STANDARDS RESEARCH

Hydrogen Storage and Transport Beyond Pipelines: Regulations and Standardization

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Executive Summary

In Canada, there is growing interest in the use of hydrogen as a sustainable, green fuel. The research conducted for this report reviewed regulations, standards, and best practices for the transport and storage of hydrogen that could facilitate its swift and safe adoption. The research also included consultations with experts and interviews with key industry representatives. The literature review included current regulations and existing codes and standards pertaining to the transport of hydrogen by maritime vessels, rail, and road vehicles, and those pertaining to the storage of hydrogen above and below ground, with the goals of identifying potential gaps and providing recommendations for standardization.

Safe handling, transportation, and storage of hazardous materials, which include hydrogen, are regulated by both Canadian and US federal regulations, and additional requirements are outlined in provincial, territorial, state, and other regional regulations. There are also standards specific to hydrogen quality, hydrogen handling, gas and liquid hydrogen installations, and hydrogen transport by pipelines, as well as standards for testing the materials for containers and pipelines carrying hydrogen. Many of the standards applicable to hydrogen transport by various modes of transportation are currently being revised to provide specific requirements for hydrogen.

This report provides recommendations for revisions of standards to accommodate scaled-up means of hydrogen transportation and storage, as new solutions are emerging in this area. In particular, bulk liquid hydrogen transportation by waterways needs to be addressed. For hydrogen transport by rail, it is recommended that standards account for the design of hydrogen tender cars, transport by ISO containers, and applicability of existing liquefied natural gas rail cars design requirements for hydrogen transport.

Furthermore, this report also recommends that discussions, forums, and platforms should be an ongoing effort across sectors, industries, authorities having jurisdiction, and borders to share experiences and define specific needs within certain codes and standards to advance the use of hydrogen technology.

"The Hydrogen Strategy for Canada aims to modernize Canada's energy system using Canadian expertise, encouraging hydrogen uptake through new uses, and building supply and distribution infrastructure."

1 Introduction

The Hydrogen Strategy for Canada [1] was published in 2020 to help Canada meet its climate change goal of net-zero greenhouse gas emissions by 2050. Developed by Natural Resources Canada through extensive participation of interested parties, the strategy aims to modernize Canada's energy system using Canadian expertise, encouraging hydrogen uptake through new uses, and building supply and distribution infrastructure.

The Hydrogen Codes and Standards Working Group (CSWG) is an established group of experts supporting Canada's hydrogen strategy, co-chaired by Natural Resources Canada and the Standards Council of Canada. The primary purpose of the CSWG relates to one of the eight hydrogen strategy pillars, which focuses on revising current and developing new standards to respond to industry needs and to facilitate hydrogen deployment.

This report reviews regulations, standards, and best practices for the transport and storage of hydrogen in Canada and the US, then identifies gaps and provides recommendations to overcome them. It addresses the transport of hydrogen by maritime, rail, and road vehicles, as well as aboveground and underground storage.

The transport of hydrogen by pipelines or by air, the use of hydrogen as a transportation fuel, hydrogen vehicle refueling stations and hydrogen transportation via chemical carries are beyond the scope of this study.

2 Methods

Information on practices pertinent to the transportation and storage of hydrogen was collected through a literature review, consultations with experts, and information provided by key industry representatives via interviews. The interviews were conducted to complement information gathered through the literature research and review of codes and standards. The interviews provided insights into the industry's current activities regarding transportation and storage of hydrogen, as well as the role of standards and codes in these activities. Industry representatives raised concerns and identified gaps that hinder progress pertaining to the transport and storage of hydrogen.

Table 1 summarizes the survey outreach and participation by sector. The survey response rate was 35%, and only one response was obtained from a Regulatory and Commission representative, which prompted greater reliance on the literature review to draw conclusions and make recommendations about regulations. It should be noted that an interviewed individual may represent more than one sector category, depending on the activities of their company.

Table 1: Sector Representation of Survey Respondents

Sector	Feedback Requested	Feedback Received
Standards Development Organizations and Committee Members	33	5
Engineering, Manufacturing, Industry Associations	23	12
Gas Suppliers and Utility Companies	7	3
Regulatory and Commission	6	1
Government and Research	4	4
Total	**72**	**25**

3 Results

3.1 Overview

Hydrogen can be stored and transported either as a gas, compressed at pressures of 350 or 700 bar to increase storage capacity, or as a liquid, stored at temperatures of −253°C (−423°F) and below at near atmospheric pressure [2]. Because hydrogen is non-toxic, extremely light, and easily dissipates into air without accumulation in case of outdoors leaks, it is safer to use and handle in open air than most other commonly used fuels [3]. However, due to low ignition energy and a wide range of flammable concentrations in air, hydrogen can easily ignite, therefore it is treated as a hazardous material for storage and a dangerous good for transportation.

According to the United Nations (UN) Model Regulations, compressed hydrogen and refrigerated liquid hydrogen (UN numbers 1049 and 1966, respectively) belong to Class 2, division 2.1, flammable gas [4], [5]. This classification has been adopted in both Canada and the US. Labels and placards on containers for hydrogen transportation are shaped as red diamonds and contain a flammability symbol, the applicable UN number, and the class designation, as shown in Figure 1.

In addition to pure hydrogen transportation, hydrogen can also be transported via chemical carriers such as ammonia (NH_3), which is typically liquefied by increasing pressure or chilling the gas. However, hydrogen transportation via chemical carriers is beyond the scope of this report.

Figure 1: Example labels and placards for hydrogen transportation

3.1.1 Hydrogen Transport

While transportation of hydrogen to regions with substantial hydrogen demand is usually conducted via pipelines, smaller scale commercial demands are fulfilled via trucks and, in limited amounts, via rail and ship.

There are four types of construction (see Figure 2) for compressed gas containers for storage and transport that can handle different gas pressures:

- Type I pressure vessels are fully made of metal (e.g., steel or aluminum);
- Type II metallic pressure vessels have a fiber/resin composite-wrapped hoop;
- Type III metallic inner pressure vessels are fully wrapped with a fiber/resin composite; and
- Type IV polymeric inner pressure vessel are fully wrapped with a fiber/resin composite. The connection area between type IV hydrogen storage vessels and external valves, called boss, are metallic [6].

Compressed gas vessels are transported in tube trailers. Type III and type IV composite vessels are designed for portable applications and are preferred for integration into containers because of their relatively low weight when compared to steel containers [7], [8], [9]. As shown in Figure 3, multiple element gas containers (MEGCs), or ISO containers, are framed assemblies of UN cylinders and tubes interconnected by a manifold [10]. MEGCs include service equipment and structural equipment necessary for the transport of gases [11] and are typically built of two standard lengths of 20 ft and 40 ft, and up to 53 ft on jumbo tube trailers. The number of tubes typically ranges from 5 to 12 with lengths that can vary between 18 ft 6 in to 36 ft. UN and US Department of Transportation tubes can be used to construct a MEGC [12].

Under Canadian [1] and US regulations, hydrogen tube trailers are currently limited to pressures of 250 bar, but the US Department of Transportation has granted exemptions for operation at higher pressures (e.g., 500 bar or higher) [9]. Type III steel tube trailers are the most common among tube trailers and can carry approximately 380 kg of hydrogen. Type IV composite storage vessels have capacities of 560 to 900 kg of hydrogen per trailer [8], [9].

Liquid hydrogen is usually transported in trucks with a single cryogenic cylinder that is permanently attached as part of a trailer. Cylinder-shaped containers on cryogenic liquid cargo trailers (see Figure 4) are constructed from specialized steel materials that can withstand cryogenic temperatures [13]. Liquid hydrogen trailers typically transport up to 4,000 kg per trailer [14].

It should be noted that supplying hydrogen as a fuel for use by ships, which is called bunkering, is beyond the scope of this report.

3.1.2 Hydrogen Storage

Hydrogen may be stored above ground in parked transport trailers, transportable tank containers, or in purpose-built storage containers that, similar to MEGCs, consist of several pressure vessels in a frame installed on a concrete foundation. Liquid hydrogen can be stored in cryogenic containers, and larger volumes of liquid hydrogen are stored in insulated spheres, like those shown in Figure 5.

Large quantities of hydrogen can also be stored in underground caverns or geological structures to be retrieved for later use [15]. Three primary underground structures can be used for storing hydrogen underground: salt caverns, depleted oil or gas reservoirs and aquifers [16]. Additionally, hydrogen can be stored in lined rock caverns.

Figure 2: Sketches of the four cylinder types

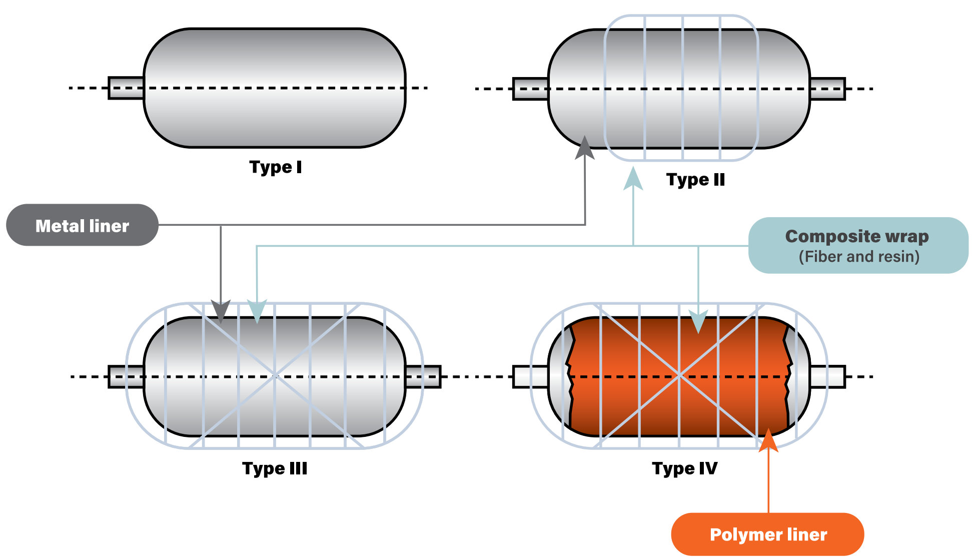

Figure 3: Truck hauling multiple element gas containers (MEGCs)

Figure 4: Truck with cryogenic liquid cargo trailer

Figure 5: Insulated spheres for liquid storage of gaseous materials

The most common method for storing hydrogen below ground is salt caverns. These storage areas are created by injecting water into a well that has been drilled down to a geological salt layer. The salt-saturated brine is then extracted, leaving a cavern in the salt deposit. Resulting caverns can measure up to 100 meters in diameter and several hundred meters in depth, depending on the thickness of the salt layer. Salt caverns do not require lining as the salt acts as a sealant. However, there may be a risk of hydrogen diffusion through the salt walls, and because they contain residual brine solutions, the humidity level of the hydrogen may increase, which could cause issues in downstream processing after extraction unless further treated [17]. Hydrogen can be stored at extremely high pressures if the salt layer is deep enough.

Another method for storing large quantities of hydrogen or hydrogen-methane blends below ground is through injection into porous rock, depleted oil or gas fields, or aquifers. An important requirement for the use of these types of formations is modeling and biochemical testing of the reservoir. One of the risks associated with storing hydrogen in porous rock is potential contamination of the hydrogen through contact with solids and fluids in the reservoir. Furthermore, microbes in the reservoir could lead to the formation of hydrogen sulfide (H_2S), a toxic and corrosive gas. Another challenge is the potential for leakage, as pure hydrogen has low density and high diffusivity, which could significantly reduce the amount of recoverable hydrogen [18]. If stored as a hydrogen-methane mix, it can be withdrawn and injected into the network or separated at the well head using pressure swing adsorption technology, for example.

The last method for underground storage of large quantities of hydrogen is a lined rock cavern. This consists of constructing a storage cavern with a lining of gas-tight steel encased in a layer of concrete. The use of casing-lined depleted oilfield wells is similar. These types of underground structures can also be used for hydrogen converted into a liquid carrier, such as ammonia. The liner is required to prevent contact between ammonia and water. The advantage of using ammonia is that proper storage conditions do not require excessive pressure or temperature. Research studies are underway to look at compressed storage (gaseous hydrogen) or cryogenic storage (liquid hydrogen) in these types of facilities [19], [20]. A specialized liner is required to ensure safe storage of hydrogen under extremely high pressures or low temperatures, or both. Studies are also underway to examine the qualification of well casing connections for hydrogen storage and the challenges that need to be addressed [21].

Canada has no underground hydrogen storage facilities, although favourable locations for pilot projects in sedimentary basins and crystalline rocks have been reported [22]. There are three underground salt cavern storage facilities in Texas for storing backup hydrogen for hydrogen pipeline customers [23]. In the late 1990s, the US Department of Energy and other researchers studied the use of lined rock caverns for the storage of natural gas, and this method is currently being used to store natural gas in Skallen, Sweden [24], [25].

3.2 Regulations

3.2.1 Canadian Federal, Provincial, and Territorial Regulations for Hydrogen Transportation and Storage

Natural Resources Canada has identified current regional hydrogen production resources and hydrogen end-use applications, as well as potential pathways for the production of hydrogen based on electrical grid and feedstock access in each province and territory [1]. Location of hydrogen production is important for identifying storage and transportation needs, as well as for identifying regulations, codes, and standards that encompass these topics.

In some cases, provincial or territorial regulations are directly enforced by a ministry, such as the Yukon Department of Energy, Mines and Resources. Other provinces and territories may appoint outside agencies or corporations to administer these responsibilities. For example, the Ontario Technical Standards and Safety Act established the Technical Standards and Safety Authority as a corporation responsible for the administration of technical standards applying to boilers and pressure vessels, as well as fuels [26].

The transportation of hydrogen in Canada is regulated by the Transportation of Dangerous Goods (TDG) Regulations [27], which apply to the transportation of dangerous goods by road, rail, air, and water [28]. The Canada Shipping Act [29], the Railway Safety Act [30], and their respective regulations further detail specific requirements of the modes of transport under their jurisdictions. The Canadian Energy Regulator Onshore Pipeline Regulations [31] outline requirements for onshore pipelines.

Additional requirements beyond those covered in the federal regulations may also be enforced by provincial or territorial regulations. Similarly, local jurisdictions (cities or regions) may also enact local bylaws on these topics. For example, Transport Canada is responsible for the TDG Regulations [32]. The Province of British Columbia (BC) has enacted the BC Transport of Dangerous Goods Act, which harmonizes provincial and federal requirements for transportation of dangerous goods on BC highways, including provincial ferry routes [33]. The Greater Vancouver Transportation Authority Act [34] addresses municipalities' authority with respect to the transportation of dangerous goods within their jurisdictions.

Canadian federal requirements for gas storage are outlined in the Canada Oil and enforced by provincial or territorial regulations. Additionally, on the federal level, some industries and workforces are regulated by the Canada Occupational Health and Safety Regulations [36]. Unlike US regulations, where federal occupational health and safety laws set a minimum requirement, in Canada, provinces have jurisdiction over this issue [37].

3.2.2 US Federal and State Regulations for Hydrogen Transportation and Storage

The US government continues to support the advancement of the hydrogen industry and explore various hydrogen initiatives. In 2021, Sandia National Laboratories issued a report on federal regulatory oversight of hydrogen systems [38], which provided an overview of US regulations applicable to hydrogen, as well as those that may indirectly address hydrogen.

The Pipeline and Hazardous Materials Safety Administration (PHMSA), an agency of the US

Department of Transportation, is the primary US regulatory authority for all modes of transportation of dangerous goods, including pipelines, under Title 49 of the US Code of Federal Regulations (US 49 CFR) Part 192 [39]. The following five parts of US 49 CFR, under the purview of PHMSA, are commonly applied to on-road, maritime, and rail modes of transportation:

- Part 171 provides general information, such as applicability, waste, incident reporting, definitions, and authorization and conditions for use of international standards and regulations.
- Part 172 lists hazardous materials for the purposes of transportation and prescribes the requirements for shipping papers, package marking, labeling, and transport vehicle placarding, as well as emergency response and training.
- Part 173 outlines classification of hazardous materials and gives specific requirements for hazardous materials preparation for shipment, inspection and testing, and retesting of containers.
- Part 178 provides details on the design and approval of packing and containers, including cylinders and tanks.
- Part 180 provides specifications for continuing qualification of packaging used for transportation of hazardous materials.

Specific parts of the US 49 CFR for each mode of transportation are identified in Section 3.4 of this report. In the US, the transport of hydrogen by road is also regulated by the Federal Highway Administration (FHWA), the Federal Trade Commission (FTC), and the Federal Motor Carrier Safety Administration (FMCSA), for specific requirements under their respective purviews [38]. PHMSA coordinates with the Federal Railroad Administration for permits to allow transportation of prohibited hazardous materials by rail and regulates waterways transportation of containerized hazardous materials with the US Coast Guard [38].

Aboveground storage and installation of hydrogen is regulated by the Occupational Health and Safety Administration (OSHA) under the US Department of Labor [40]. PHMSA regulates underground natural gas and hydrogen storage [41], which is discussed in Section 3.6 of this report. Additionally, US states and local authorities can create more stringent storage, siting and transportation of hydrogen requirements for their jurisdiction [38], [42].

For example, the Railroad Commission of Texas has enacted the following four rules that apply to natural gas and other gases within the State of Texas:

- Rule §3.95: Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations [43];
- Rule §3.96: Underground Storage of Gas in Productive or Depleted Reservoirs [44];
- Rule §3.97: Underground Storage of Gas in Salt Formations [45]; and
- Rule §3.98: Standards for Management of Hazardous Oil and Gas Waste [46].

3.2.3 Harmonization Between Regulations

The alignment of regulations across international jurisdictions is an ongoing effort. In 2017, PHMSA issued a rule to amend the Hazardous Materials Regulation to authorize the use of Transport Canada's equivalency certificates in the US "until the shipment's initial transportation ends" [47]. Equivalency certificates are granted by Transport Canada if a specific application cannot meet aspects of the defined requirements [48] when the risks are reasonably mitigated [49].

Transport Canada has also proposed to amend the TDG Regulations to allow the use of dangerous goods safety marks prescribed under US 49 CFR and special permits issued in the US for the transportation of dangerous goods across North America by road and railway vehicles. The proposed amendments would also include updates to two Canadian standards, CAN/CGSB-43.150 [50] and CAN/CGSB-43.125 [51], to better align with the UN recommendations for the design, manufacture, and use of means of containment.

Canada and the US have a railway vehicle reciprocity process, as defined in the regulations [52]. Cross-border vehicles that originate in the US must meet US 49 CFR to enter and to and travel through Canada, as well as the specific requirements in in parts 2 (Classification), 3 (Documentation), and 4 (Dangerous Goods Safety Marks) of the TDG Regulations [27].

Canada also recognizes and supports the transportation of dangerous goods to or from a vessel, a port facility, or a maritime terminal in accordance with the classification, marking, labeling, placarding, and documentation requirements of the International Maritime Dangerous Goods (IMDG) Code [53], [54].

During reshipping in Canada, when a consignment of dangerous goods is transported from a place outside Canada to a place in Canada and is reshipped within Canada by railway vehicle, the dangerous goods safety marks at the time of entry into Canada may continue to be displayed in accordance with US 49 CFR (road or rail), the International Civil Aviation Organization's Technical Instructions for the Safe Transport of Dangerous Goods (air), or the IMDG Code (maritime). The only exception is large means of containment, which must have placards displayed on them in accordance with Part 4 of the TDG Regulations [55].

3.3 Hydrogen Codes and Standards for Transport and Storage

A comprehensive listing of the technical documents, including codes, standards, recommended practices, and technical reports specific to the transport and storage of hydrogen for each sector is provided in Appendix A. Transport is divided into road, rail, and maritime, and storage is segmented into above and below ground. It should be noted that several documents were deemed to apply to more than one sector.

3.4 Hydrogen Transport

The scale of hydrogen required and supplied determines the mix of potential modes of transport and types of storage. For maritime transportation, gaseous hydrogen is best converted into liquid hydrogen due to its low energy density by volume [56]. The National Research Council conducted a study that identified active Canadian companies involved in various means of hydrogen transportation, as well as international companies active in Canada. No companies were identified for maritime and rail transportation of liquid organic hydrogen carrier, and only one international company for maritime transportation of liquid hydrogen was reported [57].

3.4.1 Hydrogen Transport by Road

3.4.1.1 Transport Canada Regulations

The TDG Regulations allow transportation of hydrogen stored in various types of containers that are mounted or permanently affixed to a heavy-duty truck trailer. When trucks travel on provincial and territorial roads or on municipally governed roads, additional highway safety regulations and bylaws apply. These may outline specific hydrogen transport requirements such as gross vehicle weight rating, trailer configurations, access to bridges, tunnels, parking, and storage [58].

In its definitions, the TDG Regulations provide a list of the safety standards and other safety requirement documents that apply to the transportation of hydrogen by truck [59]. Part 5 provides requirements for the means of containment for all modes of transportation and dangerous goods classes, and Part 9 provides specific requirements for road transportation [60], [61].

Part 5 of the TDG Regulations also references the use of containers in accordance with specific CSA, CGSB, or Transport Canada standards, including the following that are relevant to transporting hydrogen [62]:

- Cylinders, spheres, and tubes must comply with requirements of CSA B339 and CSA B340 [63], [64]. Cylinders and tubes manufactured in accordance with CSA B339 and used for the transport of Class 2 dangerous goods must be manufactured at facilities registered with Transport Canada.
- UN cylinders, UN tubes, UN cryogenic receptacles, and MEGCs [65] must comply with CSA B341 [66] and be selected for an application according to CSA B342 [67].
- Railway tank cars and ton containers transporting dangerous goods are subject to TP 14877 [68].

“The scale of hydrogen required and supplied determines the mix of potential modes of transport and types of storage.”

- Tank trucks and trailers and Transport Canada (TC) portable tanks must comply with CSA B620, CSA B621, CSA B622, and CSA B626 [69], [70], [71], [72].
- UN intermediate bulk containers and UN portable tanks are subject of CAN/CGSB-43.146 [73] and CSA B625 [74], respectively. UN small means of containment must fulfill requirements of CAN/CGSB-43.150 (former TP 14850) [50], while remanufacturing, reconditioning, and repair for re-use of certain drums is subject of CAN/CGSB-43.126 [75].

The primary standards referenced in the TDG Regulations for high-pressure hydrogen gas containment for on-road transport by tank trucks and trailers are:

- CSA B620, which sets out the requirements for highway tanks and TC portable tanks for the transportation of dangerous goods;
- CSA B339, which sets out the requirements for the manufacturing, inspection, testing, marking, re-qualification, reheat treatment, repair, and rebuilding of cylinders, spheres, and tubes (containers) for the transportation of dangerous goods. It also sets out requirements for new design qualification and facility registration; and
- CSA B625, which sets out the requirements for UN portable tank design, manufacture, and modification, and the requirements for UN, IM, and IMO portable tank selection, use, inspection, testing, and repair.

Selection of the container and use criteria is performed according to CSA B340, CSA B342, CSA B622, CSA B625, CGSB-43.123 [76] (not applicable to hydrogen), or TP 14877 if the means of containment is a ton container (see Section 3.4.3). Specifically:

- CSA B340 sets out the requirements for the selection, use, handling, and filling of cylinders, spheres, tubes, and other containers for the transportation of gases in Class 2.
- CSA B342 sets out the requirements for the selection, use, handling, and filling of UN pressure receptacles, MEGCs, and other pressure receptacles for the transport of Class 2 dangerous goods included.
- CSA B622 sets out the requirements of the selection and use of highway tanks and TC portable tanks for the transportation of Class 2 dangerous goods.

For transportation of liquid hydrogen on highways, the following containers are applicable:

- TC 331 tanks, designed to CSA B620 for liquefied compressed gases (e.g., LPG, NH_3); made of steel or aluminum; with a design pressure of at least 690 kPa (100 psi) and not more than 3450 kPa (500 psi);
- TC 338, designed to CSA B620, an insulated highway tank for gases as refrigerated liquids; made with supported welded inner vessel enclosed within a jacket with insulation between the inner vessel and jacket; insulation may be by vacuum; with a design pressure of at least 180 kPa (26 psi) and not more than 3450 kPa (500 psi);

- TC 3AXM/3AAXM/3T tube trailers, which are specialized units designed to CSA B339. They hold gases that cannot be easily liquefied, such as natural gas, at very high pressure. These units are usually re-tested using acoustic methods under permits issued by Transport Canada. US Department of Transportation units are allowed if they have passed inspection and testing in CSA B339 [77].

3.4.1.2 US Federal Regulations

In the US, transportation of hydrogen over roads is subject to regulations of PHMSA, FTC, FMCSA, and FHWA, in addition to state and local regulations, as noted in Section 3.2.2.

The PHMSA-regulated US 49 CFR Part 177 specifically lists requirements for carriage by public highways. It includes general information for on-road transportation, requirements for loading and unloading, segregation of hazardous materials, and provision for passenger carrying and vehicles in transit [38]. In addition, parts 356 (motor carrier routing), 389 (general motor carrier safety), and 397 (transportation for hazardous materials requirements), all regulated by FMCSA, also apply to on-road transportation. The FHWA regulates highway safety, which includes bridges, tunnels, and other associated elements under US 23 CFR Part 924 [78], while the FTC regulates labelling requirements for automotive fuel ratings via US 16 CFR Part 306 [79].

In 2010, PHMSA proposed to amend the Hazardous Materials Safety Regulations, specifically US 49 CFR parts 171, 173, 178, and 180, to allow use of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), Section XII for the design, construction, and certification of cargo tank motor vehicles, cryogenic portable tanks, and ton tanks [80]. However, the standard is not yet referenced in the Hazardous Materials Safety Regulations.

3.4.2 Maritime Transport of Hydrogen

3.4.2.1 International Maritime Organization

Generally, maritime applications are focused on large-scale global shipping of liquid hydrogen. The International Maritime Organization (IMO), a UN agency, is the international authority for the safety, security, and environmental performance of international shipping. Its main role is to create an international regulatory framework for the shipping industry [81].

In 2016, the IMO's Maritime Safety Committee adopted interim recommendations for the carriage of liquified hydrogen in bulk [82], which were prepared by the Sub-Committee on Carriage of Cargoes and Containers and state that ships carrying liquefied hydrogen gases in bulk should comply with the International Code for the Construction and Equipment of Ships Carrying Liquified Gases in Bulk (IGC Code) [83], and provide specific requirements for hydrogen carrying ships, allowing type 2G ships of IMDG Code to be used for this purpose [82]. Type 2G ships are chemical tankers allocated mainly to Class 2.1 gases. The Maritime Safety Committee also agreed to acquire information on safe carriage of liquefied hydrogen in bulk prior to amendment of the IGC Code for the inclusion of liquefied hydrogen. The Committee urged member states and the industry to submit information, observations, comments, and recommendations based on practical experience gained through application of the interim recommendations, and to submit relevant safety analysis on ships carrying liquefied hydrogen in bulk.

The adoption of these recommendations provides a framework for the future design, development, and learnings that will guide future codes, standards, and regulations for the bulk transport of liquid hydrogen on maritime vessels across member states, including Canada.

3.4.2.2 Transport Canada Regulations

Transport Canada, working alongside the IMO, is responsible for addressing the safe use and the unique context surrounding the transportation of hydrogen as cargo. In addition, they are responsible for ensuring all vessels and operators comply with the Transportation of Dangerous Goods Act [84], the Canada Shipping Act [85], and the Safe Containers Convention Act [86], and their respective regulations.

The Transportation of Dangerous Goods Act applies to maritime applications through Part 11 of the TDG Regulations [87] and specifies that anyone who imports, offers for transport, handles, or transports dangerous goods by vessel must comply with the IMDG Code. The IMDG Code sets out requirements for maritime transportation and stowage of dangerous goods in packaged form, detailing individual substances, materials, and covering matters such as packing, with particular reference to the segregation of incompatible substances [54].

The TDG Regulations also define the waters that fall under Canadian jurisdiction and, if transporting dangerous goods from one country through Canada to another country, the transporters must comply with the IMDG Code and Part 8 (Reporting Requirements) of the TDG Regulations [88].

The Canada Shipping Act and related regulations set out the requirements for safety and environmental protection for Canadian vessels and their operators, and provide a mechanism to request exemptions and equivalencies or appeal a decision to detain a vessel.

The Safe Containers Convention Act and the Safe Containers Convention Regulations [89] outline Canada's requirements for building and maintaining the shipping containers set out by the IMO International Convention for Safe Containers [90].

3.4.2.3 US Federal Regulations

PHMSA regulates maritime transportation of containerized hazardous materials specifically through US 49 CFR Part 176, which details the requirements for shipment preparation and containers inspection and testing. International transport requirements are subject to the IMDG Code and US 49 CFR §171.22-25 [91]. The US Coast Guard, through parts 154 and 156 of US 33 CFR [92], regulates transfer of hazardous materials between ships and facilities and navigable waters or contiguous zones. It also regulates bulk dangerous goods via US 46 CFR [93]. Part 150 gives requirements for compatibility of cargoes, Part 151 describes barges for bulk liquid hazardous materials, Part 153 specifies requirements for ships carrying hazardous materials, and Part 154 provides a list of applicable standards and requirements for self-propelled vessels carrying bulk liquefied gases.

3.4.3 Hydrogen Transport by Rail

3.4.3.1 Transport Canada Regulations

Transport Canada is responsible for rail transportation in Canada to ensure safe and secure railways and shipping by rail, to issue railway operating certificates, and to conduct incident reporting and investigations. The key legislation that grants Transport Canada the responsibility to oversee rail safety within a national framework is the Railway Safety Act [30], which states that federal and local railway companies operating on federally regulated track are responsible for the safety of their own operations [94].

Specific requirements for railway transport of dangerous goods, tank cars, and ton containers are outlined in Part 10 of the TDG Regulations and in TP 14877 [52], [68], and have been incorporated into CAN/CGSB-43.147 and CAN/CGSB-43.149 [95], [96]. TP 14877 covers large means of containment used in the handling, offering for transport, and transport of dangerous goods by rail, and will remain in effect until the Regulations reference CAN/CGSB-43.147 and CAN/CGSB-43.149. It includes requirements for the construction, qualification, and modification of railway tank cars and ton containers, as well as the selection, use, and handling of large containers or transport units [68].

Part 5.10 of the TDG Regulations defines CSA B340, CSA B342, CSA B625, or CGSB-43.123 as additional standards applicable for the manufacture, selection, and use of containers for the transport of Class 2 dangerous goods [60].

3.4.3.2 US Federal Regulations

US transport of hydrogen by rail falls under parts 174 and 179 of the US 49 CFR [39], in addition to previously discussed parts 171, 172, 173, 178, and 180. Part 174 for transport by rail outlines general requirements specifying limitations of other authorities having jurisdiction (AHJs) and other restrictions, inspections and acceptance requirements, and hazardous material removal and disposition. It also gives general operating, and handling loading requirements, and handling placarded cars, vehicles and cargo. Additionally, Part 174 provides detailed requirements for explosive

(Class 1), gases and flammable liquids (Classes 2 and 3), poisonous (Division 6.1) and radioactive (Class 7) hazardous materials.

US 49 CFR Part 179 provides specifications for general and specific tank car tank designs, including cryogenic liquid tank car tanks, and provides details on tank-head puncture resistance and pool and torch-fire testing.

3.5 Aboveground Hydrogen Storage

3.5.1 Canadian Regulations and Standards

Provincial acts and regulations are fundamental legislation for gas equipment regulations and the basis for permit approvals granted by AHJs.

In Canada, all pressure equipment must be registered in each province or territory where it is used. Manufacturers require registration in each province or territory to demonstrate registration across Canada overall. The requirement to have a Canadian Registration Number (CRN) is frequently reported as an ongoing trade issue by the natural gas and hydrogen industry at various consultation forums.

In 2018, the Canadian Free Trade Agreement [97] established a regulatory reconciliation process to help address the trade barriers pertaining to pressure equipment (boilers, pressure vessels, and fittings) across provincial and territorial borders. The resulting Reconciliation Agreement facilitates trade through the mutual recognition of regulatory requirements and administrative processes related to the issuance of a CRN [98]. It obliges the governments of all provinces and territories, except Alberta, to directly or by reference incorporate CSA B51-14 [99] into their regulations, and to make all reasonable attempts in future to adopt other relevant technical codes and standards, which may include future versions of CSA B51.

3.5.1.1 Storage Containers

The primary code for hydrogen storage in Canada is CSA B51, *Boiler, pressure vessel, and pressure piping code* [99], which is directly referenced in the Canada Oil and Gas Installations Regulations [35], and the Canada Occupational Health and Safety Regulations [36]. National Building Code of Canada [100] and CAN/BNQ 1784-000, *Canadian hydrogen installation code* [101], also references CSA B51. Regulations that have adopted CSA B51 are summarized in Appendix B.

CSA B51 was first published in 1939 and is currently in its 19th edition [102]. In keeping with CSA Group's goal of harmonizing its standards with those of other countries, CSA's Technical Committee on Boilers and Pressure Vessels and its subcommittees worked closely with the National Board of Boiler and Pressure Vessel Inspectors in the US and with the ASME committees responsible for producing the National Board Inspection Code and ASME's BPVC.

Part 1 of CSA B51 contains requirements for boilers, pressure vessels, pressure piping, and fittings. It is intended to fulfill two key objectives: (1) to promote safe design, construction, installation, operation, inspection, testing, and repair practices; and (2) to facilitate adoption of uniform requirements by Canadian jurisdictions. Part 2 contains requirements for high-pressure cylinders for the on board storage of natural gas, blends of natural gas and hydrogen (hydrogen blends), and hydrogen as fuels for automotive vehicles. It has been harmonized with the International Organization for Standardization (ISO) Standard 11439 [103]. In addition, the CSA subcommittee responsible for developing Part 2 consulted with committees responsible for developing compressed natural gas and compressed hydrogen gas vehicle containers, CSA/ANSI NGV 2 [104], CSA/ANSI HGV 2 [105], respectively, and the requirements of this section were published in the 2023 editions of these standards. Part 3 contains requirements for compressed natural gas and hydrogen refueling station pressure piping systems and ground storage vessels.

No specific gaps in the requirements to support hydrogen aboveground storage were identified through the literature review or the interviewees discussions.

3.5.1.2 Installation

CAN/BNQ 1784-000 [101] defines the installation requirements for hydrogen generating equipment for non-process end use, hydrogen utilization equipment, hydrogen dispensing equipment, hydrogen storage containers, hydrogen piping, and their related accessories. It has been adopted in several provincial regulations (see Appendix B), and it applies to all gaseous and liquid hydrogen installations except industrial installations producing and venting hydrogen as by-product, cryogenic systems used for hydrogen liquefaction, and hydrogen installations on vehicles for on-board use and hydrogen transportation modes. The standard requirements are harmonized to some of the NFPA 2, *Hydrogen technologies code* [106].

Clause 7.8 of CAN/BNQ 1784-000 provides registration requirements and references acceptable standards for design and storage of gaseous hydrogen and metal hydride, as well as usage time of the containers.

3.5.1.3 Risk and Safety Management

Considering hydrogen's flammability at a wide range of concentrations, risk management and safety process management are important aspects of hydrogen storage activities. CAN/BNQ 1784-000 references ISO 31000 [107] and ISO/IEC 31010 [108] standards for risk management, and CSA Z767 [109] for process management requirements. Additionally, AHJs may have specific requirements for risk assessment and they may not all take the same approach. CSA Z767 identifies the requirements for a process safety management system for facilities and worksites handling or storing materials that are potentially hazardous [109].

3.5.2 US Federal Regulations and Standards

The appropriate regulations for a hydrogen storage system depend on the purpose of the storage system and whether the hydrogen is stored in gaseous or liquid form. In the US, OSHA regulates hydrogen installation on customer premises and storage through US 29 CFR Part 1910 Subpart H [40]. This CFR section provides safety requirements for gaseous and liquid hydrogen except for single gaseous hydrogen systems containing less than 11 m^3 hydrogen, portable containers containing less than 150 L hydrogen, and liquid hydrogen systems with more than 283,910 L of hydrogen.

Section VIII, Division 1 of the ASME BPVC [110] gives requirements for the design, construction, and testing of pressure vessels exceeding 15 psi, and Division 3 provides requirements for vessels exceeding 10,000 psi [111]. Article KD-10 of Division 3 provides additional requirements specific to hydrogen transport and storage of high-pressure vessels. Section X, Appendix 8 outlines requirements for fiber-reinforced thermosetting plastic pressure vessels applicable for hydrogen transportation and storage [112], [113]. Piping systems are designed, constructed, and tested in accordance with requirements of the ASME B31 series of standards, with ASME B31.12 giving requirements for hydrogen piping and pipelines [114].

NFPA 2 addresses generation, installation, storage, use, and transfer of hydrogen in concentrations above 95% in compressed gas or cryogenic liquid form [106]. The code includes fire safety requirements, hydrogen requirements, vehicle fueling facilities, hydrogen fuel cell power systems, hydrogen generation systems, and requirements for some hydrogen applications. More than 30 states have adopted NFPA 2 as their code reference [115].

In 2017, the Hydrogen Safety Panel published a safety planning guide [116] that instructs on essential safety planning principles, safety plan content, and supporting documentation on safety planning for hydrogen and fuel cell projects. The guide provides a rational framework given the project roles, scope, and timing for emerging hydrogen projects.

Canadian hydrogen industry representatives have raised the idea of revisiting the use of CSA Z767 as well as some risk assessment methods outlined in the Hydrogen Safety Panel's guide to address the current state of hydrogen technology development, recognize other hazard and operability analysis methods, and address the challenge of AHJs requiring their own specific approaches.

3.6 Underground Hydrogen Storage: Canadian and US Regulatory Framework and Standards

Underground storage of hydrocarbons requirements are outlined in the CSA Z341, *Storage of hydrocarbons in underground formations series* [117], which is referenced in the Canadian Energy Regulator Onshore Pipeline Regulations [31]. Provincial and territorial regulations that have adopted the CSA

"Expanded use of hydrogen in different applications requires a review of the existing codes, standards, and regulations to ensure that these applications and processes are adequately addressed within the current documents."

Z341 series are detailed in Appendix B. The CSA committee responsible for this series also developed a supplement, CSA Z341S1 [118], to cover minimum requirements for the design, construction, operation, maintenance, abandonment, and safety storage of hydrogen and hydrogen blends in underground formations and associated equipment. These revisions are based on the current requirements for reservoir storage outlined in CSA Z341.1 and salt cavern storage in CSA Z341.2. In addition, CSA Group is developing a new standard, CSA W228, which will provide requirements for quantitative risk assessment of underground storage of hydrogen [119].

In the absence of national regulations surrounding underground hydrogen storage, the investigation of application procedures and approvals for projects storing hydrocarbons in underground formations is the responsibility of provinces and territories. For example, a guideline published by the BC Oil and Gas Commission states that "Section 80 of the Drilling and Production Regulation requires wells and facilities that form part of the storage project be constructed and operated in accordance with CSA Standard Z341" [120]. Other provinces and territories have similar processes and requirements.

Underground natural gas storage in the US is regulated by PHMSA, and the underground natural gas storage facilities requirements were amended in 2017 to include minimum safety standards for salt caverns, depleted-hydrocarbon reservoirs, and aquifer reservoirs, for natural gas storage [121]. API RP 1170 [122] and API RP 1171 [123] have been referenced in US 49 CFR Part 192 for design, construction, operation, monitoring, maintenance, and documentation practices for underground natural gas storage reservoirs, but hydrogen is out of the scope of those standards.

4 Discussion and Recommendations

4.1 Overview

There is an increasing interest in hydrogen as demand increases for its various applications. Expanded use of hydrogen in different applications requires a review of the existing codes, standards, and regulations to ensure that these applications and processes are adequately addressed within the current documents. Similarly, as increased amounts of hydrogen are used in any given operation, a review of these documents is also required to ensure all the safety concerns associated with using increased volumes of hydrogen are adequately addressed.

The transport and storage of hydrogen is a mature industry, focused primarily on industrial processes requiring hydrogen, which rely on existing codes, standards, and regulations.

The regulatory environments in Canada and the US are similarly structured, in that federal and regional jurisdictions may all establish regulatory requirements for the storage and transport of hydrogen. Lack of harmonization at any of these levels of government, or between jurisdictions, can cause challenges in promoting hydrogen technologies consistently across either country or between the two countries. In the case of jurisdictions where there are no regulations, implementation of hydrogen technologies is often left to the AHJs and their permitting processes.

Lacking, outdated, or unharmonized regulations and standards was one of the most discussed topics at a bulk hydrogen storage workshop organized by the US Department of Energy, along with hydrogen underground storage and hydrogen blending with natural gas transportation and storage activities [124]. Specific standardization and regulation gaps that were identified include:

- Clarification on risks of co-locating hydrogen with other gases and materials;
- Methods for onsite testing and recertification of tanks;
- Repurposing and recycling options for tanks that have a limited 15-year lifespan; and
- Storage tank health monitoring and potential implementation of cycle counting and monitoring software.

4.2 Identified Gaps, Challenges, and Recommendations

4.2.1 Advancement of Technological Change

Transport and storage of hydrogen cannot be studied in isolation. The transfer of hydrogen from one user to the next along the value supply chain requires further study. The current design-to-operation cycle involves many steps, external drivers, and methods and processes to meet very specific requirements. There may not be processes in place to rapidly integrate and implement technological change. It is therefore imperative to continue management and coordination of learnings across interested parties, and to drive for common solutions in support of scale, specifically by supporting the codes and standards development processes.

4.2.2 Hydrogen Transport by Road

The current transport of hydrogen by road via compressed hydrogen tube trailers or specialized liquid hydrogen single container trailers is considered a mature practice, and it is well supported by the TDG Regulations and standards. No gaps or issues with the hydrogen containers currently being used were identified by industry representatives, but the topic of containers should be assessed in more detail as hydrogen transport and storage projects evolve in Canada and the US. To support a potentially expanded demand for hydrogen requires scaled-up means for on-road transportation and temporary storage solutions under the current framework of codes, standards, and regulations. The anticipated increase in hydrogen demand could drive the need for additional safety requirements, such as additional hydrogen transport trailers on the road, multiple hydrogen transport vehicles at user sites, and different user duty cycles.

Monitoring the development of new solutions for hydrogen cylinders and containers is recommended to determine whether there is a need to add or modify current requirements. For example, significant efforts have been put into the integration of hydrogen storage modules in various sizes of intermodal tank containers using equivalence certificates and special permits. New hydrogen storage module systems used in multimodal applications (maritime, rail, truck) that are also suitable for hydrogen ground storage applications might potentially address the need for multi-purpose hydrogen containers. This type of opportunity means there is potential to support the integration of these solutions within the framework of existing transport standards and regulations.

The flexibility to select more than one hydrogen storage design solution, especially if designed and manufactured outside of Canada, comes with the added complexity of satisfying requirements of various AHJs in Canada. Harmonization of design assessments by each province is still a fundamental building block to achieve best practices applied at scale.

The industry is exploring different hydrogen transport solutions at points of delivery to address the complexities of access, siting, and safety requirements, while assessing impact on vehicle design, flexibility, and utilization. This research did not find evidence of best practices and common solutions that could help identify new requirements in the existing standards or highlight the need for new standards.

4.2.3 Maritime Hydrogen Transport

In Canada, maritime applications appear to be focused on hydrogen as a propulsion fuel on board relatively small maritime vessels that are in the early development stage. The potential to export hydrogen by maritime vessel is also an area of study, as is the storage of hydrogen at port facilities and the transfer of hydrogen onto maritime vessels. It is therefore recommended to explore the potential applicability of existing liquefied natural gas codes, standards, and regulations, and to modify them to support bulk hydrogen transport by maritime vessels.

4.2.4 Hydrogen Transport by Rail

In Canada, current rail activities are focused on the storage of compressed hydrogen used to propel line locomotives, switching locomotives, and passenger trains using fuel cells. These initiatives seek solutions for scaled ground hydrogen storage or direct fueling of hydrogen by truck. The operating environment, duty cycle, and range requirements for North American locomotives could generate new hydrogen storage system-specific requirements leading to a hydrogen storage system standard for rail.

The use of hydrogen and hydrogen blends to power rail equipment could begin to define the overall future operating environment. Transport Canada's equivalency certificates and the US Department of Transportation special permits support the potential for a container manufacturer to obtain a certification for modular ISO containers equipped with gaseous hydrogen cylinders, which would allow the transport of these containers by rail across jurisdictions. Therefore, future standardization efforts in hydrogen transport by rail should account for:

- Design of hydrogen tender cars;
- Modular ISO containers with compressed hydrogen cylinders and tubes currently developed for trucking transport; and
- Applicability of existing liquefied natural gas rail car design requirements for hydrogen rail cars.

4.2.5 Aboveground Hydrogen Storage

Solutions for large aboveground storage of hydrogen and storage in public spaces are being actively explored. Without a common framework for risk assessments of hydrogen installations and associated hydrogen storage solutions approvals, the ability to apply a specific solution across multiple jurisdictions is already seen as a challenge. The ability to incorporate different perspectives and considerations across jurisdictions into the existing codes and standards is especially important for hydrogen storage at scale.

Fuel transfer challenges include balancing the amount of stored fuel with the rate of supply and consumption. Current large industrial-scale liquid and gaseous hydrogen storage requirements are met by either providing a larger physical footprint for storage or increased frequency of transport. Very large aboveground liquid hydrogen storage spheres currently support the storage of hydrogen delivered by pipelines. They are located in environments with extreme safety control systems and fulfill the short period requirements of a relatively high hydrogen demand, where the thermal losses are acceptable. However, for locations where the footprint or regulations do not allow for such solutions, flexible methods of storage, such as parked hydrogen trailers or use of ISO containers with hydrogen cylinders, could act as temporary solutions for overcoming the discrepancy between high hydrogen demands and lower capacity storage means. Permitting parked hydrogen transport trailers or trailers with hydrogen storage modules on site is determined by local and provincial building and fire regulations. Efforts should focus on simplifying permit approval processes and harmonizing the requirements, such as storage size footprint and scale, across jurisdictions.

The technical hydrogen storage solutions being designed, deployed, and supported by equivalency certificates, special permits, and approvals by various AHJs should be explored for potential new requirements of existing CSA hydrogen storage and associated system standards. One important aspect to consider, as reported during the Bulk Storage of Gaseous Hydrogen Workshop [124], is the detection of hydrogen leaks and fires. Relevant codes and standards need to look at hydrogen reactivity with relevant materials, such as seals, geological formations, cushion gases, and combinations of these materials.

4.2.6 Underground Hydrogen Storage

As noted, CSA Z341S1 covers underground storage of hydrogen and hydrogen blends. No information could be found on whether the future editions of API RP 1170 [122] and API RP 1171 [123] will include requirements for hydrogen. Western Canada, Atlantic Canada, and southern Ontario are all being explored for potential underground storage of hydrogen, with the primary focus on the possibility of using existing salt caverns [125]. Existing underground hydrogen storage sites in the US and the UK are in salt caverns [18].

5 Conclusion

Hydrogen transportation and storage are regulated through various hazardous materials regulations in Canada and the US. Although the regulation of current practices are well established, new modes of transportation and storage for large amounts of hydrogen are required to fulfill the future needs of the hydrogen industry. In particular, bulk liquid hydrogen transportation by waterways needs to be addressed by standards. For hydrogen transport by rail, it is recommended that standards account for the design of hydrogen tender cars, transport by ISO containers, and applicability of existing liquefied natural gas rail cars design requirements for hydrogen transport.

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Appendix A – Table of Key Standards and Other Guidance Documents with Requirements Specific to Hydrogen Transportation and Storage

Standards Development Organization	Designation	Publication Year or Reference	Title	Transport Road	Transport Rail	Transport Maritime	Storage Above Ground	Storage Below Ground
American Institute of Aeronautics and Astronautics (AAIA)	ANSI/AIAA G-095A	2017	Guide to Safety of Hydrogen and Hydrogen Systems	A	A	A	A	A
American Bureau of Shipping (ABS)	ABS 338	2023	Requirements for Hydrogen Fueled Vessels			A		
ABS	ABS 342	2023	Requirements for Liquefied Hydrogen Carriers			A		
American Petroleum Institute (API)	API RP 934-A	2019	Materials and Fabrication of 2¼Cr-1Mo, 2¼Cr-1Mo-¼V, 3Cr-1Mo, and 3Cr-1Mo-¼V Steel Heavy Wall Pressure Vessels for High-Temperature, High-Pressure Hydrogen Service				A	
API	API TR 934-B	2022	Fabrication Considerations for Vanadium-Modified Cr-Mo Steel Heavy Wall Pressure Vessels				A	
API	API RP 934-C	2019	Materials and Fabrication of 1¼Cr-½Mo Steel Heavy Wall Pressure Vessels for High-Pressure Hydrogen Service Operating at or Below 825°F (440°C)				A	
API	API TR 934-D	2010	Technical Report on the Materials and Fabrication Issues of the 1¼CR-½Mo and 1Cr-½Mo Steel Pressure Vessels				A	
API	API TR 934-F PART 1	2017	Impact of Hydrogen Embrittlement on Minimum Pressurization Temperature for Thick-Wall Cr-Mo Steel Reactors in High-Pressure H2 Services – Initial Technical Basis for RP 934-F				A	
API	API TR 934-F PART 2	2017	Literature Review of Fracture Mechanics-Based Experimental Data for Internal Hydrogen-Assisted Cracking of Vanadium-Modified 2¼Cr-1Mo Steel				A	
API	API TR 934-F PART 3	2017	Subcritical Cracking of Modern 2¼ Cr-1Mo-¼V Steel due to Dissolved Internal Hydrogen and H_2 Environment, Research Report				A	
API	API TR 934-F PART 4	2018	The Effects of Hydrogen for Establishing a Minimum Pressurization Temperature (MPT) for Heavy Wall Steel Reactor Vessels				A	
API	API TR 934-H	2022	Inspection, Assessment, and Repair of Heavy Wall Reactor Vessels in High-Temperature High-Pressure Hydrogen Service				A	
API	API PUBL 938-A	1996	An Experimental Study of Causes and Repair of Cracking of 1¼ Cr-½ Mo Steel Equipment				A	
API	API RP 941	2016	Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants				A	
API	API TR 941-A		The Technical Basis Document for API RP 941				A	
API	API TR 942-B	2017	Materials, Fabrication, and Repair Considerations for Austenitic Alloys Subject to Embrittlement and Cracking in High Temperature 565°C to 760°C (1050°F to 1400°F) Refinery Services				A	
American Society of Mechanical Engineers (ASME)	BPVC	2021	Boiler and Pressure Vessel Code	A	A	A	A	

Standards Development Organization	Designation	Publication Year or Reference	Title	Transport Road	Transport Rail	Transport Maritime	Storage Above Ground	Storage Below Ground
ASME	B31.12	2019	Hydrogen Piping and Pipelines				A	A
ASME	B31G	2012	Manual for Determining the Remaining Strength of Corroded Pipelines				A	A
ASME	STP-PT-003	2005	Hydrogen Standardization Interim Report for Tanks, Piping, and Pipelines	A	A	A	A	A
ASME	STP-PT-006	2007	Design Guidelines for Hydrogen Piping and Pipelines				A	A
ASME	STP-PT-005	2006	Design Factor Guidelines for High-Pressure Composite Hydrogen Tanks	A	A	A	A	
ASME	STP-PT-014	2008	Data Supporting Composite Tank Standards Development for Hydrogen Infrastructure Applications	A	A	A	A	
ASME	STP-PT-017	2008	Properties for Composite Materials in Hydrogen Science	A	A	A	A	
ASME	STP-PT-021	2008	Nondestructive Testing and Evaluation Methods for Composite Hydrogen Tanks	A	A	A	A	
ASME	STP-PT-023	2009	Guidelines for In-Service Inspection of Composite Pressure Vessels	A	A	A	A	
ASME	STP-PT-043	2010	ASME Flawed Cylinder Testing	A	A	A	A	
ASME	STP-PT-064	2013	Evaluation of Fracture Properties Test Methods for Hydrogen Service	A	A	A	A	
Bureau de normalisation du Québec (BNQ)	CAN/BNQ 1784-000	2022	Canadian Hydrogen Installation Code				A	A
Compressed Gas Association (CGA)	CGA G-5	2017	Hydrogen	A	A	A	A	A
CGA	CGA G-5.3	2017	Commodity Specification for Hydrogen	A	A	A	A	A
CGA	CGA G-5.4	2019	Standard for Hydrogen Piping Systems at User Locations				A	A
CGA	CGA G-5.5	2021	Standard for Hydrogen Vent Systems				A	A
CGA	CGA G-5.6	2005	Hydrogen Pipeline Systems				A	A
CGA	CGA H-3	2019	Standard for Cryogenic Hydrogen Storage				A	
CGA	CGA H-4	2020	Terminology Associated with Hydrogen Fuel Technologies	A	A	A	A	A
CGA	CGA H-5	2020	Standard for Bulk Hydrogen Supply Systems (an American National Standard)				A	A
CGA	CGA P-6	2012	Standard Density Data, Atmospheric Gases and Hydrogen	A	A	A	A	A
CGA	CGA P-12	2023	Guideline for Safe Handling of Cryogenic and Refrigerated Liquids				A	A
CGA	CGA P-28	2022	OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Supply Systems				A	A

Standards Development Organization	Designation	Publication Year or Reference	Title	Transport Road	Transport Rail	Transport Maritime	Storage Above Ground	Storage Below Ground
CGA	CGA P-37	2014	Good Environmental Management Practices for the Compressed Gas Industry				A	A
CGA	CGA P-41	2023	Standard for Locating Bulk Liquid Storage Systems in Courts				A	
CGA	CGA P-59	2023	Prevention of Excessive Pressure During Filling of Cryogenic Vessels				A	
CGA	CGA P-74	2019	Standard for Tube Trailer Supply Systems at Customer Sites				A	
CGA	CGA S-1.1	2022	Pressure Relief Device Standards – Part 1 – Cylinders for Compressed Gases	A	A	A	A	
CGA	CGA S-1.3	2020	Pressure Relief Device Standards – Part 3 – Stationary Storage Containers for Compressed Gases	A	A	A	A	
Canadian Standards Association (CSA Group)	CSA B51	2019	Boiler, Pressure Vessel, and Pressure Piping Code	A	A	A	A	A (vessels buried underground)
CSA Group	CSA B339	2018	Cylinders, Spheres, and Tubes for the Transportation of Dangerous Goods	A	A	A		
CSA Group	CSA B340	2018	Selection and Use of Cylinders, Spheres, Tubes, and Other Containers for the Transportation of Dangerous Goods, Class 2	A	A	A		
CSA Group	CSA B341	2018	UN Pressure Receptacles and Multiple-Element Gas Containers for the Transport of Dangerous Goods	A	A	A		
CSA Group	CSA B342	2018	Selection and Use of UN Pressure Receptacles and Multiple-Element Gas Containers for the Transport of Dangerous Goods, Class 2	A	A	A		
CSA Group	CSA B620	2020	Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods	A	A	A		
CSA Group	CSA B622	2020	Selection and Use of Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods, Class 2	A	A	A		
CSA Group	CSA B625	2020	Portable Tanks for the Transport of Dangerous Goods	A	A	A		
CSA Group	ANSI/CSA CHMC 1	2014	Test Methods for Evaluating Material Compatibility in Compressed Hydrogen Applications – Metals	A	A	A	A	A
CSA Group	CSA/ANSI CHMC 2	2019	Test Methods for Evaluating Material Compatibility in Compressed Hydrogen Applications – Polymers	A	A	A	A	A
CSA Group	CSA Z341 Series and CSA Z341S1	2022 and 2023	Storage of Hydrocarbons in Underground Formations and Supplement No. 1 to CSA Z341 Series					A (underground formations)
European Industrial Gas Association (EIGA)	EIGA Doc 15/21	2021	Gaseous Hydrogen Installations				A	
EIGA	EIGA Doc 06/19	2019	Safety in Storage, Handling and Distribution of Liquid Hydrogen	A	A	A	A	
EIGA	EIGA TB 42/22	2022	Welded Gaseous Storage Vessels and Hydrogen Compatibility				A	
EIGA	EIGA Doc 100/20	2020	Hydrogen Cylinders and Transport Vessels	A	A	A		
International Maritime Organization (IMO)	IMDG Code		International Maritime Dangerous Goods Code			A		

Standards Development Organization	Designation	Publication Year or Reference	Title	Transport Road	Transport Rail	Transport Maritime	Storage Above Ground	Storage Below Ground
IMO	IGC Code		International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk			A		
IMO	IGF Code		International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels			A		
International Organization for Standardization (ISO)	ISO 11114-4	2017	Transportable Gas Cylinders – Compatibility of Cylinder and Valve Materials with Gas Contents – Part 4: Test Methods for Selecting Steels Resistant to Hydrogen Embrittlement	A	A	A	A	
ISO	ISO 11119 Series		Gas Cylinders – Design, Construction and Testing of Refillable Composite Gas Cylinders and Tubes	A	A	A	A	
ISO	ISO 14687	2019	Hydrogen Fuel Quality – Product Specification	A	A	A	A	A
ISO	ISO/TR 15916	2015	Basic Considerations for the Safety of Hydrogen Systems	A	A	A	A	A
ISO	ISO/TS 17519	2019	Gas Cylinders – Refillable Permanently Mounted Composite Tubes for Transportation	A	A	A		
ISO	ISO 19891-1	2017	Ships and Marine Technology – Specifications for Gas Detectors Intended for Use on board Ships – Part 1: Portable Gas Detectors for atmosphere Testing of Enclosed Spaces			A		
ISO	ISO 20421-1	2019	Cryogenic Vessels – Large Transportable Vacuum-Insulated Vessels – Part 1: Design, Fabrication, Inspection and Testing				A	
ISO	ISO 21029-1	2018	Cryogenic vessels – Transportable Vacuum Insulated Vessels of not more than 1 000 Litres Volume – Part 1: Design, Fabrication, Inspection and Tests				A	
ISO	ISO AWI TR 19884-2	Under development	Gaseous Hydrogen – Cylinders and Tubes for Stationary Storage – Part 2: Material Test Data of Class A Materials (Steels and Aluminum Alloys) Compatible to Hydrogen Service	A	A	A	A	
ISO	ISO AWI TR 19884-3	Under development	Gaseous Hydrogen – Cylinders and Tubes for Stationary Storage – Part 3: Pressure Cycle Test Data to Demonstrate Shallow Pressure Cycle Estimation Methods	A	A	A	A	
European Committee for Standardization (CEN)	EN 17339	2020	Transportable Gas Cylinders – Fully Wrapped Carbon Composite Cylinders and Tubes for Hydrogen	A	A	A	A	
CEN	EN 17533	2020	Gaseous Hydrogen – Cylinders and Tubes for Stationary Storage				A	
National Fire Protection Association (NFPA)	NFPA 2	2020	Hydrogen Technologies Code	A	A	A	A	
NFPA	NFPA 55	2023	Compressed Gases and Cryogenic Fluids Code	A	A	A	A	
Transport Canada	TP 14877	2019	Containers for Transport of Dangerous Goods by Rail		A			
Canadian General Standards Board (CGSB)	CAN/CGSB-43.147	2023	Containers for Transport of Dangerous Goods by Rail		A			
CGSB	CAN/CGSB-43.149	2023	Ton Containers for the Transportation of Dangerous Goods		A			

Appendix B – Table of Federal, Provincial, and Territorial Regulations that have Adopted CAN/BNQ 1784-000, CSA B51, and CSA Z341

	CAN/BNQ 1784-000 Adoption	CSA B51 Adoption	CSA Z341 Series Adoption
Federal	No	▪ CSA B51-M1991 *in* Canada Oil and Gas Installations Regulations, SOR/96-118 ▪ CSA B51-97 *in* Canada Occupational Health and Safety Regulations, SOR/86-304 ▪ CSA B51, Part 2 *in* Motor Vehicle Safety Regulations, CRC, c. 1038	▪ CSA Z341 *in* Canadian Energy Regulator Onshore Pipeline Regulations SOR/99-294
Alberta	No	▪ CSA B51:19 *in* Pressure Equipment Safety Regulation, Alta Reg 49/2006 ▪ CSA B51:19 *in* Design, Construction and Installation of Boilers and Pressure Vessels Regulations, Alta Reg 227/1975 ▪ CSA B51:19 *in* Occupational Health and Safety Code, Alta Reg 191/2021 ***Note.*** *Alberta's Safety Codes Act, RSA 2000, c S-1, Section 65(4) provides for ambulatory reference "on the first day of the month following the expiry of 12 months after the date on which the amendment or replacement is published".*	No
British Columbia	▪ CAN/BNQ 1784-000-2022 *in* Gas Safety Regulation, B.C. Reg. 103/2004	▪ CSA B51 and CSA B51-14 *in* Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation, B.C. Reg. 104/2004 ▪ CSA B51-M1991 *in* Occupational Health and Safety Regulation, B.C. Reg. 296/97	▪ CSA Z341 *in* Drilling and Production Regulation, B.C. Reg. 282/2010 ▪ CSA Z341 *in* Greenhouse Gas Emission Reporting Regulation, B.C. Reg. 249/2015
Manitoba	No	▪ CSA B51 in Steam and Pressure Plants Regulation, M.R. 108/87 R ▪ CSA B51-M1991 in Drilling and Production Regulation, M.R. 111/94	No
New Brunswick	▪ CAN/BNQ 1784-000/2007 *in* Standards Regulation, NB Reg 84-177	▪ CSA B51-14 *in* Standards Regulation, NB Reg 84-177 ▪ CSA B51 *in* General Regulation, NB Reg 91-191	▪ CSA Z341 *in* Pipeline Regulation, NB Reg 2006-2
Newfoundland and Labrador	▪ CAN/BNQ 1784-000 *in* Boiler, Pressure Vessel and Compressed Gas Regulations, NLR 119/96	▪ CSA B51 *in* Boiler, Pressure Vessel and Compressed Gas Regulations, NLR 119/96	No
Northwest Territories	No	▪ CSA B51 *in* Boilers and Pressure Vessels Regulations, NWT R-006-93 ▪ CSA B51 *in* Gas Protection Regulations, RRNWT 1990, c.G-1 ▪ CSA B51-95 *in* Mine Health and Safety Regulations, NWT R-125-95 ▪ CSA B51-M1991 *in* Oil and Gas Installations Regulations, NWT R-029-2014	No
Nova Scotia	No	▪ CSA B51:19 *in* Technical Safety Standards Regulations, N.S. Reg. 102/2014 ▪ CSA B51 *in* Boiler and Pressure Equipment Regulations, N.S. Reg. 10/2011 ▪ CSA B51-M1991 *in* Nova Scotia Offshore Area Petroleum Installations Regulations, N.S. Reg. 166/97	▪ CSA Z341 *in* Pipeline Regulations, N.S. Reg. 66/98

	CAN/BNQ 1784-000 Adoption	CSA B51 Adoption	CSA Z341 Series Adoption
Nunavut	No	▪ CSA B51 *in* Boilers and Pressure Vessels Regulations, NWT R-006-93 ▪ CSA B51 *in* Gas Protection Regulations, RRNWT 1990, c.G-1 ▪ CSA B51-95 *in* Mine Health and Safety Regulations, NWT R-125-95	No
Ontario	▪ BNQ 1784-000 *in* Gaseous Fuel Code Adoption Document, under Codes and Standards Adopted by Reference, O. Reg. 223/01	▪ B51 *in* Oil, Gas and Salt Resources of Ontario, Provincial Operating Standards, under Oil, Gas and Salt Resources Act, R.S.O. 1990 c.P.12 ▪ CSA B51:19 *in* Boilers and Pressure Vessels Code Adoption Document, under Codes and Standards Adopted by Reference, O. Reg. 223/01 ▪ B51-09 *in* Fire Code, O. Reg. 213/07	▪ CSA Z341 *in* Oil, Gas and Salt Resources of Ontario, Provincial Operating Standards, under Oil, Gas and Salt Resources Act, R.S.O. 1990 c.P.12 ▪ CSA Z341 *in* Provincial Standards for Compressed Air Energy Storage in Salt Caverns: Applications and Operations, under O. Reg. 245/97
Prince Edward Island	▪ CAN/BNQ 1784-000 *in* Boilers and Pressure Vessels Act Regulations, PEI Reg EC234/85	▪ CSA B51-14 *in* Boilers and Pressure Vessels Act Regulations, PEI Reg EC234/85	No
Quebec	No ***Note.*** *The Régie du bâtiment du Québec has not yet adopted CAN/BNQ 1784 in the Construction Code, CQLR c. B-1.1, r. 2, but they strongly encourage the use of CAN/BNQ 1784 for hydrogen installations (See https://www.rbq.gouv.qc.ca/domaines-dintervention/installations-sous-pression/reglementation/installations-a-lhydrogene-exigences-specifiques/)*	▪ CSA B51 *in* Regulation respecting pressure installations, CQLR c. B-1.1, r. 6.1 ▪ CSA B51 *in* Construction Code CQLR, c. B-1.1, r. 2 ▪ CSA B51-M2003 *in* Regulation respecting safety standards for road vehicles, CQLR c. C-24.2, r. 32	▪ CSA Z341 *in* Regulation respecting petroleum exploration, production and storage licences, and the pipeline construction or use authorization, CQLR c. S-34.1, r. 3 ▪ CSA Z341 *in* Regulation respecting petroleum exploration, production and storage on land, CQLR c. S-34.1, r. 2 ▪ CSA Z341 *in* Regulation respecting petroleum exploration, production and storage in a body of water, CQLR c. S-34.1, r. 1
Saskatchewan	▪ BNQ 1784-000/2007, as amended from time to time, *in* Gas Inspection Regulations, G-3.2 Reg 1	▪ CSA B51-14 *in* Boiler and Pressure Vessel Regulations, 2017, B-5.1 Reg 2	No
Yukon	No	▪ CSA-B51-14 *in* Design, Construction and Installation of Boilers and Pressure Vessels Regulations, O.I.C. 1980/303 ▪ CSA-B51-14 *in* Gas Regulations, O.I.C. 1998/213	No

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