fuel systems. It is applicable to vehicles using CNG in mono-fuel, bi-fuel, or dual-fuel applications, original-production vehicles, and converted vehicles.

ISO 15501-2 specifies the test methods for checking the minimum safety requirements specified in ISO 15501-1. It is applicable to the functionality of the fuel systems designed to operate on CNG.

The Canada Motor Vehicle Safety Act was enacted in 1993 to regulate the manufacture and importation of motor vehicles and motor vehicle equipment to reduce the risk of death, injury, and damage to property and the environment. Pursuant to the Act, the Canada Motor Vehicle Safety Regulations (CMVSS) were created. CMVSS Test Method 301.1 outlines the compliance requirements for a vehicle equipped with a propane fuel system. CMVSS Test Method 301.2 outlines the compliance requirements for a vehicle equipped with a CNG fuel system.

2.3 Industry Practices

NFPA codes, standards, recommended practices, and guides are developed through a consensus standards development process approved by ANSI. Published codes and standards are intended to minimize the possibility and effects of fire and other risks. For the purposes of this review, applicable NFPA codes are:

- NFPA 52 Vehicular Natural Gas Fuel Systems Code—applies to the design, installation, operation, and maintenance of CNG and LNG engine fuel systems on vehicles of all types. It also applies to vehicle fueling (dispensing) systems and facilities and associated storage, including original equipment manufacturers, and final-stage vehicle integrator/manufacturer. The first edition of NFPA 52 was issued in 1984, and it has been subsequently revised several times. The latest edition available when this report was written is 2019.
- NFPA 58 LPG-Code—applies to the storage, handling, transportation, and use of propane. The first NFPA standard on propane was adopted in 1932, which has been periodically amended. The latest edition available when this report was written is 2020.

CSA is a standards development and testing and certification organization. In the United States, CSA is accredited by ANSI. CSA standards reflect a national consensus of producers and users, professional organizations, and governmental agencies. The standards are used widely by industry and are often adopted by municipal and federal governments in their regulations. For the purposes of this review, applicable CSA standards are:

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- CSA/ANSI NGV 2, CNG vehicle fuel containers— “contains requirements for the material, design, manufacture, and testing of serially produced, refillable Type NGV 2 containers intended only for the storage of CNG for vehicle operation. These containers are to be permanently attached to the vehicle. This Standard applies to containers up to and including 1000 L (35.4 ft^3) water capacity.” The sixth and current edition of NGV 2 was approved and published in 2019.
- CSA/ANSI NGV 6.1, CNG fuel storage and delivery systems for on-road vehicles—applies to the design, installation, inspection, repair, and maintenance of a fuel storage and delivery system installed in an on-road vehicle for use with CNG. This includes a fuel system on a self-propelled vehicle for the provision of motive power. The first and current edition of NGV 6.1 was published in 2016.

SAE International recommends practices with the intention to provide a guide for standard practice and promote safety and efficiency. For the purposes of this review, applicable SAE International recommended practices are:

- J1616 Surface Vehicle Recommended Practice for CNG Vehicle Fuel—applies to all CNG vehicle applications.
- J2406 Surface Vehicle Recommended Practice for CNG Medium and Heavy-Duty Trucks—applies to commercial CNG powered medium- and heavy-duty vehicles for construction, operation, and maintenance of such vehicles with a GVWR of greater than 14,001 lbs., excluding all passenger vehicles such as buses, recreational vehicles, or motor homes.
- J2343 Surface Vehicle Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles—applies to commercial liquefied LNG powered medium- and heavy-duty vehicles for construction, operation, and maintenance of such vehicles and all LNG vehicles used for public transit with a GVWR of greater than 14,001 lbs.

2.4 Codes, Standards and Regulations Summary

A line-by-line review of federal, international, and industry codes and standards was conducted in support of compiling comprehensive considerations to reflect current best practices and existing standards for light-, medium-, and heavy-duty CNG and propane vehicle fuel system container integrity, fuel container integrity, and fuel container fire tests and are summarized in the below tables.

The primary natural gas international and industry codes standards reviewed for the purposes of identifying best practices for fuel system and container integrity requirements are detailed in Table 1.

Table 1. Natural Gas Regulatory Landscape Summary

Organization	Code Number	Title	Latest Edition
CMVSS	Section 301.2	CNG Fuel System Integrity	Jul-05

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Organization	**Code Number**	**Title**	**Latest Edition**
CSA/ANSI	NGV 2:19	CNG vehicle fuel containers	Jan-19
CSA	NGV 6.1	CNG fuel storage and delivery systems for road vehicles	Sep-16
CSA	B339	Cylinders, Spheres, And Tubes For The Transportation Of Dangerous Goods	Jun-18
FMVSS	303	Fuel system integrity of CNG vehicles	Nov-95
FMVSS	304	CNG fuel container integrity	Oct-00
ISO	11439	Gas cylinders - High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles	Jun-13
ISO	15500 -12	Road vehicles - CNG fuel system components Part 12: PRD	Dec-15
ISO	15501 -1	Road vehicles - CNG fuel systems - Part I: Safety requirements	Nov-16
ISO	15501 -2	Road vehicles - CNG fuel systems - Part II: Test Methods	
NFPA	52	Vehicular Natural Gas Fuel Systems Code	2019
RRC	N/A	Regulations for CNG and LNG	Oct-19
UN	GTR 13	GTR on Hydrogen and Fuel Cell Vehicles	Jun-13
UNECE	R. 67	Concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations	Nov-19
UNECE	R.110	Uniform provisions concerning the approval of: I. Specific components of motor vehicles using CNG in their propulsion system; II. Vehicles with regard to the installation of specific components of an approved type for the use of CNG in their propulsion system	Jun-19

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The propane international and industry codes standards reviewed for the purposes of identifying best practices for fuel system and container integrity requirements are detailed in Table 2.

Table 2. Propane Regulatory Landscape Summary

Organization	Code Number	Title	Latest Edition
CMVSS	Standard 301.1	LPG Fuel System Integrity	Feb-01
CSA	B149.5	Installation code for propane fuel systems and containers on motor vehicles	2020
ISO	20766-6	Road vehicles - LPG fuel systems components - Part 6: PRD	Jun-19
NFPA	58	LPG-Code	2020

3 Natural Gas Vehicle Codes and Standards

This section summarizes existing codes and standards; highlights code commonalities; and identifies differing and/or unique requirements. The detailed comparison can be found in Appendices A-C.

3.1 Natural Gas Fuel System Integrity

FMVSS No. 303 is the U.S. federal fuel system integrity standard for CNG vehicles. It also only covers light-duty vehicles at or below 10,000 lbs. GVWR and school buses. It defines labeling requirements for CNG fuel tanks as well as several barrier crash tests to verify fuel system integrity.

CMVSS 301.2 defines requirements on crash tests of CNG vehicles. ISO 15500-12 defines testing requirements for PRDs on CNG vehicles. ISO 15501-1 and ISO 15501-2 provide design guidance for CNG vehicles.

NFPA code 52 regulates fire safety for natural gas vehicles (NGVs). CSA/ANSI NGV 6.1 is a design standard for CNG vehicles related to fuel storage and delivery. Two SAE International recommended practices, J2406 and J2343 medium- and heavy-duty trucks relate to CNG and LNG respectively, and the Railroad Commission of Texas (RRC) also promulgates regulations for CNG and LNG vehicles.

UN GTR No. 13 is a global technical regulation on hydrogen and fuel cell vehicles and provides guidance on tank and vehicle fuel system integrity for hydrogen vehicles. While it does not apply directly to CNG vehicles, it provides applicable practices of testing requirements for high pressure fuel cylinders.

More details can be found in Appendix A.

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3.2 Natural Gas Fuel Container Integrity

FMVSS No. 304 is the U.S. federal fuel container integrity code for CNG vehicles and is applicable to all tank types mounted on all vehicles, without a specific weight limit. It specifies labeling requirements on the tanks, as well as pressure cycling and hydrostatic burst tests.

ISO 11439 is specific to CNG cylinders types 4 and 5. It also contains labeling requirements and specifies testing listed in UN GTR No. 13, including leak testing, permeation testing, composite flaw tolerance testing, and gas cycling testing. In addition, ISO 11439 specifies penetration testing and non-destructive testing.

NGV 2 is a fuel container standard pertaining more to design and design changes of tanks rather than compliance regulation for CNG vehicle tanks. It specifies validation requirements for the tank design and design changes. It does not have label requirements but contains all the tests specified in ISO 11439 with specific guidelines for tank manufacturers.

Other industry codes include NFPA code 52, which regulates fire safety for NGVs; CSA/ANSI NGV 6.1, which is a design standard for CNG vehicles related to fuel storage and delivery; and CGA S-1:3, which sets minimum standards for how PRDs are connected to CNG cylinders.

UN GTR No. 13, while a hydrogen and fuel cell vehicle code, specifies additional testing requirements for container integrity, which include pressure cycling, hydrostatic burst tests, chemical exposure testing, impact testing, drop testing, and extreme temperature cycling of the hydrogen fuel tanks.

More details can be found in Appendix B.

3.3 Natural Gas Fuel Container Integrity Fire Test

FMVSS No. 304 also contains fire testing requirements for fuel container integrity. It defines positioning, temperature measurement, data recording, duration of the fire exposure, shielding, and wind velocity.

Other codes that provide details on cylinder integrity fire testing include NGV 2, NGV 6.1, UN GTR No. 13, and ISO 11439.

FMVSS No. 304 contains specifications for testing that are similar to that specified in NGV 2 and ISO 11439. However, NGV 6.1 and UN GTR No. 13 have a novel fire test that includes a localized fire followed by an engulfing fire so as to better represent certain fires in the field where the PRDs failed to activate. The fire test is currently undergoing revision by the informal working group under the UNECE Working Party on Passive Safety, which is developing Phase 2 revisions to UN GTR No. 13[6] to improve repeatability and reproducibility. The revisions are expected to be finalized by December 2020.

[6] Information on this regulation revision can be found online at https://wiki.unece.org/display/trans/HFCV-GTR13-Phase+2+session.

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Other codes that provide details on external temperature requirements are FMVSS No. 304, NFPA 52, SAE International J2343, UN GTR No. 13, ISO 11439, and NGV 6.1. Out of these, FMVSS No. 304 has the lowest external temperature requirement by more than 100 degrees Celsius, and NGV 6.1, ISO 11439, and UN GTR No. 13 are within 10 degrees Celsius of each other.

More details can be found in Appendix C.

4 Propane Vehicle Codes and Standards

This section summarizes existing codes and standards; highlights code commonalities; and identifies differing and/or unique requirements for LPG vehicle fuel systems. The detailed comparison can be found in Appendices D-F.

4.1 Propane Fuel System Integrity

There are no FMVSS codes that relate to fuel system integrity for LPG fuel vehicles.

CSA B149.5 contains requirements for the installation, servicing, and repair of LPG fuel system components and fuel tanks for on-road vehicles. CMVSS 301.1 defines requirements on crash tests of LPG vehicles.

ECE R.67 also provides design standards for vehicles utilizing LPG in their propulsion system.

See Appendix D for more details.

4.2 Propane Fuel Container Integrity

There are no FMVSS codes that relate to fuel container integrity for LPG fuel vehicles.

NFPA 58 provides some design guidance on LPG vehicle fuel systems in Chapter 11. However, there is very little guidance for verification of fuel container integrity and is limited to pressure and labeling requirements.

CSA B149.5 defines installation requirements for the LPG fuel tank, with validation criteria of specified directional force testing, and requires manufacturers to provide tank mounting brackets.

See Appendix E for more details.

4.3 Propane Fuel Container Integrity Fire Test

There are no FMVSS codes that define fuel container integrity during a fire test for LPG fuel vehicles.

See Appendix F for more details.

5 Expert Panel Meetings and Other Meeting Types

This section summarizes the meetings conducted and attended by NREL, where subject matter experts discussed existing CNG and LPG fuel system and tank integrity codes, standards, and

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best practices, as well as highlighted code commonalities and identified differing and/or unique requirements.

5.1 Natural Gas Vehicle Technology Forum

The NGVTF is an annual meeting that provides an opportunity for participants to discuss data and research related to natural gas engines, regulations, market barriers, and opportunities for NGV technologies and to gain a greater understanding of new developments in CNG fueling infrastructure for NGVs. Results of the forum are used to develop next steps for research and development of NGVs and technology, regulations, market barriers, and opportunities. NREL's summary of observations about differences and possible recommendations when comparing the requirements based on literature review and research were presented at the 2019 and 2020 annual meetings held in North Carolina and California, respectively. The discussions included various stakeholders and subject matter experts to refine and gather further considerations to update the federal standards and reduce barriers.

5.2 CSA Group Natural Gas Transportation Technical Committee

CSA Group's Standard Development is a not-for-profit organization that conducts standards research, development, and education. It has over 10,000 members who contribute to the management and technical development of standards referenced in the United States, Canada, Europe, and Asia. The Transportation Technical Committee supports the Alternative Energy Vehicle group within CSA. NREL attended committee meetings as a guest and presented literature review findings and considerations to committee members who then provided feedback and recommendations to harmonize with CSA standards and industry best practices.

5.3 CSA Group Transportation Strategic Steering Committee

The Transportation Strategic Steering Committee supports the Alternative Energy Vehicle group within CSA. NREL attended committee meetings as a guest where members provided feedback and recommendations to update FMVSS and harmonize with CSA standards and industry best practices.

5.4 CSA Group Propane Autogas Advisory Council

The Propane Autogas Advisory Council supports the Alternative Energy Vehicle group within CSA. NREL has council members who attend meetings and support the development and management of propane standards. NREL has also discussed the FMVSS considerations with members and received feedback.

5.5 NPGA Technology, Standards and Safety Committee

NPGA is a U.S. trade association representing the U.S. propane industry. The Technology, Standards and Safety Committee is a member-only event where codes and standards that regulate the storage, transportation, and utilization of LPG are reviewed and developed. NREL attended two committee meetings in 2019 as a guest and conducted discussions and reviews of existing LPG fuel container and fuel system requirements for vehicles, as well as CNG fuel container and fuel system requirements and potential applicability to LPG fuel vehicles.

6 Review Assessment

This section breaks down the evaluation methodology of combining literature review and subject matter expert feedback to determine the considerations to update FMVSS fuel system and fuel container integrity codes to reflect minimum safety standards applicable to light-, medium-, and heavy-duty CNG and LPG fuel vehicles. The literature review results summarized here were the result of NREL and ICF review, and the subject matter expert feedback was the result of conclusions drawn by group consensus.

6.1 Literature Review Results

- FMVSS No. 303 currently specifies requirements for CNG light-duty vehicles with a GVWR of 10,000 lbs. or less and CNG fuel school buses. However, according to the Alternative Fuel and Advanced Vehicle Search tool on the Alternative Fuels Data Center, the number of CNG medium- and heavy-duty vehicle models available in 2020 is more than double that of CNG light-duty model vehicles, including all bi-fuel models.
- FMVSS No. 304 only contains pressure cycling and hydrostatic burst tests. Similar industry codes, such as NGV 2, include chemical exposure testing, impact testing, drop testing and extreme temperature cycling, leak testing, permeation testing, penetration testing, composite flaw tolerance testing, natural gas cycling testing, and non-destructive testing.
- FMVSS No. 303 does not define a method to check for leaks of connections.
- Currently, there are no FMVSS for LPG fuel system or fuel container integrity.

6.2 Meeting Feedback Summary

- FMVSS No. 303 crash testing of medium- and heavy-duty vehicles may be refined by defining requirements of tank remaining retained by their mounting to ensure applicability and ease of verification across medium- and heavy-duty vehicle configurations. Due to the increased body and frame strength of heavy-duty vehicles, it might be more reasonable to use acceleration tests instead of crash tests to evaluate the strength of mounts to withstand the accelerations where simulation and modeling could be used to verify medium- and heavy-duty vehicles with varying configurations for verification.
- FMVSS No. 303 may benefit from defining a standardized leak testing method, such as a bubble solution criterion as defined in NGV 2, to ensure repeatability of the test, clarify compliance requirements, and align with industry practices.
- PRD venting requirements for medium- and heavy-duty vehicles may be added and aligned with NGV 6.1 and NFPA codes that require venting of the PRD and manifold upwards, above the vehicle to prevent injuries from PRD venting.
- PRD venting requirements for light-duty vehicles may be refined by defining where NOT to vent, such as in-line with pedestrians to prevent injuries from PRD venting.

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- FMVSS No. 304 inspection requirements for CNG tanks should be visually inspected for damage and deterioration after a motor vehicle accident or fire, and either (a) at least every 12 months when installed on a vehicle with a GVWR greater than 10,000 lbs. or (b) at least every 36 months or 36,000 miles, whichever comes first, when installed on a vehicle with a GVWR less than or equal to 10,000 lbs.
- FMVSS No. 304 may be refined by defining the burst ratio requirements per material type of tanks as done in NGV 2 to address the different material characteristics.
- FMVSS No. 304 would benefit from including drop, notch, impact, and hydraulic cycling testing to ensure that the manufacturer-certified tank complies with tank design requirements and aligns with NGV 2.
- FMVSS No. 304 might be modified to align with the fire test procedure under development by the Informal Working Group for Phase 2 UN GTR No. 13.[7] The UN GTR No. 13 fire test exposes the hydrogen container to a localized fire for 10 minutes, which is then followed by an engulfing fire until the contents in the container vent out of the thermally activated pressure relief device (TPRD). The GTR No. 13 fire test was designed to represent vehicle fires in the field and to ensure proper functioning of the TPRD in challenging fire exposures. The Phase 2 modification of the fire test in GTR No. 13 improves the repeatability and reproducibility of the fire test by specifying burner characteristics and additional temperature ranges on a standard steel cylinder in a similar fire test.
- FMVSS LPG fuel tank PRD venting requirements might be the same as CNG fuel tank PRD venting requirements.
- FMVSS LPG crash testing might also be defined by tank mounting requirements, which would be the same as CNG fuel tanks.
- FMVSS LPG label requirements may be refined to include the type of alternative fuel and the fuel system shut off valve location. The label requirements would then harmonize with CSA B149.5 and normalize LPG fuel vehicles in North America.
- This opportunity might be leveraged to harmonize FMVSS LPG requirements with CSA B149.5 as they are also similar to NFPA 58.

7 Considerations

The section outlines the considerations to update FMVSS alternative fuel system and fuel container integrity codes. The considerations are broken into those that reflect minimum safety standards and those to reflect industry best practices and harmonization applicable to light-, medium-, and heavy-duty CNG and LPG fuel vehicles.

[7] Procedure is summarized in Appendix G

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7.1 Considerations for Minimum Safety Standards

The considerations to update FMVSS alternative fuel system and fuel container integrity codes to reflect minimum safety standards of CNG and LPG fuel vehicles are broken into four categories.

7.1.1 Medium- and Heavy-duty Vehicles

Consider expanding the applicability of FMVSS No. 303 S3 to medium- and heavy-duty CNG fuel vehicles to address the majority of the on-road CNG fuel vehicle population, which is compiled of medium- and heavy-duty vehicles that are typically used in commercial fleet operations, because the current FMVSS application only includes passenger cars, multipurpose passenger vehicles, trucks and buses with a GVWR of 10,000 lbs. or less and use CNG as a motor fuel, as well as school buses, regardless of weight, that use CNG as a motor fuel.

7.1.2 Propane Fuel Systems and Container Integrity

Consider including fuel container and fuel system integrity requirements for LPG fuel vehicles in FMVSS to address the availability of new light- and medium-duty propane vehicles that has surged in recent years and the large population of LPG fuel vehicles on the road.

7.1.3 CNG Cylinder Integrity Test Requirements

Consider modifying FMVSS No. 304 S7 test requirements to include chemical test specifications that subject CNG containers to various chemical agents, as described in NGV 2, to better represent the external container environment of real-world applications.

7.1.4 Fire Test Procedure for CNG Fuel Container Integrity

Consider modifying FMVSS No. 304 S8 test to effectively represent container failures experienced in field CNG vehicle fires and to improve repeatability and reproducibility of the fire test for efficient compliance verification.

7.2 Considerations to Reflect Industry Best Practices

The considerations to update FMVSS alternative fuel system and fuel container integrity codes to reflect industry best practices and harmonize with applicable light-, medium-, and heavy-duty CNG and LPG fuel vehicles codes and standards are broken into four categories.

7.2.1 Medium- and Heavy-duty Vehicles

Consider modifying FMVSS No. 303 S6.1–S6.4 to define acceleration tests, instead of barrier crash tests, to evaluate the integrity of tank mounts to ensure applicability and ease of verification across the large variety of medium- and heavy-duty vehicle configurations.

Consider modifying FMVSS to include PRD venting requirements for medium- and heavy-duty vehicles that align with NGV 6.1 and NFPA codes that require venting of the PRD and manifold upwards, above the vehicle to prevent injuries from PRD venting.

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7.2.2 Propane Fuel Systems and Container Integrity

Consider including a label on the type of alternative fuel and the fuel system shut off valve location in FMVSS promulgated for LPG fuel vehicles to harmonize with North American industry practices.

7.2.3 CNG Cylinder Integrity Test Requirements

Consider modifying FMVSS No. 304 S7 test requirements to include a drop test, notch test, and impact test, as defined in NGV 2, to better represent the external container environment of real-world applications, harmonize with North American standards, and ensure compliance with tank manufacturer design requirements.

7.2.4 Fire Test Procedure for CNG Fuel Container Integrity

Consider modifying FMVSS No. 304 S8 test to harmonize with a newly developed test procedure in Phase 2 of UN GTR No. 13.

8 Conclusion

DOT NHTSA is researching fuel system safety for medium- and heavy-duty natural gas and propane fueled vehicles to update FMVSS Nos. 303 and 304. NHTSA is also researching current best practices and existing standards for high pressure fuel tanks in motor vehicles.

NREL completed a review of FMVSS Nos. 303 and 304 against the latest editions of natural gas and propane international and industry codes and standards. NREL reviewed codes and standards requirements for the purposes of identifying commonalities and differing technical approaches as they pertain to natural gas and propane vehicle fuel system and fuel container integrity requirements. NREL conducted and attended expert panel meetings and other meeting types where feedback was gathered from subject matter experts about existing codes, standards, and industry best practices applicable to natural gas and propane fuel system and fuel container integrity requirements.

NREL's provided considerations reflect minimum safety standards, as well as industry best practices, to harmonize applicable light-, medium-, and heavy-duty natural gas and propane fuel vehicle codes and standards. These considerations are justified by literature review, relevant research, and technical forum feedback.

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Appendix A: CNG Fuel System Integrity Comparison

	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Applies To	This standard applies to passenger cars, multipurpose passenger vehicles, trucks and buses that have a gross vehicle weight rating (GVWR) of 10,000 pounds or less and use CNG as a motor fuel. This standard also applies to school buses regardless of weight that use CNG as a motor fuel.	NG engine fuel systems on vehicles of all types	Fuel storage and delivery system installed in an on road CNG vehicle	CNG vehicles (dedicated, bi-fuel, or dual-fuel applications)	CNG vehicles (dedicated, bi-fuel, or dual-fuel applications)	CNG vehicles (dedicated, bi-fuel, or dual-fuel applications)	LNG powered medium, heavy-duty vehicles and all LNG vehicles used for public transit or commercial	CNG vehicles GVWR > 14,000 lbs.	CNG engine fuel systems on vehicles of all types	NG engine fuel systems on vehicles of all types	Cylinders, spheres, and tubes for the transportation of dangerous goods.	All hydrogen fueled vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.
Operating Pressure		Varying pressure in a fuel system component during normal use (1.25 times the service pressure)					As specified by the vehicle manufacturer		As specified by the vehicle manufacturer	As specified by the vehicle manufacturer	As defined by the manufacturer	As defined by the manufacturer
Service Pressure	Internal pressure of a CNG fuel container when filled to design capacity with CNG at 20 °C (68 °F).	Internal pressure when filled to design capacity with CNG at 21°C (70°F).	• The settled pressure at a uniform gas temperature of 21 °C (70 °F) when the vehicle fuel container is fully charged with gas. • The service pressures in common usage are 207 bar (3,000 psi) and 248 bar (3,600 psi) at 21 °C (70 °F).	Settled pressure of 20 MPa (200 bar) at a uniform gas temperature of 15 °C (59°F).	Settled pressure of 20 MPa (200 bar) at a uniform gas temperature of 15 °C (59°F).			Internal pressure when filled to design capacity with CNG at 21°C (70°F).	• Internal pressure when filled to design capacity with CNG at 21°C (70°F) 20,680 kPa or the maximum operating pressure		As defined by the manufacturer	

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Labeling	Each CNG vehicle shall be permanently labeled, near the vehicle refueling connection, with the statements specified below. The information shall be visible to a person standing next to the vehicle during refueling, in English, and in letters and numbers that are not less than 4.76 mm (3/16 inch) high. • The statement: "Service pressure ______________ kPa (______ psig)." • The statement "See instructions on fuel container for inspection and service life."	•" Each CNG or LNG vehicle shall be identified with a permanent, diamond-shaped label located on the exterior vertical surface or near-vertical surface on the lower right rear of the vehicle other than on the bumper of the vehicle — or on the trunk lid of a vehicle so equipped, but not on the bumper or tailgate of any vehicle — inboard from any other markings. • The labels for vehicles less than 19,500 lb. (8863 kg) GVWR shall be a minimum of 4.72 in. long × 3.27 in. high (120 mm × 83 mm). • The labels for vehicles with a GVWR of 19,500 lb (8863 kg) or greater shall be a minimum of 5.7 in. long × 4.2 in. high (145 mm × 107 mm). • The marking in the label shall consist of a border and the letters "CNG or LNG,"	• All markings shall comply with the appropriate country codes and regulations. • Additional labels may be required depending on jurisdiction. Known vehicle system labels are listed below: - vehicle refueling connection; - fuel identification label (i.e., CNG diamond); - engine compartment; - container label; - fuel carrying components (if applicable); - manual shutoff valve; - container valve(s); - vent location; and - PRD location	• The manufacturer's or agent's name, trademark or symbol; • The model designation (part number); • Working pressure and temperature range. The following additional markings are recommended: — The direction of flow (when necessary for correct installation); — The type of fuel; — Electrical ratings (if applicable); — The symbol of the certification agency; — The type approval number; — The serial number or date code; — A reference to this part of ISO 15500. NOTE This information can be provided by a suitable identification code on at least one part of the component when it consists of more than one part.	If non-vehicle original equipment manufacturer (OEM), a label or plate identifying the installer of the CNG system with reference to the document shall be permanently attached to the vehicle.		• "Each fuel storage tank shall be labeled with the following minimum data: Design Code, Service Pressure, Serial Number, Gross Capacity in Water Liters (Gallons), Manufacturer's Name or Trademark, Date of Manufacture (MM/YY), LNG Symbol (Blue and White Diamond), and shall contain the statement: "This container meets or exceeds the drop test requirements of SAE J2343 in effect on the date of manufacture. • Container markings shall be visible after the container is permanently installed on a vehicle. A portable lamp and mirror shall be permitted to be used when reading			• A vehicle equipped with a CNG fuel system shall bear a durable label, readily visible and located at the fueling connection receptacle. • The label shall include - Identification as a CNG/LNG-fueled vehicle -CNG: System working pressure; LNG: MAWP - Name of company or entity and license number • Each vehicle shall be identified with a weather-resistant diamond-shaped label located on an exterior vertical or near vertical surface on the lower right rear of the vehicle (on the trunk lid of a vehicle so equipped, but not on the bumper of any vehicle), inboard from		A label shall be permanently affixed on each container with at least the following information: Name of the Manufacturer, Serial Number, Date of Manufacture, MAWP, Type of Fuel. Any label affixed to the container in compliance with this section shall remain in place. Contracting parties may specify additional labelling requirements.

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
		as appropriate [1 in. (25 mm) minimum height centered in the diamond] of silver or white reflective luminous material on a blue background. • The marking in the label shall consist of a border and the letters “CNG” or “LNG,” as appropriate [1.2 in. (30 mm) minimum height centered in the diamond] of silver or white reflective luminous material on a blue background. • A vehicle equipped with a CNG fuel system shall bear the following permanent labels: • A label(s) readily visible and located in the engine compartment shall include the following: - Identification as a CNG/LNG-fueled vehicle - System designed and installed in conformance					markings. Markings shall be visible either directly or by use of a mirror after installation. • All tank connections shall be adequately labeled as to its function per the latest NFPA document: Current NFPA 52-2006 label is 120 mm wide x 83 mm high (4.75 in wide x 3.25 in high). •A vehicle equipped with an LNG fuel system shall bear a durable label located at the fueling connection receptacle that shall include: - Identification as an LNG-fueled vehicle, - The maximum allowable working pressure of the vehicular fuel container."			any other markings. The label shall be approximately 4-3/4 inches by 3-1/4 inches. The marking shall consist of a border and the letters “CNG” or "LNG" (one inch minimum height centered in the diamond) of silver or white reflective luminous material on a blue background.		

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
		with NFPA 52-XXXX (insert the edition year of the code) - CNG: Service pressure; LNG: MAWP - Installer/converter's name or company and contact information (i.e., address, telephone number, and email) • A label(s) located at the primary fueling connection receptacle shall include the following: * CNG: - Identification as a CNG-fueled vehicle - System service pressure (CNG) - Fuel container life expiration (insert date for limited-life fuel containers. This label item is not required for containers with unlimited life.) - "Fuel containers are to be inspected by (insert date) and each (insert number) months thereafter." * LNG:										

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
		- Identification as a LNG-fueled vehicle - Primary PRV relief set pressure • Label(s) located at each auxiliary fueling connection receptacle shall include the following: * CNG: - Identification as a CNG-fueled vehicle - Service pressure"										

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Frontal Barrier Crash Test Conditions	When the vehicle traveling longitudinally forward at any speed up to and including 30 mph impacts a fixed collision barrier that is perpendicular to the line of travel of the vehicle, or at any angle up to 30 degrees in either direction from the perpendicular to the line of travel of the vehicle, with 50th percentile test dummies as specified in part 572 of this chapter at each front outboard designated seating position and at any other position whose protection system is required to be tested by a dummy under the provisions of Standard No. 208, under the applicable conditions of S7, the fuel pressure drop shall not exceed the limits of S5.2.		• Light duty vehicles and all school bus fuel systems should be designed with the goal of providing fuel system integrity in a collision equivalent to that required by FMVSS 303. • FMVSS 304 should also be used as a reference in determining the impact resistance design requirements for commercial vehicle fuel systems.		• When tested in accordance with ISO 15501-2, the cylinder shall remain attached to the vehicle under the following accelerations, where g is the gravitational acceleration. • The fuel containers or cylinders shall be mounted and fixed so that the following accelerations can be absorbed (without damage occurring) when the containers are full at the service pressure. •Vehicles of categories M1 and N1: 20 g in the direction of travel (forward/backward);							

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Rear Moving Barrier Crash Test Conditions	When the vehicle is impacted from the rear by a barrier moving at any speed up to and including 30 mph, with test dummies as specified in part 572 of this chapter at each front outboard designated seating position, under the applicable conditions of S7, the fuel pressure drop shall not exceed the limits of S5.2.				• When tested in accordance with ISO 15501-2, the cylinder shall remain attached to the vehicle under the following accelerations, where g is the gravitational acceleration. • The fuel containers or cylinders shall be mounted and fixed so that the following accelerations can be absorbed (without damage occurring) when the containers are full at the service pressure. • Vehicles of categories M1 and N1: 20 g in the direction of travel (forward/backwa rd);				• 30 mph • Moving barrier • Perpendicular to the longitudinal centerline of the vehicle			
Lateral Moving Barrier Crash Test Conditions	When the vehicle is impacted laterally on either side by a barrier moving at any speed up to and including 20 mph with 50th percentile test dummies as specified in part 572 of this chapter at positions required for testing to Standard No. 208, under the applicable conditions of S7, the fuel pressure drop shall not				• When tested in accordance with ISO 15501-2, the cylinder shall remain attached to the vehicle under the following accelerations, where g is the gravitational acceleration. • The fuel containers or cylinders shall be mounted and fixed so that the following accelerations can be absorbed				• 20 mph • Moving barrier • Perpendicular to longitudinal axis of the vehicle • Moving barrier has mass of 1814 kg • The impact surface of the barrier shall be a vertical, rigid, flat rectangle 1,981 mm wide and			

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
	exceed the limits of S5.2.				(without damage occurring) when the containers are full at the service pressure. • Vehicles of categories M1 and N1: 8 g horizontally perpendicular to the direction of travel • Vehicles of categories M2, M3 and N2, N3: 5 g horizontally perpendicular to the direction of travel;				1,524 mm high, perpendicular to its direction of movement with its lower edge horizontal and 127 mm above the ground surface.			
Moving Contoured Barrier Crash Test Conditions	When the moving contoured barrier assembly traveling longitudinally forward at any speed up to and including 30 mph impacts the test vehicle (schoolbus with a GVWR exceeding 10,000 pounds) at any point and angle, under the applicable conditions of S7, the fuel pressure drop shall not exceed the limits of S5.2.								• 40 mph • Moving barrier has mass of 1,814 kg ± 23 kg • 499 kg over each front wheel, 408 kg over each rear wheel • The contoured impact surface, measuring 629 mm high by 1,981 mm wide and be attached to the carriage. The ground clearance to the lower edge of the impact surface shall be 133 ± 13 mm and the wheelbase shall be 3,048 ± 50 mm.			

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test - Fuel Storage Container	Each fuel storage container is filled to 100 percent of service pressure with nitrogen, N_2. The gas pressure shall stabilize to ambient temperature before testing may be conducted.		100% filled					Refer to maintenance manual		90% of the MAWP of the container		95% filled

	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test – Max Pressure Drop	For all vehicles, the pressure drop in the high pressure portion of the fuel system, expressed in kilopascals (kPa), in any fixed or moving barrier crash from vehicle impact through the 60 minute period following cessation of motion shall not exceed: (1) 1062 kPa (154 psi), or (2) 895 kPa (T/VFS); whichever is higher where T is the average temperature of the test gas in degrees Kelvin, stabilized to ambient temperature before testing, where average temperature (T) is calculated by measuring ambient temperature at the start of the test time and then every 15 minutes until the test time of 60 minutes is completed; the sum of the ambient temperatures is then divided by five to yield the average temperature (T); and where VFS is the internal volume in liters of the fuel container and the fuel lines up to the first pressure regulator.		A preliminary pressure test of the entire system to between 5 and 10 bar (72.5 and 145 psi), using inert gas, which shall be vented before introducing natural gas into the system					Refer to maintenance manual	• 20,680 kPa or maximum operating pressure • All fuel system manual shutoff valves shall be in the open position			The volumetric flow of hydrogen gas leakage shall not exceed an average of 118 NL per minute for 60 minutes after the crash (30 g/min)

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test - Temperature	The ambient temperature is not to vary more than 5.6 °C (10 °F) during the course of the test.		Ambient temperature	Test the PRV at -40 °C or -20 °C, room temperature and 85 °C or 120 °C (if required by the operating conditions), at working pressure		Ambient temperature		Refer to maintenance manual	Internal pressure when filled to design capacity with CNG at 21°C (70°F).			Ambient temperature
Leakage Test - Test Agent	Each fuel storage container is filled to 100 percent of service pressure with nitrogen, N2.	• Testing shall be performed using natural gas or inert gas • Noncorrosive leak detector solution • If the completed assembly is leak tested with natural gas, the testing shall be done under ventilated conditions	• Acceptable inert test gases are non-flammable and non-reactive (e.g., nitrogen and helium). • DO NOT USE compressed air. • After complete inert gas test, conduct natural gas leak testing	Air, nitrogen, or natural gas		Fill the vehicle fueling system upstream of the first-stage regulator with an appropriate gas.	Nitrogen	Refer to maintenance manual	Nitrogen	•Natural gas or inert gas (carbon dioxide or nitrogen, or a mixture of these) • After installation, every connection shall be checked with a non-ammonia soap solution or a leak detector instrument after the equipment is connected and pressurized to its working pressure. •If the completed assembly is leak tested with natural gas, the testing shall be done under adequately ventilated conditions.	Charged air or nitrogen	Compressed hydrogen or helium gas

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test - Connection Pressure		• Pressurized to its service pressure • Valves: leakage shall not occur at less than 1.5 times rated operating pressure	A pressure test of the piping and tubing system with the fuel container valve closed, conducted at 1.25 times the service pressure of the receptacle			1 MPa (10 bar) ± 0,1 MPa.	Operating pressure	Refer to maintenance manual				
Leakage Test - Connection Time		Each connection shall have no bubbles in 3 minutes.	Show no bubbles in 3 minutes or each individual connection leakage rate shall be less than a 0.2 Ncc (normal cubic centimeter)/hour natural gas leak rate.	• Cycle time shall be within a period of 10 s ± 2 s • 600 cycles of operation	Connections shall either be bubble-free for 3 min or have a leak rate for each connection in compliance with 15501-2	• Check all connections with a gas detector, foam-producing liquid or any other equivalent method. • No bubbles shall be detected during 3 minutes or the leak rate for each connection shall be less than 20 cm3/h (normal).		Refer to maintenance manual				60 minutes

	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test - Other Connection Conditions			• General leak test requirements are as follows: - testing of high-pressure systems shall be performed by a qualified person; - compressed air shall not be introduced into a container or into a piping system, or any other part that is being pressure tested; and - when piping and tubing are pressure tested with natural gas, the testing shall be carried out in an adequately ventilated location equipped with the appropriate precautions, monitors, and countermeasures to prevent the accumulation of ignitable concentrations of natural gas. •A leak test is not a substitute for checking that all fittings are properly attached. Fittings that are not correctly tightened may come apart at high pressure or under use.	• A test cycle consists of pressurizing the PRV to the set pressure. This action shall cause the PRV to open and vent. Once the valve is venting, reduce the inlet pressure; when the PRV re-seats, the cycle is finished. • After 600 cycles, test the PRV for leakage at 20 °C ± 5 °C at its working pressure. Cycle time shall be within a period of 10 s ± 2 s.	• It must be ensured that any leaked gas will be directed safely to the atmosphere • Where a cylinder is located within the driver or passenger compartment or other insufficiently ventilated space, the valves, connections and pipework shall be enclosed in a gas-tight housing such that any gas leakage is vented and directed to the outside of the vehicle. • When the valves are self-venting, the gas tight housing/ventilation hose shall enclose the connections, pipework and venting orifices. There is no need to enclose the body of the valve, if all the possible leakage sources	• Perform this test again with the system upstream of the first regulator at 20 MPa (200 bar) ± 1 MPa. • Stop the test if any leakage occurs during the filling from 1 MPa (10 bar) to 20 MPa (200 bar). Where a leak is detected, it shall be rectified by first relieving any pressure, then resealing. The system shall then be re-tested.	• All cryogenic piping shall be protected against blocking LNG between valved sections by relief device. • Refer to the maintenance manual for the leak testing procedure	Refer to maintenance manual	• If the vehicle has any fuel system electric shutoff valves that are normally open when the electrical system is activated, they shall be open at the time of the barrier crash and shall be set to close on impact. • If any electric shutoff valves prevent sensing of the pressure in the high-pressure portion of the fuel system by the pressure transducer when closed, they must be open for both the pre-test pressure measurement and after the vehicle ceases motion from the impact. All such electric shutoff valves shall be open for a period of one minute prior to completing the pre-test fuel system pressure			

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									measurement and for 60 minutes after the vehicle ceases motion from the impact.			

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
Leakage Test - Results	The vehicle must be capable of meeting the requirements at all points within the range of specified conditions.	Passing inspection requires: (1) Each connection shall have no bubbles in 3 minutes. (2) Any leakage must be corrected. (3) The system must be leak-checked again after any corrections, modifications, disassembly, repairs or replacement of components of the natural gas system.	• Vehicle fuel systems, subjected to fuel container pressure shall be pressure tested and shall retain a settled test pressure (pressure present after test gas has returned to ambient temperature) for not less than 10 minutes without showing any drop in pressure • Any leakage greater than the allowable amount shall be corrected and the system shall be leak checked again after any corrections, modifications, disassembly, or repairs	•Three randomly selected samples shall be subjected to the following test procedure. This test has three steps, which shall be conducted in the order given. -Establish the opening and re-seating values for the samples at 20 °C ± 2 °C. Do this by first slowly pressurizing the inlet of the sample to 110 % of the set pressure, noting the value at which it first opens. • Lower the inlet pressure until the PRV re-seats; note that value. The valves are considered to have passed if all the following requirements are met: 1) opening pressures shall be ±5 % of the manufacturer's set pressure; 2) re-seating pressures shall be no less than 90 % of the set pressure; 3) all re-seating pressures shall be within ±5 % of the average re-seating pressure. • Repeat at -40 °C or -20 °C (as applicable) and 85 °C or 120 °C (as required by		At the conclusion, the cylinder or cylinders shall - Remain attached to the vehicle body or part of the vehicle body, and - Not interfere with the seat structure.		Refer to maintenance manual	The pressure measurement shall be made using a location on the high-pressure portion of the fuel system that is in accordance with the vehicle manufacturer's recommendation.			Hydrogen gas leakage must not result in a hydrogen concentration in the air greater than 3 ± 1.0% by volume. The requirement is satisfied if it is confirmed that the shut-off valve of the storage system has closed within 5 seconds of the crash and no leakage from the storage system.

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	FMVSS No. 303	NFPA 52	NGV 6.1	ISO 15500-12	ISO 15501-1	ISO 15501-2	SAE J2343	SAE J2406	CMVSS 301.2	RRC	CSA B339-18	UNECE GTR 13
				the operating conditions). At each test temperature, the following criteria shall be met: 1) opening pressures ±15 % of the manufacturer's set pressure; 2) re-seating pressures no less than 80 % of the set pressure; 3) all re-seating pressures within ±15 % of the average re-seating pressure.								

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Appendix B: CNG Fuel Container Integrity Comparison

	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
Applies To	This standard applies to each passenger car, multipurpose passenger vehicle, truck, and bus that uses CNG as a motor fuel and to each container designed to store CNG as motor fuel on-board any motor vehicle.	Type 4 & 5 cylinders	CNG vehicles (dedicated, bi-fuel, or dual-fuel applications)	• Specific components of motor vehicles using CNG in their propulsion system • Vehicles with regard to the installation of specific components of an approved type for the use of CNG in their propulsion system.	CNG/LNG Type 1-4 containers	Fuel storage and delivery system installed for CNG vehicles		LNG	Cylinders, spheres, and tubes for the transportation of dangerous goods.	All hydrogen fueled vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.
Labeling	Each CNG fuel container shall be permanently labeled with the information specified in paragraphs (a) through (h) of this section. Any label affixed to the container in compliance with this section shall remain in place and be legible for the manufacturer's recommended service life of the container. The information shall be in English and in letters and numbers that are at least 6.35 mm (1⁄4 inch) high. (a) The statement: "If	• Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of type 1 and 2 designs, or any combination thereof. For composite cylinders, permanent markings may be achieved by use of a printed label encapsulated either by placing it under the resin or by covering it with a permanent transparent layer. Multiple labels are allowed and should be located such that they are not obscured by mounting brackets. Each cylinder	If other than vehicle original equipment manufacturer (OEM), a label or plate identifying the installer of the CNG system with reference to this document shall be permanently attached to the vehicle.	On each cylinder the manufacturer shall provide clear permanent markings not less than 6 mm high. Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of type CNG-1 and CNG-2 designs, or any combination of the above. Multiple labels are allowed and should be located such that they are not obscured by mounting brackets. Each cylinder complying shall be marked as follows: • Mandatory information: (i) 'CNG ONLY'; (ii) 'DO NOT USE AFTER XX/XXXX', where 'XX/XXXX' identifies the month and the year of expiry (6) (iii) Manufacturer's	• Each container complying with this Standard shall be marked with the following mandatory information: a) marking in accordance with FMVSS 304 or equivalent label as required in other jurisdictions; b) NGV 2-xx (where "xx" denotes the year of this Standard to which the container is designed); c) manufacturer's part number, and batch number or serial number; d) the statement "For Use Only With The Container Manufacturer's Approved Pressure Relief Devices and Valves"; e) the statement	• All markings shall comply with the appropriate country codes and regulations. • Additional labels may be required depending on jurisdiction. Known vehicle system labels are listed below: - vehicle refueling connection; - fuel identification label (i.e., CNG diamond); - engine compartment; - container label; - fuel carrying components (if applicable); - manual shutoff valve; - container valve(s); - vent location; and - PRD location				• A label shall be permanently affixed on each container with at least the following information: name of the manufacturer, serial number, date of manufacture, NWP, type of fuel, and date of removal from service. Each container shall also be marked with the number of cycles used in the testing program. • Any label affixed to the container in compliance with this section shall remain in place and be legible for the duration of the manufacturer's recommended service life for the container. • Date of removal from service shall not be more than 15 years after the date of manufacture.

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
	there is a question about the proper use, installation, or maintenance of this container, contact__________," inserting the CNG fuel container manufacturer's name, address, and telephone number. (b) The statement: "Manufactured in ______," inserting the month and year of manufacture of the CNG fuel container. (c) The statement: "Service pressure ______ kPa, (______ psig)." (d) The symbol DOT, constituting a certification by the CNG container manufacturer that the container complies with all requirements of this standard. (e) The container designation (e.g., Type 1, 2, 3, 4). (f) The statement:	conforming to this International Standard shall be marked with at least: - "CNG ONLY"; - "DO NOT USE AFTER XX/XXXX", where XX/XXXX identifies the month and year of expiry. The period between the dispatch date and the expiry date shall not exceed the specified service life. The expiry date may be applied to the cylinder at the time of dispatch, provided that the cylinders have been stored in a dry location without internal pressure; - manufacturer's identification; - cylinder identification (a serial number unique for every cylinder); - working pressure and temperature; - reference to this International Standard, "ISO 11439:2013", along with cylinder type and certification registration number (if applicable); - "Use only a manufacturer-specified PRD"; - when labels are		identification; (iv) Cylinder identification (applicable part number and a serial number unique for every cylinder); (v) Working pressure and temperature; (vi) ECE Regulation number, along with cylinder type and certification registration number; (vii) The pressure relief devices and/or valves which are qualified for use with the cylinder, or the means for obtaining information on qualified fire protection systems; (viii) When labels are used, all cylinders shall have a unique identification number stamped on an exposed metal surface to permit tracing in the event that the label is destroyed; • Non-mandatory information: On a separate label(s) the following non-mandatory information may be provided: (i) Gas temperature range, e.g. – 40 °C to 65 °C; (ii) Nominal water capacity of the cylinder to two significant numbers. e.g. 120 litres; (iii) Date of original pressure test (month and year). The markings shall be placed in the listed sequence but the specific arrangement	"Mounting Shall Be In Accordance With The Container Manufacturer's Instructions"; and f) Canadian Registration Number (CRN), where applicable. • Non-mandatory information may be added but it shall be presented in such a form that it will not be confused with mandatory information. All non-mandatory information shall follow or be separate from the mandatory information sequence. • The markings shall be placed in the listed sequence but the specific arrangement may be varied to match the space available.					

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
	"CNG Only." (g) The statement: "This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration. (h) The statement: "Do Not Use After ______" inserting the month and year that mark the end of the manufacturer's recommended service life for the container.	used, a unique identification number and the manufacturer's identification stamped on an exposed metal surface to permit tracing in the event that the label is destroyed; - date of manufacture (month and year); - any additional markings as required by the Inspector of the country(ies) of use.		may be varied to match the space available. An acceptable example of mandatory information is: CNG ONLY DO NOT USE AFTER …/… Manufacturer/Part Number/Serial Number 20 MPa/15 °C ECE R 110 CNG-2 (Registration Number) 'Use Only Manufacturer-Approved Pressure Relief Device'						

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
PRD Flow Orientation			• There is no general best direction to release the gas through the PRV or PRD, it should be evaluated on a case by case design. • The gas shall be released in a dispersed manner. The dispersion method shall not restrict the venting capacity of any PRV or PRD. • The PRD shall be protected from dirt and water ingress and shall be located as far away as possible from sources of ignition and heat in the vehicle			• The discharge from the pressure relief device referred shall be vented to the outside • When multiple devices share a vent system, the vent system shall allow for the flow of all the devices that can be expected to function at the same time.	• Should be tested every 5 years • Each pressure relief valve shall be subject to an air or gas pressure test to determine that: -the start-to-discharge pressure setting is within tolerances of the set pressure marked on the valve as required by the applicable standard; and -after the start-to-discharge pressure test, the resealing pressure is not less than 90% of the start-to-discharge pressure. If the valve has adjustable blowdown, the resealing pressure shall not be less than 95% of the start-to-discharge pressure. • In setting the valve, ensure that evidence of start-to-discharge pressure is due to opening of the valve and not due to a defect.			

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
Burst Pressure	• Each Type 1 CNG fuel container shall not leak when subjected to burst pressure and tested in accordance with S8.2. Burst pressure shall not be less than 2.25 times the service pressure for non-welded containers and shall not be less than 3.5 times the service pressure for welded containers. • Each Type 2, Type 3, or Type 4 CNG fuel container shall not leak when subjected to burst pressure and tested in accordance with S8.2. Burst pressure shall not be less than 2.25 times the service pressure.	The minimum burst pressure shall be not less than 2.25 times working pressure.	The PRD ventilation line and system shall have a minimum burst pressure at least 1.5 times the service pressure of the fuel cylinder.	• The minimum actual burst values for each container are: • CNG-1 All-metal: 45 MPa • CNG-2 Hood-wrapped: - Glass: Stress ratio: 2.75 MPa, Burst pressure: 50 MPa - Aramid: Stress ratio: 2.35, Burst pressure: 47 MPa - Carbon: Stress ratio: 2.35 MPa, Burst pressure: 47 MPa - Hybrid: see guidance below • CNG-3 Fully-wrapped: - Glass: Stress ratio: 3.65 MPa, Burst pressure: 70 MPa - Aramid: Stress ratio: 3.10, Burst pressure: 60 MPa - Carbon: Stress ratio: 2.35 MPa, Burst pressure: 47 MPa - Hybrid: see guidance below • CNG-4 All-composite: - Glass: Stress ratio: 3.65 MPa, Burst pressure: 73 MPa - Aramid: Stress ratio: 3.1, Burst pressure: 62 MPa - Carbon: Stress ratio: 2.35 MPa, Burst pressure: 47 MPa - Hybrid: see guidance below • For type CNG-2, CNG-3 and CNG-4 designs the composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting	• Three containers shall be pressurized to failure • Pressurization rate shall not exceed 1400 kPa/s (200 psi/s) at pressures above 80% of calculated burst pressure • Minimum burst pressure shall exceed 125% of service pressure • For Type 2 containers Minimum burst pressure shall not be less than 2.25 times the service pressure	The fuel storage system shall be designed to meet or exceed the minimum burst pressure of FMVSS 304 in the United States, and CMVSS 301.2 in Canada, and shall further meet the minimum design burst requirements specified in NGV 2.			• Three containers shall be tested hydrostatically to failure •Pressurization rate shall not exceed 1.4Mpa/s and burst pressure shall be that required by the specification.	• The minimum burst pressure for glass fiber containers is 3.5 times the NWP Three randomly selected new containers are hydraulically pressure cycled at 20(±5)°C to 125% NWP without rupture for 22,000 cycles or until a leak occurs

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
				or exceeding the composite reinforcement stress ratio values given above. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure; For type CNG-4 designs, the stress ratio is equal to the burst ratio; For type CNG-2 and CNG-3 designs (metal-lined, composite over-wrapped) stress ratio calculations must include: (a) An analysis method with capability for non-linear materials (special purpose computer program or finite element analysis program); (b) Elastic-plastic stress-strain curve for liner material must be known and correctly modelled; (c) Mechanical properties of composite materials must be correctly modelled; (d) Calculations must be made at: auto-frettage, zero after auto-frettage, working and minimum burst pressures; (e) Pre-stresses from winding tension must be accounted for in						

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				the analysis; (f) Minimum burst pressure must be chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used; (g) When analyzing cylinders with hybrid reinforcement (two or more different fibre types), the load share between the different fibres must be considered based on the different elastic moduli of the fibres. The stress ratio requirements for each individual fibre type must be in accordance with the values given in table 6.3 of this Annex. Verification of the stress ratios may also be performed using strain gauges.						
Hydrostatic Burst Testing	• The requirements of S7.2 shall be met under the conditions of S8.2.1 through S8.2.2. •Hydrostatically pressurize the CNG fuel container, as follows: • The pressure is increased up to the minimum prescribed burst pressure determined in S7.2.1 or	• On one cylinder • The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 80% of the design burst pressure. • If the rate of pressurization at pressures in excess of 80% of the design burst pressure exceeds 3.5 bar/s, either the cylinder shall be located between the pressure source and the pressure		• The rate of pressurization shall not exceed 1.4 MPa per second (200 psi/second) at pressures in excess of 80% of the design burst pressure. If the rate of pressurisation at pressures in excess of 80% of the design burst pressure exceeds 350 kPa/second (50 psi/second), then either the cylinder must be placed schematically between the pressure source and the pressure	a) Three representative containers shall be hydrostatically pressurized to failure. If the rate of pressurization at pressures in excess of 80% of the required burst pressure exceeds 350 kPa/s (50 psi/s), then either the container shall be placed schematically between the pressure source and the pressure measurement device or there	• At least one CNG storage system shall demonstrate the capability to function through the expected cumulative exposures associated with worst-case conditions of fueling and de-fueling (pressure cycling at environmental temperature limits), and parking (during a static pressure hold).				• Three randomly selected new containers from a batch of at least ten containers, are hydraulically pressurized until burst. • The hydraulic burst test is conducted at 20(±5)°C using a non-corrosive fluid. The rate of pressurization is less than or equal to 1.4MPa/s for pressures higher than 150% of the NWP. If the rate exceeds 0.35MPa/s at pressures higher

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	S7.2.2, and held constant at the minimum burst pressure for 10 seconds. The pressurization rate throughout the test shall be any value up to and including 1,379 kPa (200 psi) per second.	measurement device, or there shall be a 5 s hold at the minimum design burst pressure, or the pressurization rate shall be less than 3.5 bar. • The minimum required (calculated) burst pressure shall be at least the minimum burst pressure specified for the design, and in no case less than the value necessary to meet the stress ratio requirements. • The burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.		measurement device, or there must be a 5 second hold at the minimum design burst pressure; • The minimum required (calculated) burst pressure shall be at least 45 MPa, and in no case less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.	shall be a 5 s hold at the minimum required burst pressure. b) The minimum required burst pressure shall be at least 2.25 times the service pressure, and in no case less than the value necessary to meet the burst/service pressure ratio for Type 1 containers or the stress ratio requirement for Type 2, 3, and 4 containers. Actual burst pressure shall be recorded. c) For Type 2 designs, one liner shall also be hydrostatically burst. The burst pressure shall exceed 125% times service pressure. d) For conformable containers, cycle testing requires a hold at the maximum and minimum pressure of each cycle, to achieve uniform equalized pressure in the pressure-containing elements. e) For CT2 and CT3 conformable containers, the burst test shall be conducted with the protective shell.	• A CNG storage system that has completed routine production-type tests will demonstrate required performance through the following specified tests: Pneumatic Pressure Proof Test, Gas Cycling, Static Gas Exposure, Hydraulic Pressure Proof Test, and Residual Hydraulic Burst Test.				than 150% NWP, then either the container is placed in series between the pressure source and the pressure measurement device, or the time at the pressure above a target burst pressure exceeds 5 seconds. • Hydrostatic Strength Test - A hydrostatic pressure of 250 per cent NWP (+2/-0 MPa) is applied to the inlet of the component for three minutes. The component is examined to ensure that rupture has not occurred. The hydrostatic pressure is then increased at a rate of less than or equal to 1.4 MPa/sec until component failure. The hydrostatic pressure at failure is recorded. The failure pressure of previously tested units shall be no less than 80 per cent of the failure pressure of the baseline, unless the hydrostatic pressure exceeds 400 per cent NWP.

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Chemical Exposure (Environmental Test)		• On one cylinder, applicable to types 2, 3, and 4 cylinders only. • The upper section of the cylinder shall be divided into 5 distinct areas and marked for pendulum impact preconditioning and fluid exposure. The areas shall be nominally 100 mm in diameter. While convenient for testing, the areas need not be oriented along a single line, but shall not overlap. • Although preconditioning and fluid exposure is performed on the cylindrical portion of the cylinder, all of the cylinder, including the domed sections, shall be as resistant to the exposure environments as the tested areas. • The impact body shall be of steel and have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm. The centre of percussion of the pendulum shall coincide with the centre of gravity of the pyramid; its		A cylinder is first preconditioned by a combination of pendulum and gravel impacts to simulate potential underbody conditions. The cylinder is then subjected to a sequence of immersion in simulated road salt/acid rain, exposure to other fluids, pressure cycles and high and low temperature exposures. At the conclusion of the test sequence the cylinder will be hydraulically pressured to destruction. The remaining residual burst strength of the cylinder shall be not less than 85% of the minimum design burst strength. • Cylinder set-up and preparation The cylinder shall be tested in a condition representative of installed geometry including coating (if applicable), brackets and gaskets, and pressure fittings using the same sealing configuration (i.e. O-rings) as that used in service. Brackets may be painted or coated prior to installation in the immersion test if they are painted or coated prior to vehicle installation. Cylinders will be tested horizontally and nominally divided along their horizontal centreline into 'upper' and 'lower' sections. The lower section of the cylinder will be	• This test shall apply to Type 2, 3, and 4 containers only. • One container shall be tested, including coating if applicable. • The upper section of the container shall be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure. The areas shall be nominally 4 in (10 cm) in diameter. While convenient for testing, the areas need not be oriented along a single line but shall not overlap. • Although preconditioning and other fluid exposure is performed on the cylindrical section of the container, all of the container, including the domed sections, shall be as resistant to the exposure environments as the exposed areas. Each marked area is to be exposed to one of five solutions. The five solutions are a) sulfuric acid — 19% solution by volume in water; b) sodium hydroxide — 25% solution by weight in water; c)	• At least one CNG storage system, which has completed the routine production-type tests, shall demonstrate capability to survive without burst or leak the exposure to harsh environmental exposures, and usage beyond expected service. • The storage system shall demonstrate required durability through the following sequence of exposures: Drop Test, Flaw Tolerance Test, Environmental Test (Chemical Exposure), Ambient Durability Test Cycling, Extreme Pressure Cycling (proof pressure), Accelerated Stress Rupture Test, Extreme Temperature Cycling, and Hydrostatic Burst. • Tests shall be run in accordance with applicable design qualification tests contained in the latest version of NGV 2.				• Chemical exposure and ambient temperature pressure cycling test. • The storage container is exposed to chemicals found in the on-road environment and pressure cycled to 125% NWP at 20° (±5)°C for 60% number of Cycles pressure cycles. • Chemical exposure is discontinued before the last 10 cycles, which are conducted to 150% NWP. • Each of the 5 areas of the unpressurized container preconditioned by pendulum impact is exposed to one of five solutions: (a) 19% (by volume) sulphuric acid in water (battery acid); (b) 25% (by weight) sodium hydroxide in water; (c) 5% (by volume) methanol in gasoline (fluids in fueling stations); (d) 28% (by weight) ammonium nitrate in water (urea solution); and (e) 50% (by volume) methyl alcohol in water (windshield washer fluid). • The test container is oriented with the fluid exposure areas on top. A pad of glass wool approximately 0.5 mm thick and 100 mm in diameter is placed on each of the five preconditioned

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		distance from the axis of rotation of the pendulum shall be 1 m. The total mass of the pendulum shall be such that the impact energy of the pendulum at the moment of impact is not less than 30 Nm and is as close to that value as possible. • During pendulum impact, the cylinder shall be held in position by the end bosses or by the intended mounting brackets. Each of the five areas shall be preconditioned by impact of the pendulum body summit at the centre of the area. The cylinder shall be un-pressurized during preconditioning. • Each marked area is to be exposed to one of five solutions. The five solutions are: a) Sulfuric acid – 19% solution by volume in water; b) Sodium hydroxide – 25% solution by weight in water; c) 5% Methanol/95% gasoline - gasoline concentration of M5 fuel meeting the requirements of ASTM D4814; d) Ammonium nitrate – 28% by		alternatively immersed in road salt/acid rain environment and in heated or cooled air. The upper section will be divided into 5 distinct areas and marked for preconditioning and fluid exposure. The areas will be nominally 100 mm in diameter. The areas shall not overlap on the cylinder surface. While convenient for testing, the areas need not be oriented along a single line, but must not overlap the immersed section of the cylinder. Although preconditioning and fluid exposure is performed on the cylindrical section of the cylinder, all of the cylinder, including the domed sections, should be as resistant to the exposure environments as are the exposed areas. • Test conditions and sequence: 1) Exposure environment: Other fluids; Number of pressure cycles: -; Temperature: Ambient 2) Exposure environment: Immersion; Number of pressure cycles: 1,875; Temperature: Ambient 3) Exposure environment: Air; Number of pressure cycles: 1,875; Temperature: High 4) Exposure environment: Other fluids; Number of pressure cycles: -; Temperature: Ambient	methanol/gasoline — 5/95% concentration of M5 fuel meeting the requirements of ASTM D4814; d) ammonium nitrate — 28% by weight in water; and e) windshield washer fluid — 50% by volume solution of methyl alcohol When exposed, the test sample shall be oriented with the exposure area uppermost. A pad of glass wool approx. 0.5 mm (1/64 in) thick and between 90 and 100 mm (3.5 and 4.0 in) in diameter shall be placed on the exposure area. Test fluid shall be applied to the glass wool to evenly wet the pad across its surface and through its thickness for the duration of the test, and to verify that the concentration of the fluid is not changed significantly during the duration of the test.					areas. A sufficient amount of the test fluid is applied to the glass wool sufficient to ensure that the pad is wetted across its surface and through its thickness for the duration of the test. • The exposure of the container with the glass wool is maintained for 48 hrs with the container held at 125% NWP (applied hydraulically) and 20 (±5) °C before the container is subjected to further testing. • The glass wool pads are removed and the container surface is rinsed with water the final 10 cycles to specified final target pressure are conducted.

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		weight in water; e) Windshield washer fluid (50% by volume solution of methyl alcohol and water). • When exposed, the test sample shall be oriented with the exposure area uppermost. A pad of glass wool approx. 0.5 mm thick and between 90 and 100 mm in diameter shall be placed on the exposure area. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted evenly across its surface and through its thickness for the duration of the test, and to ensure that the concentration of the fluid is not changed significantly during the duration of the test. • The cylinder shall be hydraulically pressure cycled between less than or equal to 20 bar and 260 bar for a total of 3,000 cycles. The maximum pressurization rate shall be 27.5 bar per second. After pressure cycling, the cylinder shall be pressurized to		5) Exposure environment: Immersion; Number of pressure cycles: 1,875; Temperature: Ambient 6) Exposure environment: Air; Number of pressure cycles: 3,750; Temperature: Low 7) Exposure environment: Other fluids; Number of pressure cycles: -; Temperature: Ambient 8) Exposure environment: Immersion; Number of pressure cycles: 1,875; Temperature: Ambient 9) Exposure environment: Air; Number of pressure cycles: 1,875; Temperature: High 10) Exposure environment: Other fluids; Number of pressure cycles: -; Temperature: Ambient 11) Exposure environment: Immersion; Number of pressure cycles: 1,875; Temperature: Ambient						

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		260 bar and held at that pressure a minimum of 24 hours and until the elapsed exposure time (pressure cycling and pressure hold) to the environmental fluids equals 48 hours. The cylinder shall be burst, except that the burst pressure shall be no less than 1.8 times the working pressure.								

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Impact Testing		• The impact test shall be carried out on material taken from the cylindrical part of the finished cylinder or liner on three test pieces • The impact test pieces shall be taken in the directions given from the wall of the cylinder • The notch shall be perpendicular to the face of the cylinder wall. For longitudinal tests the test piece shall be machined all over (on six faces). If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. Test pieces taken in the transverse direction shall be machined on four faces only, the inner and outer face of the cylinder wall shall be unmachined. • Impact test acceptance values for cylinders with a diameter > 140mm • Direction of testing: Transverse • Width of test piece: 3-5 mm; >5-7.5 mm; >7.5-10mm • Test temperature: -		• Impact test, steel cylinders and steel liners • The impact test shall be carried out on the material taken from the cylindrical part of the finished cylinder on three test pieces. The impact test pieces shall be taken in the direction as required below from the wall of the cylinder. For cylinders with welded stainless steel liners, impact tests shall be also carried out on material taken from the weld. The notch shall be perpendicular to the face of the cylinder wall. For longitudinal tests the test piece shall be machined all over (on six faces), if the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. The test pieces taken in transverse direction shall be machined on four faces only, the inner and outer face of the cylinder wall unmachined. • Impact test acceptable values • Cylinder diameter: > 140 mm - Direction of testing: transverse - Width of test piece: 3-5; >5-7.5; >7.5-10, respectively - Test temperature: -50C - Mean of 3 specimens: 30; 35; 40, respectively - Individual specimen: 34; 28; 32,	• The impact body shall be of steel and have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm (0.12 in). The center of percussion of the pendulum shall coincide with the center of gravity of the pyramid; its distance from the axis of rotation of the pendulum shall be 1 m (39.37 in). The total mass of the pendulum referred to its center of percussion shall be 15 kg (33 lb). • Cylinder shall be impacted by steel pyramid at an impact of not less than 30 NM (22.1 ft-lbs)					• The upper section of the horizontal storage container is divided into five distinct (not overlapping) areas 100 mm in diameter each. • After 12 hours preconditioning at –40 °C in an environmental chamber, the center of each of the five areas sustains the impact of a pendulum having a pyramid with equilateral faces and square base, the summit and edges being rounded to a radius of 3 mm. • The center of impact of the pendulum coincides with the center of gravity of the pyramid. • The energy of the pendulum at the moment of impact with each of the five marked areas on the container is 30 J. • The container is secured in place during pendulum impacts and not under pressure.

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		50C • Average impact strength (corresponds to width): 30; 35; 40 J/cm2 • Impact test acceptance values for cylinders with a diameter </= 140mm • Direction of testing: Longitudinal • Width of test piece: 3-10mm • Test temperature: -50C • Average impact strength: 60 J/cm2		respectively • Cylinder diameter: ≤ 140 mm - Direction of testing: longitudinal - Width of test piece: 3-5 - Test temperature: -50C - Mean of 3 specimens: 60 - Individual specimen: 48						
Drop Testing		• For type 3 and type 4 designs, one or more finished cylinders (including end caps that are part of the design) shall be tested at ambient temperature without internal pressurization or attached valves. The surface onto which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring. • One cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface on to which it is dropped. One cylinder shall be dropped vertically		• One or more finished cylinders shall be drop tested at ambient temperature without internal pressurisation or attached valves. • The surface onto which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring. One cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface onto which it is dropped. One cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, but in no case shall the height of the lower end be greater than 1.8 m. One cylinder shall be dropped at a 45° angle onto a dome from a height	• Applies to Type 2, 3, and 4 containers only • One or more finished containers shall be drop tested at ambient temperature without internal pressurization or attached valves. Each test may be conducted on a different container or one (1) container may be used for more than one drop test. • The surface onto which the containers are dropped shall be a smooth, horizontal concrete pad or flooring. The container shall be dropped in a horizontal position	• At least one CNG storage system, which has completed the routine production-type tests, shall demonstrate capability to survive without burst or leak the exposure to harsh environmental exposures, and usage beyond expected service • The storage system shall demonstrate required durability through the following sequence of exposures: Drop Test, Flaw Tolerance Test, Environmental Test (Chemical Exposure), Ambient Durability Test		Each family of fuel tanks shall be drop tested to verify tank integrity. Drop tests shall include a 9.1 m (30 ft.) drop test of the fuel tank on the most critical area of the tank (other than the piping end) and a 3.1 m (10 ft.) drop test on the piping end. Tank shall contain an equivalent full weight of liquid nitrogen saturated at one half the MAWP.	• Dropped from height of 3m, onto a concrete surface 3 times once vertically onto the end, once horizontally onto the sidewall and once horizontally onto a piece of angle iron 38 mm x 3 mm with the angle in the downward position. • The dropped cylinder shall be subjected to a 1000 cycle pressure cycling test to service pressure • The dropped cylinder shall be subjected to a burst test and shall not fail at a pressure less	• Ambient temperature without internal pressurization or attached valves. • The surface must be a smooth, horizontal concrete pad or other flooring type with equivalent hardness. • One to four containers may be tested • Container orientations: (i) Dropped from a horizontal position; 1.8 m above the surface; (ii) Dropped onto the end of the container from a vertical position with the ported end upward with a potential energy of not less than 488 J; and a height of no greater than 1.8 m; (iii) Dropped onto the

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		on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, but in no case shall the height of the lower end be greater than 1.8 m. • One cylinder shall be dropped at a 45° angle on to a dome, from a height such that the centre of gravity is at 1.8 m; however, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a center of gravity of 1.8 m. • The cylinders shall be allowed to bounce on the concrete pad or flooring after the initial impact. No attempt shall be made to prevent this secondary impacting, but the cylinder may be prevented from toppling during the vertical drop tests. • Following the drop impact, the cylinders shall be pressure cycled between 20 bar and 1.3 times the working pressure at ambient temperature for the design lifetime		such that the centre of gravity is at 1.8 m; however, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a centre of gravity of 1.8 m. • Following the drop impact, the cylinders shall be pressure cycled from not more than 2 MPa to not less than 26 MPa bar for 1,000 cycles times the specified service life in years. The cylinders may leak but not rupture, during the cycling. Any cylinders completing the cycling test shall be destroyed;	with the lowest point of the container no less than 1.83 m (72 in) above the surface onto which it is dropped. The container shall be dropped vertically on each end at a sufficient height above the floor or pad that the potential energy is 488 joules (360 ft-lbs), but in no case shall the height of the lower end be greater than 1.83 m (72 in). The container shall be dropped at a 45° angle onto a dome from a height such that the center of gravity is at 1.83 m (72 in); however, if the lower end is closer to the ground than 0.6 m (24 in), the drop angle shall be changed to maintain a minimum height of 0.6 m (24 in) and a center of gravity of 1.83 m (72 in). • The container(s) shall be allowed to bounce on the concrete pad or flooring after the initial impact. No attempt shall be made to prevent this secondary impacting, but the container may be	Cycling, Extreme Pressure Cycling (proof pressure), Accelerated Stress Rupture Test, Extreme Temperature Cycling, and Hydrostatic Burst. • Tests shall be run in accordance with applicable design qualification tests contained in the latest version of NGV 2.		There shall be no loss of product for a period of one hour subsequent to the drop test other than relief valve operation and vapor between the filler neck and the secondary check valve in the case of a drop test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection, and damage to the support structure system are acceptable. Pumps and other tank attachments shall also meet the drop test requirement s for the tank and be attached as part of the tests.	than 3.06 times service pressure	end of the container from a vertical position with the ported end downward with a potential energy of not less than 488 J; and a height of no greater than 1.8 m. If the container is symmetrical (identical ported ends), this drop orientation is not required; (iv) Dropped once at a 45° angle from the vertical orientation with a ported end downward with its center of gravity 1.8 m above the ground. If the bottom is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a center of gravity of 1.8 m above the ground • If a single container was subjected to all four drop orientations, then the container being dropped must be dropped in all four orientations; • If more than one container is used to execute the four drop orientations, and if all containers reach 22,000 cycles without leakage, then the orientation of the container being dropped per requirement is the 45° orientation • If more than one container is used to execute the four

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		in years × 1,000 cycles. The cylinder shall not leak or rupture within the first 3,000 cycles, but may fail only by leakage, during the further design lifetime in years × 1,000 cycles (less the 3,000 cycles already performed). All cylinders that complete this test shall be destroyed.			prevented from toppling during the vertical drop test. • For conformable containers including the outer shell, the drop test may use one container for each drop orientation or use one container for all drop tests, or any combination in between. The manufacturer shall define a center of axis in the container from the valve end. For symmetrically shaped conformable designs, up to 4 drop tests might be required. As a minimum, the container shall be dropped on the valve end, dropped at 45° to the valve end, dropped at 90° to the valve end, and (if applicable) dropped on the part with the greatest protrusion from the main body of the container. • For non-symmetrical conformable designs, up to 8 drop tests might be required: first, conducting the drop tests required on the symmetrical design, and then repeating those					drop orientations and if any container does not reach 22,000 cycles without leakage, then the new container shall be subjected to the drop orientation(s) that resulted in the lowest number of cycles to leakage and then will undergo further testing

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					drop tests on the opposite (non-valve) end as defined by the manufacturer's determination of the center of axis. • Following the drop impact, the container(s) shall be visually examined and observations shall be recorded. After drop testing, containers shall be pressurized, from not more than 10% of service pressure to 125% of the service pressure for a number of cycles equivalent to 750 times the service life of the container in years. The container shall not leak or rupture within the first 3000 cycles, but may fail by leakage up to the maximum number of cycles. • All containers that complete this test shall be destroyed.					

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Accelerated Stress Rupture Test		• For type 2, 3 and 4 designs only, one cylinder shall be hydrostatically pressurized to 260 bar at 65 °C. • The cylinder shall be held at this pressure and temperature for 1 000 h. The cylinder shall then be pressured to burst in accordance with the procedure, except that the burst pressure shall exceed 85 % of the minimum design burst pressure.		• One finished cylinder shall be tested and meet the following requirements. • For type CNG-2, CNG-3, and CNG-4 designs only, one cylinder free of protective coating shall be hydrostatically pressurised to 26 MPa while immersed in water at 65 °C. • The cylinder shall be held at this pressure and temperature for 1,000 hours. • The cylinder shall then be pressured to burst in accordance with the procedure except that the burst pressure shall exceed 85% of the minimum design burst pressure	• Types 2,3, and 4, one finished container shall be hydrostatically pressured to 125% of service pressure while at a temperature of 65 °C (149°F) and held for 1000 hrs. • The container shall then be cooled to ambient conditions and shall exceed 75% of the minimum burst pressure	• At least one CNG storage system, which has completed the routine production-type tests, shall demonstrate capability to survive without burst or leak the exposure to harsh environmental exposures, and usage beyond expected service. • The storage system shall demonstrate required durability through the following sequence of exposures: Drop Test, Flaw Tolerance Test, Environmental Test (Chemical Exposure), Ambient Durability Test Cycling, Extreme Pressure Cycling (proof pressure), Accelerated Stress Rupture Test, Extreme Temperature Cycling, and Hydrostatic Burst. • Tests shall be run in accordance with applicable design qualification tests contained in the latest version of NGV 2.				Unidentifiable: • Three containers unless all three containers that were subjected to the ambient temperature hydraulic pressure cycling test were greater than 11,000 cycles, or if they are all within ±25% of each other High Temperature Static Pressure Test: • The storage container is pressurized to 125%NWP at 85°C for 1,000 hr.

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Leak Testing		• Type 4 designs shall be leak tested by: a) thoroughly drying the cylinders; b) pressurizing the cylinders to working pressure with dry air or nitrogen containing a detectable gas such as helium. • Any leakage detected shall be cause for rejection. • Leakage is the release of gas through a crack, pore, un-bond or similar defect.		• Each finished cylinder shall be leak tested and meet the following requirements. • Type CNG-4 designs shall be leak tested using the following procedure (or an acceptable alternative); (a) cylinders shall be thoroughly dried and pressurised to working pressure with dry air or nitrogen, and containing a detectable gas such as helium; (b) any leakage measured at any point that exceeds 0.004 standard cm 3 /h shall be cause for rejection.	• Types 1 and 2 • Three finished containers shall be pressure cycled between not more than 10% of service pressure and 150% of service pressure at a rate not to exceed 10 cycles per min. • For conformable containers, there shall be a minimum 2-s hold at the maximum and minimum pressure of each cycle, to achieve pressure equalization in the pressure-containing elements. For Type CT2 and CT3 containers, if pressure cycling causes damage to the protective shell, it shall be considered a test failure. A shell failure is defined as cracks or fractures in the shell or deformation of the shell dimensions outside the limits of the design. • All containers shall either fail by leakage or exceed a number of cycles that is 2250 times the service life in years.	• Leak testing should be performed on cylinders using a bubble method leak test using a leak detection solution conforming to ASTM G186-05. The leak detection solution shall be applied to each connection, and shall show no bubbles in 3 minutes or each individual connection leakage rate shall be less than a 0.2 Ncc/hour natural gas leak rate. • Cylinders can be filled with an inert gas (nitrogen or helium) or natural gas. • Vehicle fuel systems, subjected to fuel container pressure shall be pressure tested and shall retain a settled test pressure (pressure present after test gas has returned to ambient temperature) for not less than 10 minutes without showing any drop in pressure when subjected to: a) a preliminary pressure test of the entire system to between 5 and 10 bar (72.5 and 145 psi). If an inert gas is used,				

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						it shall be completely vented before natural gas is introduced into the system; and b) a pressure test of the piping and tubing system with the fuel container valve closed, conducted at 1.25 times the service pressure of the receptacle.				
Permeation Testing		• This test is only required on type 4 designs. • One finished cylinder shall be filled with compressed natural gas to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for up to 500 h, to establish a steady-state permeation rate. • Examples of measurement techniques include gas chromatography, mass spectrometry, and weight loss. The permeation rate shall be less than 0.25 normal cc of natural gas per hour per litre water capacity of the cylinder.		• One cylinder shall be tested for permeation and meet the following requirements. • This test is only required on type CNG-4 designs. •One finished cylinder shall be filled with CNG or a 90% nitrogen/10% helium mixture to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for a time sufficient to establish a steady state permeation rate. • The permeation rate shall be less than 0.25 ml of natural gas or helium per hour per litre water capacity of the cylinder.	• Type 4 only • One finished container shall be preconditioned with the boss subjected to twice the installation torque specified for the fittings. The container shall then be filled with natural gas to the service pressure, placed in an enclosed sealed container at ambient temperature, and monitored for 500 h to establish a steady state permeation rate. • The steady state permeation rate for natural gas shall be less than 0.25 cc of natural gas per h per L (0.432 in3 per h per ft3) water capacity of the container. • For CT1 conformable containers, the permeation test is only required if the tank liner is plastic. • For CT2 and					• The test is performed after each group of 250 pneumatic pressure cycles • The maximum allowable hydrogen discharge from the compressed hydrogen storage system is 46 mL/h/L water capacity of the storage system. • If the measured permeation rate is greater than 0.005 mg/sec (3.6Nml/min), a localized leak test is performed to ensure no point of localized external leakage is greater than 0.005mg/sec (3.6Nml/min)

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					CT3, the permeation test is only required if pressurized elements have plastic liners. To fulfil the test requirements, the entire CT2 and CT3 conformable tanks unit shall meet the permeation criteria. If protective shell is gas- tight (i.e. able to hold 50 psi), the entire conformable container assembly with protective shell shall be tested. The permeation measurement samples shall be taken from both the surrounding area and the annular space within the shell. • The annular space shall be shown to prevent a lower flammability limit (LFL) condition. Note: Consideration should be given to providing a means to prevent buildup in the annular space (e.g., a vent).					

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Penetration Testing		• A cylinder pressurized to working pressure + 10 bar with compressed gas shall be penetrated by an armor piercing bullet with a diameter of 7.62 mm or greater. • The bullet shall completely penetrate at least one side wall of the cylinder. • For type 1 designs, the bullet shall impact the sidewall at an approximate angle of 90°. For type 2, 3 and 4 designs, the bullet shall impact the sidewall at an approximate angle of 45°. • In all cases the cylinder shall not rupture.		• One finished cylinder shall be tested and meet the following requirements. • A cylinder pressurised to 20 MPa ± 1 MPa with compressed gas shall be penetrated by an armour piercing bullet with a diameter of 7.62 mm or greater. • The bullet shall completely penetrate at least one side wall of the cylinder. • For type CNG-2, CNG-3 and CNG-4 designs, the projectile shall impact the side wall at an approximate angle of 45°. • The cylinder shall reveal no evidence of fragmentation failure. Loss of small pieces of material, each not weighing more than 45 grams, shall not constitute failure of the test. • The approximate size of entrance and exit openings and their locations shall be recorded	• A container pressurized to service pressure with natural gas or nitrogen shall be penetrated by an armor-piercing bullet with a diameter of 7.62 mm (0.3 in) or greater. The bullet shall completely pass through at least one side wall of the container. • For Type 2, 3, and 4 designs, the projectile shall impact the sidewall at an approximate angle of 90°. The container shall not rupture. • For containers where the diameter of the pressure-containing element is less than 120 mm (4.72 in) or the targeting profile is less than 200 mm (7.87 in), it is acceptable to penetrate the fuel container using a 5.6 mm armor-piercing bullet. • For conformable containers, the penetration test shall be performed on the pressure-containing element.					

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Extreme Temperature Cycling		• Finished cylinders, with the composite wrapping free of any protective coating, shall be cycle tested: a) condition for 48 h at zero pressure, 65 °C or higher, and 95 % or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 65 °C; b) hydrostatically pressurize for 500 cycles multiplied by the specified service life in years between 20 bar and 260 bar at 65 °C or higher, and 95 % or greater relative humidity; The rate should not exceed 10 cycles/minute. c) condition the cylinder and fluid at – 40 °C or lower as measured in the fluid and on the cylinder surface; d) pressurize from 20 bar to 200 bar for 500 cycles multiplied by the specified service life in years at – 40 °C or lower. Adequate recording instrumentation shall be provided to ensure the minimum temperature of	• The ventilation line and system shall not lose its gas-carrying capability when exposed for 12 min to a temperature of 590 °C. • The vent lines may be shielded or sleeved to comply with this requirement;	• One finished cylinder shall be tested and meet the following requirements. • Finished cylinders, with the composite wrapping free of any protective coating, shall be cycle tested, without showing evidence of rupture, leakage, or fibre unravelling, as follows: (a) Condition for 48 hours at zero pressure, 65 °C or higher, and 95% or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 65 °C; (b) Hydrostatically pressurised for 500 cycles times the specified service life in years between not more than 2 MPa and not less than 26 MPa at 65 ° or higher and 95% humidity; (c) Stabilise at zero pressure and ambient temperature; (d) Then pressurise from not more than 2 MPa to not less than 20 MPa for 500 cycles times the specified service life in years at – 40 °C or lower; • The pressure cycling rate of (b) shall not exceed 10 cycles per minute. The pressure cycling rate of (d) shall not exceed 3 cycles per minute unless a pressure transducer is installed directly within the cylinder. Adequate recording instrumentation shall	• One representative container shall be cycle tested, without leakage or rupture, as follows: a) Stabilize the container at zero pressure and 85 °C (185°F) or higher. b) Hydraulically pressure cycle between less than or equal to 10% of service pressure and 125% of service pressure for 4000 cycles. c) Stabilize the container at zero pressure and ambient conditions. d) Stabilize the container at zero pressure and -40 °C (-40°F) or lower. e) Hydraulically pressure cycle between less than or equal to 10% of service pressure and 80% of service pressure for 4000 cycles. • The temperature measurements shall be made on the working fluid in the container, and the temperature limits specified in Items a) and d) shall be maintained throughout the cycling specified in Items b) and e), respectively. The cycling rate shall not exceed 10 cycles per min.	• At least one CNG storage system, which has completed the routine production-type tests, shall demonstrate capability to survive without burst or leak the exposure to harsh environmental exposures, and usage beyond expected service. • The storage system shall demonstrate required durability through the following sequence of exposures: Drop Test, Flaw Tolerance Test, Environmental Test (Chemical Exposure), Ambient Durability Test Cycling, Extreme Pressure Cycling (proof pressure), Accelerated Stress Rupture Test, Extreme Temperature Cycling, and Hydrostatic Burst. • Tests shall be run in accordance with applicable design qualification tests contained in the latest version of NGV 2.				The storage container is pressure cycled at ≤ -40°C to 80 per cent NWP for 20 per cent number of Cycles and at ≥ +85°C and 95 per cent relative humidity to 125 per cent NWP for 20 per cent number of Cycles

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		the fluid is maintained during the low temperature cycling. • The rate should not exceed 3 cycles/minute unless a pressure transducer is installed directly within the cylinder. • The cylinder shall show no evidence of rupture, leakage or fiber unravelling.		be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling. • Following pressure cycling at extreme temperatures, cylinders shall be hydrostatically pressured to failure in accordance with the hydrostatic burst test requirements, and achieve a minimum burst pressure of 85% of the minimum design burst pressure.	• For conformable containers, cycle testing shall include a hold at the maximum and minimum pressure of each cycle, to achieve a uniform equalized pressure in the pressure-containing elements. For Type CT2 and CT3 containers, if pressure cycling causes damage to the protective shell, then this is considered a test failure. A shell failure is defined as cracks or fractures in the shell, or deformation of the shell dimensions outside the limits of the design.					
Composite Flaw Tolerance Testing		•For type 2, 3 and 4 designs only, one finished cylinder, complete with protective coating, shall have flaws cut into the composite in the longitudinal direction. • The flaws shall be greater than the visual inspection limits as specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1,25 mm in depth, and another flaw shall be 200 mm long		• For type CNG-2, CNG-3 and CNG-4 designs only, one finished cylinder, complete with protective coating, shall have flaws in the longitudinal direction cut into the composite. The flaws shall be greater than the visual inspection limits as specified by the manufacturer. • The flawed cylinder shall then be pressure cycled from not more than 2 MPa to not less than 26 MPa for 3,000 cycles, followed by an additional 12,000 cycles at ambient temperature; the cylinder shall not leak	• One uncoated container shall have two flaws in the longitudinal direction cut into the composite sidewall. One flaw shall be a minimum 25 mm (1 in) long and a minimum 1.25 mm (0.05 in) in depth, and the other flaw shall be a minimum 200 mm (8 in) long and a minimum 0.75 mm (0.03 in) in depth. • For CT1 and CT3 conformable containers, the flaws shall be made at exposed					

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		and 0,75 mm in depth, cut in the longitudinal direction into the cylinder sidewall. • The flawed cylinder shall be pressure cycled between 20 bar and 1,3 times working pressure at ambient temperature for the design lifetime in years × 1 000 cycles. • The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further design lifetime in years × 1 000 cycles (less the 3 000 cycles already performed). • All cylinders that complete this test shall be destroyed.		or rupture within the first 3,000 cycles, but may fail by leakage during the last 12,000 cycles. • All cylinders which complete this test shall be destroyed.	(external) locations where the highest stress location exists. Flaws shall be oriented perpendicular to the maximum stress direction. • This test is not required for CT2 conformable containers with an outer shell with a thickness greater than 1.25 mm (0.05 in) or with an enclosure with a distance of 1.25 mm (0.05 in) to the inner container. • The flawed container shall then be pressure cycled, from not more than 10% of the service pressure to 125% of the service pressure for a number of cycles equivalent to 750 times the service life of the container in years. • The container shall not leak or rupture within the first 3000 cycles, but may fail by leakage up to the maximum number of cycles. • All containers that complete this test shall be destroyed.					

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Natural Gas Cycling Testing		• Prior to conducting this test, cylinders of the same design shall have successfully passed the leak test, hydrostatic pressure burst test, ambient temperature pressure cycling test, and permeation test. • One finished type 4 cylinder shall be pressure cycled using compressed natural gas between less than 20 bar and working pressure for 1 000 cycles. The filling time shall be 5 min maximum, to simulate commercial filling conditions. Unless otherwise specified by the manufacturer, care should be taken to ensure that temperatures during venting do not exceed the defined service conditions. • Following completion of the natural gas cycling, the cylinder shall be sectioned and the liner and liner/end boss interface inspected for evidence of deterioration, such as fatigue cracking or electrostatic discharge, that could lead to		• One finished cylinder shall be pressure cycled using compressed natural gas from less than 2 MPa to working pressure for 300 cycles. Each cycle, consisting of the filling and venting of the cylinder, shall not exceed 1 hour. • Following the completion of the natural gas cycling the cylinder shall be sectioned and the liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge. • NOTE — Special consideration must be given to safety when conducting this test. Prior to conducting this test, cylinders of this design must have successfully passed the test requirements of hydrostatic pressure burst test, ambient temperature pressure cycling test, and permeation test. Prior to conducting this test, the specific cylinders to be tested must pass the test requirements of leak test.	Special consideration shall be given to safety when conducting this test. Prior to conducting this test, containers of this design shall have successfully passed the test requirements of the leak test, the hydrostatic burst test, the ambient cycling test,and the permeation test • Type 4 container • One finished container shall be pressure cycled as follows: a) Cycle the pressure in the container with natural gas for 100 cycles between 10% of working pressure and working pressure. Place a 2-h hold at the high-pressure portion of the cycle and a 2-h hold at the low-pressure portion of the cycle. b) Cycle the pressure in the container for 2 additional cycles. Pressurize the container to working pressure with natural gas, hold for 72 h, then release the gas freely through a fully opened valve representative of service, and hold with no pressure for 4 h. • Following completion of the	• 500 cycles for light-duty personal vehicles, and 1,000 cycles for commercial vehicles with heavy-duty use. • Each refueling pressure cycle should be from 10% to 125% of service pressure. • Tested at nominal and boundary ambient temperature conditions; with 10% to 20% of the cycles soaked when at the boundary ambient temperatures (e.g., −40 °C and 50 °C (−40 °F and 122 °F)) and remaining at ambient temperature. • The test sequence should be to conduct half of the gas cycling test, followed by the exposure test, then proceed with the remaining gas cycles, and followed by another exposure test. • The conclusion of the testing includes a hydraulic pressure proof test and a hydraulic burst test on container. Leak monitoring should be included during the test, and leak inspection shall be conducted at the end of each testing event.				• Sequential pneumatic tests • A hydrogen storage system shall not leak during proof pressure, ambient and extrem temperature gas pressure cycling, extreme temperature static pressure leak/permeation, residual proof pressure, residual strength burst, verification for service terminating performance in fire, and verification for performance durability of primary closures tests.

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	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
		failure within the design life of the cylinder. • Alternatively, to eliminate the need for sectioning and inspection, the cylinder may be natural gas cycle tested for 1 000 cycles times its design life in years without leaking.			gas cycle testing, the container shall meet the requirements of the leak test • If there is evidence of deterioration, such as fatigue cracking, disbonding of plastic, deterioration of seals, or damage from electrostatic discharge, the test shall be repeated, except that the number of cycles shall be equivalent to 750 times the service life of the container in years. Following completion of the test, the container shall meet the requirements of the leak test. • For conformable containers, cycle testing shall include a hold at the maximum and minimum pressure of each cycle, to achieve a uniform equalized pressure in the pressure-containing elements. A shell failure is defined as cracks or fractures in the shell or deformation of the shell dimensions outside the limits of the design.	Test results shall be recorded.				

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Nondestructive Testing		• The manufacturer shall specify the maximum defect size for non-destructive examination that will ensure leak before break fracture performance, and will prevent failure by leakage or rupture of the cylinder during its service life. • The maximum defect size shall be established by a method suitable to the design.			Type 1, 2 and 3 containers should be subjected to non-destructive testing. Three containers containing artificial defects that exceed the defect length and depth detection capability of the NDE inspection method required in Clause 11.1 shall be pressure cycled to failure in accordance with the test method in Clause 19.3. For Type 1 designs having a fatigue-sensitive site in the cylindrical part, external flaws shall be introduced in the side wall. For Type 1 designs having a fatigue-sensitive site outside the side wall, and for Type 2 and 3 designs, internal flaws shall be introduced. Internal flaws may be machined prior to the heat treating and closing of the end of the container. The containers shall not leak or rupture in less than a number of cycles equivalent to 750 times the service life of the container in years. The allowable defect size for					

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					NDE shall be equal to or less than the artificial flaw size at that location. As an alternative, calculations shall be performed in accordance with Section 8 of BS 7910 using the following steps: a) Fatigue cracks shall be modelled at the high-stress location in the wall/liner as planar flaws. b) The applied stress range at the fatigue-sensitive site, due to a pressure between 10% of service pressure and service pressure, shall be established from the stress analysis specified in Section 8 of BS 7910. c) The bending and membrane stress component may be used separately. d) The minimum number of pressure cycles shall be 750 times the service life. e) The fatigue crack propagation data shall be determined in air in accordance with ASTM E647 or ISO 12108. The crack plane orientation shall be in the C-L direction (i.e., crack plane					

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					perpendicular to the circumferences and along the axis of the container), as illustrated in ASTM E399 or ISO 12737. The rate shall be determined as an average of 3 specimen tests. Where specific fatigue crack propagation data are available for the material and service condition, they may be used in the assessment. f) The amount of crack growth in the thickness direction and in the length direction per pressure cycle shall be determined in accordance with the steps outlined in Section 8.4 of BS 7910 and shall be documented by integrating the relationship between the rate of fatigue crack propagation, as established in Item e), and the range of crack driving force corresponding to the applied pressure cycle. g) The incremental crack dimension or stress intensity factor calculated					

	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
					in Item f) should be compared with the limiting value, as per Section 8.2.4 of BS 7910. h) Using the above steps, the maximum allowable defect depth and length that will not cause the failure of the container during the service life due to either fatigue or rupture shall be calculated. The defect size for NDE shall be equal to or less than the calculated maximum allowable defect size for the design.					
Pressure Cycling Test at Ambient Temperature	The requirements of S7.1 shall be met under the conditions of S8.1.1 through S8.1.4. • Hydrostatically pressurize the CNG container to the service pressure, then to not more than 10 percent of the service pressure, for 13,000 cycles. • After being pressurized as specified in S8.1.1, hydrostatically pressurize the CNG container	• Pressure cycling shall be performed by: - filling the cylinder to be tested with a non-corrosive fluid such as oil, inhibited water or glycol; - cycling the pressure in the cylinder between 20 bar and 1,3 times working pressure at a rate not exceeding 10 cycles per minute. • The number of cycles to failure shall be reported, along with the location and description of the failure initiation, if applicable.		• Two finished cylinders shall be pressure cycled at ambient temperature to failure, or to a minimum of 45,000 cycles. • The cylinders shall not fail before reaching the specified service life in years times 1,000 cycles. Cylinders exceeding 1,000 cycles times the specified service life in years shall fail by leakage and not by rupture. • Cylinders which do not fail within 45,000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurising to burst. • The number of cycles to failure and	• Two finished containers shall be pressure cycled at ambient temperature to failure, or a number of cycles that is 2250 times the service life in years. Pressure cycling shall be performed in accordance with the following procedure: a) Fill the container to be tested with a non-corrosive fluid such as oil, dry nitrogen, inhibited water, or glycol. b) Perform cycle test as follows: i) Cycle the pressure in the container					• Three 3 new containers randomly selected from the batch are hydraulically pressure cycled at 20(±5)°C to 125% NWP without rupture for 22,000 cycles, or until a leak occurs .

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	to 125 percent of the service pressure, then to not more than 10 percent of the service pressure, for 5,000 cycles. • The cycling rate for S8.1.1 and S8.1.2 shall be any value up to and including 10 cycles per minute. • The cycling is conducted at ambient temperature.			the location of the failure initiation shall be recorded. • Pressure cycling shall be performed in accordance with the following procedure: (a) fill the cylinder to be tested with a non-corrosive fluid such as oil, inhibited water or glycol; (b) cycle the pressure in the cylinder between not more than 2 MPa and not less than 26 MPa at a rate not to exceed 10 cycles per minute.	between less than or equal to 10% of service pressure to 125% of service pressure at a rate not greater than 10 cycles per min. The number of cycles shall be 750 times the service life in years. ii) Cycle the pressure in the container between less than or equal to 10% of service pressure to 125% of service pressure until failure or for an additional 1500 times the service life in years, whichever occurs first. c) Containers shall meet the following conditions: i) Containers shall not fail before reaching a number of cycles equivalent to 750 times the service life of the container in years. ii) After a number of cycles equivalent to 750 times the service life of the container, containers may fail by leakage but shall not rupture. For Type 2, 3, and 4 containers, the fibers in the overwrap shall					

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					not fail. iii) Containers exceeding a number of cycles that is 2250 times the service life in years may fail by rupture. • Containers that do not fail within a number of cycles that is 2250 times the service life in years shall be destroyed either by continuing the cycling until failure occurs or by hydrostatically pressuring to burst. The number of cycles to failure shall be reported along with the location and description of the failure initiation. • For conformable containers, cycle testing shall include a hold at the maximum and minimum pressure of each cycle, to achieve a uniform equalized pressure in the pressure-containing elements. For Type CT2 and CT3 containers, if pressure cycling causes damage to the protective shell, then this is considered a test failure. A shell failure is defined as cracks or fractures in the shell, or					

	FMVSS No. 304	ISO 11439	ISO 15501-1	UNECE R.110	NGV2	NGV 6.1	CGA S-1.3	SAE J2343	CSA B339-18	UNECE GTR 13
					deformations of the shell dimensions outside the limits of the design. • Notes: 1) It is acceptable for the temperature of the pressurizing fluid to rise above ambient temperature but not to exceed 85 °C (185°F). 2) Pneumatic or gas testing can be hazardous; therefore, it is recommended that the container be tested in a way that provides personnel safety.					

Appendix C: CNG Fuel Container Fire Test Comparison

	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Applies To	This standard applies to each passenger car, multipurpose passenger vehicle, truck, and bus that uses CNG as a motor fuel and to each container designed to store CNG as motor fuel on-board any motor vehicle.	CNG/LNG containers	Fuel storage and delivery system installed for CNG vehicles	Light-weight refillable gas cylinders intended only for the on-board storage of high pressure CNG as a fuel for automotive vehicles to which the cylinders are to be fixed.	CNG on-board fuel systems	LNG	CNG/LNG	Cylinders, spheres, and tubes for the transportation of dangerous goods.	All hydrogen fueled vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.
PRD	• Each container must be equipped with a pressure relief device. • Each CNG fuel container shall completely vent its contents through a pressure relief device or shall not burst while retaining its entire contents when tested in accordance with S8.3.	One test for symmetrical design or multiple fire tests to evaluate each orientation for a non-symmetrical design.	The container shall vent through a pressure relief device without bursting.	• The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the test. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimize safety considerations. • The cylinder shall vent through a pressure relief device without rupturing.	Fire testing of the cylinder and PRD combination should be done with representative ventilation enclosures.			Cylinders shall be fitted with PRDs and charred with the intended lading to the prescribed filling pressure.	• Each container must be equipped with a thermally activated pressure device. • The container shall vent through the TPRD continuously without bursting.

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Test Conditions	• The requirements of S7.3 shall be met under the conditions of S8.3.1 through S8.3.7. • Fill the CNG fuel container with compressed natural gas and test it at: (a) 100 percent of service pressure; and (b) 25 percent of service pressure.		• Localized fire test • The container assembly shall be filled with compressed natural gas at 100%.	• The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief devices or cylinder valve). • Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.				• Engulfing fire test and localized fire test • The cylinders shall be charged with air or nitrogen	• Engulfing fire test and Localized fire test • The container assembly is filled with compressed hydrogen gas at 100% of NWP (Contracting parties under the 1998 Agreement may choose to use compressed air as an alternative test gas for certification of the container for use in their countries or regions). • The test unit is the compressed hydrogen storage system which includes all venting systems (including vent lines and coverings) and shielding permanently attached to the container. • The container assembly is exposed to a localized fire (250 mm long at a location furthest from the TPRD) for 10 minutes resulting in temperature at the bottom of the container of about 600-900 deg. C. After 10 minutes of localized fire exposure, the container is exposed to a 1.65 m long engulfing fire with temperature at the bottom of the container of 800-1100 deg. C. • The test shall continue until the container fully vents (until the container pressure falls below

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
									0.7 MPa (100 psi)). Any failure or inconsistency of the fire source during a test shall invalidate the result.

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Container Positioning	(a) Position the CNG fuel container in accordance with paragraphs (b) and (c) of S8.3.2. (b) Position the CNG fuel container so that its longitudinal axis is horizontal and its bottom is 100 mm (4 inches) above the fire source. (c)(1) Position a CNG fuel container that is 1.65 meters (65 inches) in length or less and is fitted with one pressure relief device so that the center of the container is over the center of the fire source. (2) Position a CNG fuel container that is greater than 1.65 meters (65 inches) in length and is fitted with one pressure relief device at one end of the container so that the center of the fire source is 0.825 meters (32.5 inches) from the other end of the container, measured horizontally along a line parallel to the longitudinal axis of the container. (3) Position a CNG fuel container that is fitted with pressure relief devices at more than one location along its length so that the portion of container over the center of the fire source is the portion midway between the two pressure relief devices that are separated by the greatest distance, measured horizontally along a line parallel to the longitudinal axis of the container. (4) Test a CNG fuel		The localized fire exposure area shall be located on the test article furthest from the PRD(s).	• The cylinder shall be pressurized to working pressure with natural gas and tested in the horizontal position at working pressure and, if a thermally activated PRD is not used, also at 25% of working pressure. • Immediately following ignition, the fire shall produce flame impingement on the surface of the cylinder along the 1.65 m length of the fire source and across the cylinder diameter width. • For cylinders of length 1.65 m or less, the centre of the cylinder shall be positioned over the center of the fire source. • For cylinders of length greater than 1,65 m: a) if the cylinder is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the cylinder; b) if the cylinder is fitted with pressure relief devices at both ends, or at more than one location along the length of the cylinder, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance; c) if the cylinder is additionally protected using thermal insulation, then two fire tests at service pressure shall be performed, one with the fire centred midway				• Vertical — One cylinder shall be placed in an upright position and subjected to total fire engulfment without the flame impinging on the PRD •Horizontal — One cylinder shall be placed in a horizontal position with the entire length of the cylinder subjected to flame impingement, without impingement directly on any relief device.	• The localized fire exposure area shall be located on the test article furthest from the TPRD. Engulfing fire test • If the container is less than 1.65 m in length, the centre of the container shall be positioned over the centre of the fire source. If the container is greater than 1.65 m in length, then if the container is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the container. • If the container is greater than 1.65 m in length and is fitted with pressure relief devices at both ends, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
	container that is greater than 1.65 meters (65 inches) in length, is protected by thermal insulation, and does not have pressure relief devices, twice at 100 percent of service pressure. In one test, position the center of the container over the center of the fire source. In another test, position one end of the container so that the fire source is centered 0.825 meters (32.5 inches) from one end of the container, measured horizontally along a line parallel to the longitudinal axis of the container.			along the cylinder length, and the other with the fire commencing at one of the ends of a second cylinder.					
Height	The container assembly shall be positioned horizontally approximately 100 mm (4 in) above the fire source	The container assembly shall be positioned horizontally approximately 100 mm (4 in) above the fire source	Horizontally, approximately 100 mm (4 in) above the fire source	The cylinder shall be placed horizontally with the cylinder bottom approximately 100 mm above the fire source.				The lowest part of the cylinder approximately 10 cm from the top of the wood, in the case of a wood fire, or 10 cm above the surface of the liquid in the case of gasoline of JP-4 fuel-based fire.	The container is positioned horizontally with the container bottom approximately 100 mm above the fire source.

	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Fire Source	Use a uniform fire source that is 1.65 meters long (65 inches). Beginning five minutes after the fire is ignited, maintain an average flame temperature of not less than 430 degrees Celsius (800 degrees Fahrenheit) as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval.	1.65 m (65 in) length shall provide direct flame impingement on the container surface across its entire diameter.	A uniform fire source of 1.65 m (65 in) length provides direct flame impingement on the container surface across its entire diameter. The test shall continue until the container fully vents and the pressure falls below 0.7 MPa (101.5 psi). Any failure or inconsistency of the fire source during a test shall invalidate the result.	• A uniform fire source of 1.65 m length shall provide direct flame impingement on the cylinder surface across its entire diameter width. Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the cylinder is vented. The selection of a fuel should take into consideration air pollution concerns. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of heat input to the cylinder is reproducible. • Any failure or inconsistency of the fire source during a test shall invalidate the result.				Kerosene-soaked wood, gasoline of JP-4 fuel.	A uniform fire source of 1.65 m length provides direct flame impingement on the container surface across its entire diameter.

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Thermocouples	To monitor flame temperature, place three thermocouples so that they are suspended 25 mm (one inch) below the bottom of the CNG fuel container. Position thermocouples so that they are equally spaced over the length of the fire source or length of the container, whichever is shorter.	The fire source shall consist of LPG burners configured to produce a uniform minimum temperature on the test article, measured with a minimum of five thermocouples covering the length of the test article up to 1.65 m (65 in) maximum (at least two thermocouples within the localized fire exposure area and at least three thermocouples equally spaced no more than 0.5 m [19.7 in] apart in the remaining area), located 25 (±10) mm (1 in) from the outside surface of the test article along its longitudinal axis. At the option of the manufacturer or testing facility, additional thermocouples may be located at PRD sensing points or any other locations for optional diagnostic purposes	Flame temperatures shall be monitored by at least three thermocouples suspended in the flame approximately 25 mm (1 in) below the bottom of the container. Thermocouples may be attached to steel cubes up to 25 mm (1 in) on a side.	• Surface temperatures shall be monitored by at least three thermocouples located along the bottom of the cylinder and spaced not more than 0,75 m apart and shielded from direct flame impingement with metallic shielding of a minimum 0.4 mm thickness • Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm square.					Localized fire test • The fire source consists of LPG burners configured to produce a uniform minimum temperature on the test article measured with a minimum 5 thermocouples covering the length of the test article up to 1.65 m maximum (at least 2 thermocouples within the localized fire area, and at least 3 thermocouples equally spaced and no more than 0.5 m apart in the remaining area) located 25 mm ± 10mm from the outside surface of the test article along its longitudinal axis. • At the option of the manufacturer or testing facility, additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes Engulfing firest test • Flame temperatures shall be monitored by at least three thermocouples suspended in the flame approximately 25 mm below the bottom of the container. • Thermocouples may be attached to steel cubes up to 25 mm on a side.

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Location of Fire Source	Position the CNG fuel container so that its longitudinal axis is horizontal and its bottom is 100 mm (4 inches) above the fire source. (c)(1) Position a CNG fuel container that is 1.65 meters (65 inches) in length or less and is fitted with one pressure relief device so that the center of the container is over the center of the fire source. (2) Position a CNG fuel container that is greater than 1.65 meters (65 inches) in length and is fitted with one pressure relief device at one end of the container so that the center of the fire source is 0.825 meters (32.5 inches) from the other end of the container, measured horizontally along a line parallel to the longitudinal axis of the container. (3) Position a CNG fuel container that is fitted with pressure relief devices at more than one location along its length so that the portion of container over the center of the fire source is the portion midway between the two pressure relief devices that are separated by the greatest distance, measured horizontally along a line parallel to the longitudinal axis of the container. (4) Test a CNG fuel container that is greater than 1.65 meters (65 inches) in length, is protected by thermal insulation, and does not	The localized fire exposure area shall be located on the test article furthest from the PRD(s)	• If the container is less than 1.65 m (65 in) in length, the center of the container shall be positioned over the center of the fire source. •If the container is greater than 1.65 m (65 in) in length with a pressure relief device fitted at one end of the container, the fire source shall commence at the opposite end of the container. • If the container is greater than 1.65 m (65 in) in length, and is fitted with pressure relief devices at both ends or at more than one location along the length of the container, the center of the fire source shall be centered midway between the pressure relief devices that are separated by the greatest horizontal distance.	The timing of the fire test shall start when the thermocouple temperature reaches 590 °C and all thermocouples must register a temperature ≥ 590 °C for the remainder of the test.					• The localized fire exposure area is located on t+A:Jing fire • If the container is less than 1.65 m (65 in) in length, the center of the container shall be positioned over the center of the fire source. •If the container is greater than 1.65 m (65 in) in length with a pressure relief device fitted at one end of the container, the fire source shall commence at the opposite end of the container. • If the container is greater than 1.65 m (65 in) in length, and is fitted with pressure relief devices at both ends or at more than one location along the length of the container, the center of the fire source shall be centered midway between the pressure relief devices that are separated by the greatest horizontal distance.

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	have pressure relief devices, twice at 100 percent of service pressure. In one test, position the center of the container over the center of the fire source. In another test, position one end of the container so that the fire source is centered 0.825 meters (32.5 inches) from one end of the container, measured horizontally along a line parallel to the longitudinal axis of the container.								
External Temperature		The temperature of the thermocouples in the localized fire exposure area shall increase continuously to at least 300 °C (572°F) within 1 min of ignition and to at least 600 °C (1112°F) within 3 min of ignition.	Within 5 minutes after the fire is ignited, an average flame temperature of not less than 590 °C (1,094 °F), determined by the average of the two thermocouples recording the highest temperatures over a 60-second interval, shall be attained, and maintained for the duration of the test.	• Within 5 min of ignition the temperature on at least one thermocouple shall indicate a temperature ≥ 590 °C. • This minimum temperature shall be maintained for the remainder of the test.		External temperature of 538 °C (1000 °F)	Refers to SAE J2343		Localized fire test • The temperature of the thermocouples in the localized fire area has increased continuously to at least 300 °C within 1 minute of ignition, to at least 600 °C within 3 minutes of ignition, and a temperature of at least 600 °C is maintained for the next 7 minutes. The temperature in the localized fire area shall not exceed 900 °C during this period. Compliance to the thermal requirements begins 1 minute after entering the period with minimum and maximum limits and is based on a 1-minute rolling average of each

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
									thermocouple in the region of interest. (Note: The temperature outside the region of the initial fire source is not specified during these initial 10 minutes from the time of ignition.). Engulfing fire test • Within five minutes after the fire is ignited, an average flame temperature of not less than 590°C (as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval) is attained and maintained for the duration of the test.
Data Recording	Record time, temperature, and pressure readings at 30 second intervals, beginning when the fire is ignited and continuing until the pressure release device releases	The thermocouple temperature and the container pressure shall be recorded every 30 s during the test.	Thermocouple temperature and the container pressure shall be recorded every 30 seconds during the test.	• Thermocouple temperatures and the cylinder pressure shall be recorded at intervals of every 30 s or less during the test. • The parameters that shall be monitored and recorded are: a) type and characteristics of pressure relief device; b) initial pressure; c) location of leak; d) temperature; e) time.					Localized fire test: • The arrangement of the fire is recorded in sufficient detail to ensure the rate of heat input to the test article is reproducible. The results include the elapsed time from ignition of the fire to the start of venting through the TPRD(s), and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached. • Thermocouple temperatures and container pressure are recorded at intervals of every 10 sec or less during the test. Any failure to maintain specified minimum temperature requirements based on the 1-minute

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
									rolling averages invalidates the test result. Any failure to maintain specified maximum temperature requirements based on the 1-minute rolling averages invalidates the test result only if the test article failed during the test. Engulfing fire test: • Thermocouple temperature and the container pressure shall be recorded every 30 seconds during the test.
Duration of Fire Exposure	The CNG fuel container is exposed to the fire source for 20 minutes after ignition or until the pressure release device releases, whichever period is shorter.	At least 20 min or until the containers are effectively depressurized by the PRDs, whichever is less.	If there is no data on actual fire duration for the specific vehicle, the test article shall maintain the engulfing fire for at least 20 minutes or until the containers are effectively depressurized by the PRDs, whichever is less			20 min without reaching relief pressure	Refers to SAE J2343		• Until pressure in container is less than 0.7 Mpa. • The container shall vent through a pressure relief device without bursting.
Shielding	• Use shielding to prevent the flame from directly contacting the CNG fuel container valves, fittings, or pressure relief devices. • To provide the shielding, use steel with 0.6 mm (.025 in) minimum nominal thickness. • Position the shielding so that it does not directly contact the CNG fuel container valves, fittings, or pressure relief devices.	Wind shields shall be applied to achieve uniform heating	Wind shields shall be applied to ensure uniform heating	• Metallic shielding of a minimum 0.4 mm thickness shall be used to prevent direct flame impingement on cylinder valves, fittings, and/or pressure relief devices. • The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief devices or cylinder valve).					• Wind shields are applied to ensure uniform heating • Metallic shielding is used to prevent direct flame impingement on container valves, fittings, and/or pressure relief devices. The metallic shielding is not in direct contact with the specified fire protection system (pressure relief devices or container valve).

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	FMVSS No. 304	NGV 2	NGV 6.1	ISO 11439	ISO 15501-1	SAE J2343	NFPA 52	CSA B339	UNECE GTR 13
Wind Velocity	The average ambient wind velocity at the CNG fuel container during the period specified in S8.3.6 of this standard is not to exceed 2.24 meters/second (5 mph).								

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Appendix D: Propane Fuel System Integrity Comparison

	CMVSS 301.1	NHTSA Evaluation of Methodology for LPG Fuel System Integrity Tank Test	CSA B339-18
Applies To	GVWR ≤ 4,536 kg & School buses Other vehicles that meet B149.5 requirements 48 month prior to the last manufacturing operation	All propane vehicles	Cylinders, spheres, and tubes for the transportation of dangerous goods.
General Test Conditions	• Tires are inflated to manufacturer's specifications • The portions of the fuel system that contain liquid propane are to have water in them • Prior to testing the water/pressure in the system is allowed to come to equilibrium for both temperature and pressure • For passenger car loading the following apply: (a) the vehicle rated cargo and luggage capacity mass, secured in the luggage area, and (b) the appropriate number of ATDs specified in subsection 3.5 of this test method, restrained only by the means that are installed in the vehicle for protection at the relevant seating positions. • For a multipurpose passenger vehicle, truck, or bus with a GVWR of 4 536 kg or less, the following shall be added: (a) the appropriate number of ATDs specified in subsection 3.5 of this test method, restrained only by the means that are installed in the vehicle for protection at the relevant seating positions, (b) the vehicle rated cargo and luggage capacity or 136 kg, whichever is less, secured to the vehicle and distributed so that the mass on each axle, as measured at the tire ground interface, is in proportion to its GAWR, and (c) if the mass on any axle exceeds the axle's proportional share of the test mass when the vehicle is loaded to the unloaded vehicle mass plus ATD mass, the remaining mass shall be placed so that the mass on that axle remains the same. • Multipurpose passenger vehicle, truck, or bus with a GVWR of 10,000 lbs. (4,536 kg) or less is loaded to its unloaded vehicle weight • A school bus with a GVWR greater than 10,000 lbs. (4,536 kg) is loaded to its unloaded vehicle weight, plus 121 lbs. (55 kg) of unsecured mass at each designated seating position		As specified by the vehicle manufacturer
Frontal Barrier Crash Test Conditions	• 30 mph (48 km/h) • Fixed collision barrier at any angle of up to 30 degrees perpendicular to the line of travel for vehicles 4,536 kg or less		

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	CMVSS 301.1	NHTSA Evaluation of Methodology for LPG Fuel System Integrity Tank Test	CSA B339-18
Rear Moving Barrier Crash Test Conditions	• 30 mph (48 km/h) • The barrier and test vehicle shall be positioned such that at impact: (a) the vehicle is at rest in its normal attitude (b) the barrier is travelling at 48 km/h with its face perpendicular to the longitudinal centreline of the vehicle (c) a vertical plane through the geometric centre of the barrier impact surface and perpendicular to that surface coincides with the longitudinal centreline of the vehicle		
Lateral Moving Barrier Crash Test Conditions	• 20 mph (32 km/h) • The moving barrier, including the impact surface, supporting structure and carriage, shall have a mass of 1 814 kg • The impact surface of the barrier shall be a vertical, rigid, flat rectangle 1 981 mm wide and 1 524 mm high, perpendicular to its direction of movement with its lower edge horizontal and 127 mm above the ground surface • The barrier and the test vehicle shall be positioned such that at impact: (a) the vehicle is at rest in its normal attitude, (b) the barrier is travelling in a direction perpendicular to the longitudinal axis of the vehicle at 32 km/h, and (c) a vertical plane through the geometric centre of the barrier impact surface and perpendicular to that surface passes through the driver's seating reference point in the tested vehicle.		

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	CMVSS 301.1	NHTSA Evaluation of Methodology for LPG Fuel System Integrity Tank Test	CSA B339-18
Moving Contoured Barrier Crash Test Conditions	• 30 mph (48 km/h) • The moving barrier must travel in a straight line • The contoured impact surface is 25 in (629 mm) high and 78 in (1,981 mm) wide, and is attached to the carriage with its lower edge horizontal and 127 mm above the ground surface • The wheelbase is approximately 120 in (3,048 mm ±50 mm) • The complete moving contoured barrier has a mass of approximately 4,000 lbs. (1,814 kg ±23 kg) with the mass distributed so that approximately 900 lbs. (408 kg ±11 kg) is at each rear wheel and 1100 lbs. (499 kg ±11 kg) is at each front wheel • The center of gravity is located about 54 in (1,372 mm ±38 mm) rearward of the front wheel axis, in the vertical longitudinal plane of symmetry, 16 in (401 mm ±13 mm) above the ground • The concrete surface upon which the vehicle is tested is level, rigid, and of uniform construction, with a skid number of 75 at 40 mph (64 km/h) • Contoured barrier may be located at an angle chosen by the manufacturer • The parking brake must be engaged for the test		
Leakage Test - Fuel Tank Fill	80% of capacity	Filled with 40% water and pressurized with nitrogen to 292 psig +/-2% (weight equivalent substitute for 80%)	
Leakage Test - Fuel System Fill	Normal operating level		
Leakage Test - Max Fuel Spillage	142 g and <5% ΔP; 30-min period	• 870 grams (g) in 30 minutes after a crash test; the equivalent energy maximum allowable LPG leak is 805 g (27 g per min) • For a loss of 805 g of water, the theoretical change (at normal temperature and pressure) in pressure will be -4.1 psia for the small 26.2 gallon tank and -2.6 psia for the large 41.4 gallon tank (once the pressure and temperature have stabilized to ambient conditions)	
Leakage Test - Temperature	Ambient	Ambient	

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	CMVSS 301.1	NHTSA Evaluation of Methodology for LPG Fuel System Integrity Tank Test	CSA B339-18
Leakage Test - Test Agent	Water & Nitrogen	Water & Nitrogen	
Pressurization Conditions	• 140 kPa below maximum operating pressure • All fuel system manual shutoff valves must be in the open position • If any fuel system electric shutoff valves must be open at the time of the barrier crash and must be set to close on impact • If any electric shutoff valves prevent sensing of the pressure in the high-pressure portion of the fuel system by the pressure transducer when closed, they must be open for both the pre-test pressure measurement and after the vehicle ceases motion from the impact • All such electric shutoff valves shall be open for a period of 1 minute prior to completing the pre-test fuel system pressure measurement and for 30 minutes after the vehicle ceases • Pressure measurement must be made on the high-pressure portion of the fuel system	• 312 psig below the maximum operating pressure • Set the needle valve that had controlled the water flow rate during the liquid escape tests to the exact orifice size which allowed 805 g of water to leak in 30 minutes. • This needle valve setting was moved from the liquid fill connection to a port that connected to the gas portion of the tank • Following each test, the tank was depressurized and the water “leaked” from the tank was simply reintroduced into the tank. Then for the next test, the tank was repressurized to the desired level and allowed to stabilized, with additional minor re-pressurizations as needed.	
Post-Crash Requirements	• The fuel container must remain with the vehicle with at least one bolt holding • No significant deformation of the moving barriers surface is allowed • Electric valves need to open both 1 minute prior and 30 minutes after the vehicle ceases motion from the test		

Appendix E: Propane Fuel Container Integrity Comparison

	NFPA 58	CSA B149.5	UNECE R.67	CSA B339-18
Applies To	All vehicles	Propane fuel systems and containers on motor vehicles	I. Specific equipment of passenger and goods vehicles using LPG in their propulsion system II. Passenger and goods vehicles fitted with specific equipment for the use of LPG in their propulsion system with regard to the installation of such equipment.	Cylinders, spheres, and tubes for the transportation of dangerous goods.
Labeling	The markings specified for ASME containers shall be on a stainless steel metal nameplate attached to the container, located to remain visible after the container is installed. (A) The nameplate shall be attached in such a way as to minimize corrosion of the nameplate or its fastening means and not contribute to corrosion of the container. (B) Where the container is buried, mounded, insulated, or otherwise covered so the nameplate is obscured, the information contained on the nameplate shall be duplicated and installed on adjacent piping or on a structure in a clearly visible location. (C) Stationary ASME containers shall be marked with the following information: (1) Service for which the container is designed (e.g., underground, aboveground, or both) (2) Name and address of container supplier or trade name of container (3) Water capacity of container in pounds or U.S. gallons (4) MAWP in pounds per square inch (5) Wording that reads “This container shall not contain a product that has a vapor pressure in excess of ___ psig at 100°F” (6) Outside surface area in square feet (7) Year of manufacture (8) Shell thickness and head thickness (9) OL (overall length), OD (outside diameter), and HD (head design) (10) Manufacturer's unique serial number (11) ASME Code symbol (12) Minimum design metal temperature “___°F at MAWP ____ psi” (13) Type of construction “W” (14) Degree of radiography “RT-___” (D) In addition to the markings required by this code, nameplates on cargo tanks shall include the markings required by the ASME Code and the DOT.	• When a vehicle is converted to run on propane fuel, a label of approved design shall be affized by the installer on the inside of the rear window or rear side window of the vehicle in close proximity to the filing location, where it can be observed by the attendant prior to filling. • When a vehicle is converted to run on propane fuel, a permanent label of approved design shall be affixed on either a door latch or the inside of the glove compartment. • A propane-fuelled motor vehicle shall be identified by a weather-resistant diamond-shaped label affixed to its exterior vertical, or near vertical, lower right rear surface, but not to its bumper. The label shall be apprx 120 mm wide by 80 mm high. The label marking shall consist of a boarder and the PROPANE in letters not less the 25 mm in height, centered in the diamond, of silver or white relective luminous material on a black background.	All components submitted for approval shall bear the trade name or mark of the manufacturer and the type; and for non-metallic components also the manufacturing month and year; this marking shall be clearly legible and indelible. All equipment shall have a space large enough to accommodate the approval mark including the classification of the component Every container shall also bear a marking plate, welded to it, with the following data clearly legible and indelible: (a) A serial number; (b) The capacity in litres; (c) The marking "LPG"; (d) Test pressure [kPa]; (e) The wording: "maximum degree of filling: 80 %"; (f) Year and month of approval (e.g. 99/01); (g) Approval mark according to paragraph 5.4; (h) The marking "PUMP INSIDE" and a marking identifying the pump when a pump is mounted in the container.	

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	NFPA 58	CSA B149.5	UNECE R.67	CSA B339-18
Proof Pressure			General design rules regarding components include the compartment containing the heat exchange medium of the vaporizer/pressure regulator shall be leak proof at a pressure of 200 kPa, a component consisting of both high pressure and low pressure parts shall be so designed to prevent a pressure build up in the low pressure part above 2.25 times the maximum working pressure for which it has been tested. Components connected directly to the tank pressure shall be designed for the classification pressure of 3,000 kPa, Venting to the motor compartment or outside of the vehicle is not allowed.	
Burst Pressure				
Baseline Pressure Cycle Life				
Boil Off				
Leak				
Vacuum Loss				
Verification of Components				

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Appendix F: Propane Fuel Container Fire Test Comparison

	CSA Testing of CNG Containers and Accessories Requirement	CSA B339-18
Applies To	Type 2-4 containers	Cylinders, spheres, and tubes for the transportation of dangerous goods.
Previous Test Requirements		
PRD	Attach container end plugs (complete with thermal pressure relief devices (TPRDs)) and tighten to torque value specified by manufacturer	
Initial Container Pressure	• Normal working pressure • At the start of the test, this pressure would vary depending on ambient temperature at the time of the test.	
Fire Source	The burner design involves premixing the air with the LPG before it is burned. This produces a hotter flame while using less fuel.	
Location of Fire Source	Local fire length of 250 mm length, and an engulfing fire length of 1400 mm	
External Temperature	• Increasing the LPG flow to achieve the minimum 600°C within 1 minute of entering the region had the effect of eliminating the wind effects. • 600°C to 900°C for 7 minutes in localized area test • 800°C to 1100°C until termination of the test during full engulfment fire	
Duration of Fire Exposure	At least 20 minutes	
Shielding	Wind shields may be applied to ensure uniform heating.	
Wind Velocity		
Height	The container assembly is positioned horizontally approximately 100 mm above the fire source	

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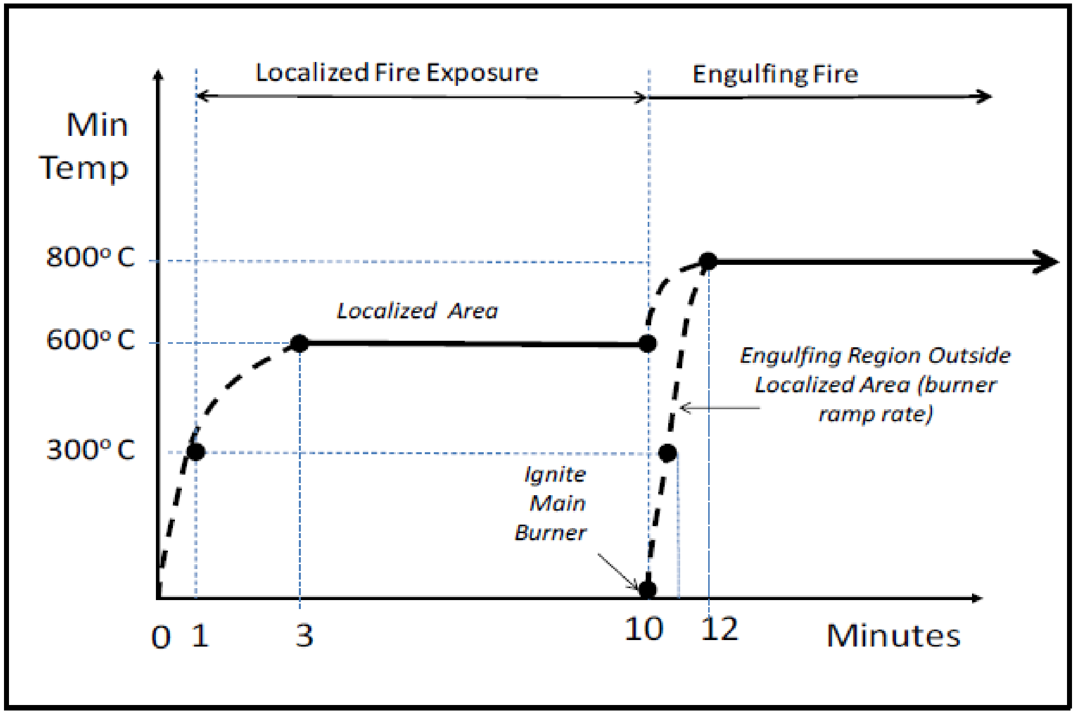
Appendix G: UN GTR No.13 Phase 2 Fire Test Procedure Proposal



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