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# **Liquid hydrogen storage for hydrogen refuelling stations – Codes and standards gap analysis**

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**CBI:** Clean Energy Innovation Research Centre





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## Table of Acronyms

Acronym	Description
<b>AHJ</b>	Authority Having Jurisdiction
<b>ANSI</b>	American National Standards Institute
<b>API</b>	American Petroleum Institute
<b>ASME</b>	American Society of Mechanical Engineers
<b>ASTM</b>	American Society for Testing and Materials
<b>ATEX</b>	Explosive Atmospheres
<b>BC</b>	British Columbia
<b>BNQ</b>	Bureau de normalisation du Québec
<b>BPVC</b>	Boiler and Pressure Vessels Code
<b>CAN</b>	Canada
<b>CcH<sub>2</sub></b>	Cryo-Compressed Hydrogen Storage
<b>CGA</b>	Compressed Gas Association
<b>CRNs</b>	Canadian Registration Numbers
<b>CSA</b>	Canadian Standards Association
<b>EIGA</b>	European Industrial Gases Association
<b>EN</b>	European Standards
<b>FMEA</b>	Failure Mode and Effects Analysis
<b>H<sub>2</sub></b>	Hydrogen
<b>HGV</b>	Hydrogen gas vehicle
<b>HRS</b>	Hydrogen Refuelling Station
<b>HYRAM+</b>	Hydrogen Plus Other Alternative Fuels Risk Assessment Models
<b>ICC</b>	International Code Council
<b>IEC</b>	International Electrotechnical Commission
<b>ISO</b>	International Organization for Standardization
<b>LEL</b>	Lower Explosive Limit
<b>LH<sub>2</sub></b>	Liquid Hydrogen
<b>LNG</b>	Liquid Natural Gas
<b>MAWP</b>	Maximum Allowable Working Pressure
<b>NFPA</b>	National Fire Prevention Association
<b>NPSH</b>	Net Positive Suction Head
<b>NRC</b>	National Research Council Canada
<b>OSHA</b>	Occupational Safety and Health Administration
<b>P&amp;ID</b>	Process and Instrumentation Diagram
<b>PBU</b>	Pressure Build Unit
<b>QRA</b>	Quantitative Risk Assessment

<b>Acronym</b>	<b>Description</b>
<b>SAE</b>	Society of Automotive Engineers International
<b>SCC</b>	Standards Council of Canada
<b>Sandia</b>	Sandia National Laboratories
<b>sLH<sub>2</sub></b>	Subcooled Liquid Hydrogen
<b>SMR</b>	Steam Methane Reforming
<b>TSBC</b>	Technical Safety BC
<b>TSSA</b>	Technical Standards and Safety Authority
<b>UN</b>	United Nations
<b>USA</b>	United States of America
<b>WG</b>	Working group

# Executive Summary

Hydrogen has a low volumetric energy density, but when in liquid form, its density is higher, making it convenient for situations with limited space. However, liquid hydrogen (LH2) has unique characteristics that require additional precautions beyond those necessary for handling gaseous hydrogen. These include a high thermal expansion rate and an extremely low boiling point, which can lead to hazards such as frostbite, ice formation, and air solidification. Similarly, LH2 necessitates distinct components and equipment such as vacuum insulated vessels, vacuum-jacketed piping, bellows expansion joints, Bayonets, etc.

The objective of this project is to identify potential roadblocks, such as insufficient or outdated codes and standards, that may hinder the adoption of LH2 as a low-pressure storage solution at hydrogen refuelling stations in Canada. The scope of this work is limited to LH2 components, including storage tanks, vaporizers, and LH2 pumps (both low and high pressure). To achieve this, a literature review was conducted, a reference design incorporating the most likely components was created, and a gap analysis of codes, standards, and regulations was performed.

There are standards that address cryogenic tanks, such as the Hydrogen Technologies code of the National Fire Prevention Association (NFPA 2), the Standard for Cryogenic Hydrogen Storage of the Compressed Gas Association (CGA H-3-2019), the Cryogenic vessels standards of the International Organization for Standardization (ISO 21009), and others listed in Appendix A – Standards Relevant to Cryogenic Tanks. Some of these standards are relevant or recommended for informational purposes to address certain hazards. However, not all hazards can be addressed by Canadian standards alone, so USA and international standards must also be utilized.

Similarly, there are standards that address various aspects of vaporizers, as listed in Appendix B – Standards Relevant to Vaporizers. While some of these standards are specifically for Liquefied Natural Gas (LNG), they may also serve as useful guidelines. Additionally, certain codes address vaporizers directly. Section 8.6 of the Canadian Hydrogen Installation Code (CAN/BNQ 1784-000/2022) outlines requirements for LH2 vaporizers, as does the section 8.3.1.2.5 of the NFPA 2. These codes and standards cover aspects such as methods to prevent the discharge of LH2 downstream from the vaporizer, vaporizer support requirements, prevention of brittle fracture in equipment and piping, and the use of adequate metals, among others.

To the best of authors' knowledge, there is currently no Canadian standard specifically for cryogenic pumps. However, relevant standards have been published by the Compressed Gas Association (CGA) and International Organization for Standardization

(ISO), which provide guidance for the design, safety, installation, and operation of cryogenic pumps (listed in Appendix C – Standards Relevant to Cryogenic Pumps).

In Canada, the regulatory framework for the storage and installation of LH2 involves a combination of federal and provincial regulations to ensure safety, environmental protection, and compliance with established standards. These general regulations include building, fire, and electrical codes, as well as Environmental Protection, Transportation of Dangerous Goods, and Occupational Health and Safety Legislation. They also include the Canada Oil and Gas Operations Act, along with the Pressure Equipment Regulations. Appendix E – Summary of Legislations at the Federal Level and for Select Provinces, provides a summary of these legislations at the federal level and for select provinces.

Key requirements from relevant standards that are applicable for the tank, pumps, and vaporizer are summarized in this report. These requirements include installation, operation, inspection, maintenance, repair, and emergency procedures. Other aspects covered by these standards include safety distances, materials, instrumentation, purging, markings, etc. These standards were classified according to the project's life cycle, as depicted in Figure 10, and the number of standards for each project phase was counted. Most standards are related to specification, design, testing, fabrication, maintenance, and operation, in that respective order.

The CAN/BNQ 1784-000/2022 and NFPA 2 have requirements for LH2 tanks and their installation. However, a standards gap exists in Canada for cryogenic tanks. As USA and international standards do exist, it may be useful to harmonize Canadian standards with the USA standards and to adopt the international standards with Canadian deviations in consultation with industry and standards development organizations.

Currently, there is no specific standard in Canada for hydrogen vaporizing systems for refuelling stations. However, the NFPA 2, CAN/BNQ 1784-000/2022 and other USA requirements do cover many aspects of vaporizers (Appendix B – Standards Relevant to Vaporizers lists the relevant standards). Therefore, for the time being these standards must be used, but a new vaporizer standard should be created.

To the best of authors' knowledge, there is currently no Canadian standard for cryogenic pumps. However, relevant standards have been published by the CGA and the ISO, which provide guidance for the design, safety, installation, and operation of cryogenic pumps. Therefore, for the time being these standards can be used but a new cryogenic pumps standard should be created (Appendix C – Standards Relevant to Cryogenic Pumps lists the relevant standards).

Eight stakeholders with experience in either LH2 or LNG provided feedback. Two of these stakeholders were from the USA, and six were from Canada. Most were identified

through the NRC Codes and Standards website (<https://csres-cnrc.gc.ca/en/canadian-hydrogen-value-chain-2024>), which provides a list of relevant companies active in Canada. A questionnaire, detailed in Appendix F – Stakeholder Consultation Questionnaire, was sent to the stakeholders for completion. It included a self-identification section, questions regarding the current state of codes, standards, and regulations, as well as the adequacy of existing safety measures and risk mitigation strategies for LH2 systems. Most Canadian respondents felt that there are some gaps and inconsistencies in codes and standards, some or minimal gaps and inconsistencies in regulations, and that current safety measures and risk mitigation strategies are adequate. All the responses are detailed in this report. These respondents also provided a wealth of additional insights.

This report has recommendations that include the need for continued review of LH2 refuelling stations operations to gather information on current practices and challenges. Canadian standards for the main components like cryogenic tanks, vaporizers and cryogenic pumps are lacking, but USA and international standards, such as CGA and ISO, provide good coverage. Canadian standards should be developed, potentially as bi-national or with international adaptations, especially for cryogenic hydrogen systems. Harmonization across provinces is necessary for streamlined approval processes while incorporating international standards could facilitate exports. Stakeholders highlight the need for consistent fundamental knowledge among regulators and streamlined approval processes, supported by the new roadmap published by NRCan (<https://natural-resources.canada.ca/energy-sources/clean-fuels/hydrogen-strategy/canadian-hydrogen-codes-standards-roadmap>). The CAN/BNQ 1784-000/2022 standard requires updates to align with the NFPA 2 standard, particularly in addressing discrepancies in setback distances and pressure tests. Risk assessment studies need more data and guidance for consistent evaluations, and Canada has an opportunity for leadership in model validations<sup>1</sup>. Risk assessments, involving methods like Failure Mode and Effects Analysis (FMEA), should be conducted with a team of regulators, codes and standards experts, and industry partners to identify and mitigate risks. Improvements are needed in Hydrogen gas vehicle standards from the Canadian Standards Association (CSA) and the American National Standards Institute (ANSI), for small hydrogen systems, and in addressing long-term storage limitations.

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<sup>1</sup> As suggested during the stakeholder consultation.

# Introduction

Hydrogen has the highest gravimetric density of all fuels (based on its lower heating value). However, it has a very low volumetric density, with compressed hydrogen gas at 700 bar having a volumetric energy density of 5.6 MJ/L and LH2 having a volumetric density of 8 MJ/L [1]

The following figure illustrates the gravimetric and volumetric densities of hydrogen as compared to other fuels.

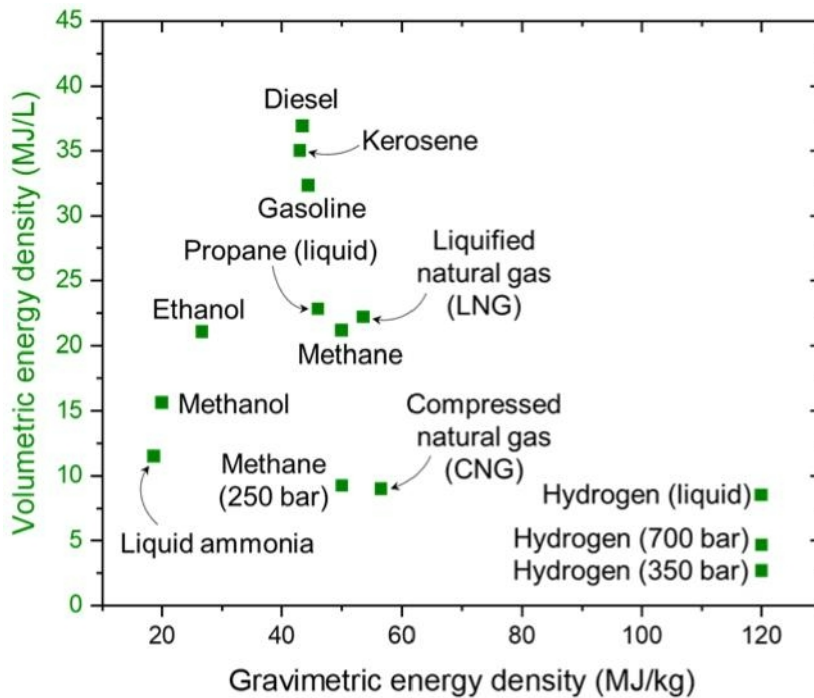


Figure 1: Comparison of gravimetric and volumetric densities for various fuels based on the lower heating values [2]

Storing hydrogen in liquid form offers advantages such as higher volumetric density, more efficient transportation to stations, and reduced pressure requirements. These benefits are particularly significant in situations with limited space<sup>2</sup> or when large quantities are needed. However, drawbacks include the additional energy costs associated with liquefaction and the complexities of maintaining cryogenic temperatures to prevent heat gain and ensure safety.

<sup>2</sup> The clearance distances for gaseous hydrogen in both CAN/BNQ 1784-000/2022 and NFPA 2 are significantly smaller than those required for liquid hydrogen installations. However, the mass of hydrogen from the clearance tables for liquid hydrogen is substantially greater.

## Liquid Hydrogen Consideration Highlights

LH2 has unique features requiring additional measures on top of those needed to handle gaseous hydrogen. Some examples of these features are described here. A much more detailed description can be found on the website H2Tools [3].

LH2 has a high expansion rate when it gains heat, expanding 23 times more than water. Therefore, if the tank is overfilled, LH2 may become trapped in the pressure relief system, increasing the likelihood of overpressure.

The extremely low boiling point temperature of  $-252.9^{\circ}\text{C}$  adds risks such as:

- Frostbite and hypothermia next to LH2 equipment.
- Because all gases become solid at those low temperatures (except for helium), air may condense on LH2 carrying components that are not sufficiently insulated. Due to the difference of the oxygen boiling point ( $90^{\circ}\text{K}$ ) as compared to nitrogen's boiling point ( $77^{\circ}\text{K}$ ), the oxygen will liquify first resulting in oxygen rich liquid air, which may drip and vaporize resulting in an oxygen rich atmosphere next to these components increasing the risk of fire or explosion<sup>3</sup>. For this reason, the insulation used for liquid hydrogen systems must have vapor tight covering and seals<sup>4</sup> and be made of non-combustible materials. Additionally, to mitigate the risk of frozen nitrogen contamination, liquid hydrogen systems must be purged to ensure residual nitrogen concentrations are below 0.1% by volume. This requirement also applies to oxygen.
- Ice formation from air humidity
  - May render valves inoperative.
  - May block vent lines increasing the risk of overpressure failures.
- The substantial temperature drop to  $-253^{\circ}\text{C}$  causes significant thermal contraction of components. These cycles of contraction and expansion must be considered.
- Minimizing heat transfer between the atmosphere and LH2 is challenging due to the large temperature difference. Consequently, LH2 tends to absorb heat and evaporate over time as a normal part of operation. This results in a pressure increase within the container that needs to be periodically relieved. Therefore, an

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<sup>3</sup> <https://ehs.princeton.edu/book/export/html/184>

<sup>4</sup> Vapor-tight coverings and seals are essential to prevent liquid oxygen from permeating into the insulation material. If this precaution is not taken and liquid oxygen is allowed to permeate into the insulation material, it may undergo a rapid, explosive expansion when it changes phase as temperatures rise after the liquid hydrogen flow stops.

adequate pressure relief system, suitable for intermittent operation, must be designed and fitted to a venting system to avoid container failure.

- If LH2 becomes trapped inside components or piping, it will eventually change phase. If it is not relieved, this can lead to the component breaking. Therefore, careful design must include pressure relief mechanisms to prevent the trapping of LH2.
- If LH2 leaks, it will quickly change phase to gas due to the heat gained from the environment. Additionally, a hydrogen gas cloud formed from a LH2 leak is dense because of the extremely low temperature. Consequently, this gas cloud could move horizontally or even downward for some distance before heating up, expanding, and rising. At the same time, the gas cloud condenses water vapor from the surrounding air, creating fog. As the gas gains heat, it mixes with air and forms a flammable cloud that could ignite or detonate in the presence of an ignition source<sup>5</sup>. If it remains unignited, once the gas gains enough heat, it quickly dissipates and rises, taking the fog with it.
- Leaks from LH2 systems are likely to create ice crystals at the leak point due to the cold temperatures. This, along with the formation of fog, makes it easier to identify leaks compared to gaseous hydrogen leaks.

## Components Used for Liquid Hydrogen

Because of the unique features of LH2 and the required corresponding measures, LH2 necessitates distinct components and equipment. Some of these components are described herein. More detailed descriptions can be found in [4], [5], [6], [7], [8], [9], [10], [3], [11], [12], [13], [14], and [15].

### Vessels

LH2 is stored in cylindrical or spherical tanks constructed from stainless steel or aluminum, with spherical tanks often used for large capacities. Tanks must be stored at a positive pressure to prevent air ingress. These cryogenic vessels feature innovative vacuum insulation to minimize heat transfer and reduce evaporation losses. Equipped with pressure relief systems, they prevent over pressurization caused by boil-off, a natural process where LH2 evaporates, increasing internal pressure. Tanks include real-time monitoring for pressure, temperature, and liquid levels. Cryogenic liquid storage vessels must be clearly marked with the label: "LIQUEFIED HYDROGEN - FLAMMABLE GAS." A warning sign should also be placed near the pressure-relief

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<sup>5</sup> The liquid hydrogen leak may cause air condensation where hydrogen pools, leading to oxygen enrichment, which lowers the energy required for ignition and increases the rate of combustion and the probability of detonation.

valve vent stack, stating: "Do not spray water on or in the vent opening." This precaution helps prevent water from entering the vent stack and then freezing during a fire scenario, which could result in an explosion.

Local emergency responders and firefighters should receive specialized training on how to effectively handle incidents involving LH2 spills. This ensures they are prepared to respond safely and efficiently in case of an emergency [4], [16], [6].

## **Vessel vortex breaker**

A vortex breaker prevents vortex formation during fluid transfer from a vessel, ensuring smooth flow. Installed at the bottom outlet and drain nozzles, it helps avoid issues like uneven drainage [7].

## **Vacuum pumps**

Vacuum pumps maintain an insulating vacuum between the inner vessel and the outer vessels in cryogenic tanks, which is essential for minimizing heat transfer and preserving the low-temperature environment required for storing substances like liquid nitrogen, liquid helium, or LH2. These pumps are also responsible for removing hydrogen and purge gases, such as nitrogen or argon, to ensure the purity and safety of the system. Pumping hydrogen, however, presents unique challenges due to its high thermal velocity, small molecular size, and rapid diffusion through materials. These properties make hydrogen prone to leakage and difficult to contain, necessitating the use of specially designed pumps that can effectively handle its characteristics.

To address different vacuum requirements, various pump technologies are employed. Positive displacement pumps, such as rotary vane or diaphragm pumps, are commonly used for low to medium vacuum levels and operate by mechanically trapping and expelling gas. Momentum transfer pumps, including turbomolecular or diffusion pumps, rely on high-speed mechanisms to transfer momentum to gas molecules, making them suitable for high vacuum applications. Entrapment pumps, such as cryopumps or adsorption pumps, capture gas molecules through condensation or adsorption, and are ideal for achieving ultra-high vacuums. The choice of pump technology depends on the specific operational needs, including the desired vacuum level and the types of gases being handled.

The capacity of vacuum pumps must be carefully selected to meet peak demand during continuous operation, ensuring efficient gas removal even under high-load conditions. Additionally, pumps must be specifically rated for hydrogen service, as hydrogen's flammability and reactivity require robust safety measures. Materials used in pump construction must be compatible with hydrogen to prevent embrittlement or degradation over time. While vacuum spaces are ideally maintained hydrogen-free to avoid safety risks, the potential for hydrogen leaks—due to its small molecular size and high

diffusivity—requires pumps to be designed to safely handle gas mixtures that may contain hydrogen. This includes incorporating features such as leak detection systems, explosion-proof designs, and proper ventilation to mitigate risks [8], [9], [10].

## **Pressure building unit**

A Pressure Build-Up Unit (PBU) is a critical component used to maintain the desired pressure in an LNG tank. It functions as a two-phase shell-and-tube heat exchanger, connected to the tank via pipes at the bottom (for liquid withdrawal) and the top (for vapor return). When LNG is withdrawn from the tank, the internal pressure drops, which lowers the saturation temperature of the fluid and causes some of the liquid to vaporize. This pressure reduction also decreases the mass flow rate of the withdrawn liquid. To counteract this, the PBU draws a portion of the LNG from the discharge line, converts it into cryogenic vapor through heat exchange, and recirculates the vapor back into the tank. This process ensures the tank's operating pressure is maintained, enabling consistent and efficient LNG withdrawal.

## **Piping**

Cryogenic LH2 piping systems require vacuum-jacketed piping to minimize heat absorption, prevent vaporization losses, and avoid ice formation. Pressure relief devices and automatic shut-off valves near the storage vessel are essential for safety, with no additional components allowed between the valve and the tank. Below-ground piping should be insulated and installed in open trenches, while systems must accommodate thermal contraction. Oxygen enrichment risks<sup>6</sup> are mitigated by using non-combustible insulation and concrete paving instead of asphalt in storage areas [3].

## **Hydrogen bellows expansion joints**

Expansion joints are necessary in LH2 systems due to the extreme temperature-induced expansion and contraction of the pipes. Bellows expansion joints are utilized in the outer jacket of vacuum-insulated pipe spools. During installation, these expansion joints should not be stretched or compressed to address length discrepancies or to correct misalignment issues. Proper alignment and accurate measurements are essential to ensure their effective and safe operation [3].

## **Bayonets**

*Bayonets provide a practical solution for creating detachable connections in vacuum-insulated piping systems. They work by isolating the vacuum seals of individual*

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<sup>6</sup> As a result of air coming into contact with a cold surface, oxygen-enriched liquefied air forms and drips onto the floor surface.

components, allowing cryogenic connections to be disconnected without compromising the overall vacuum insulation. Additionally, bayonet connections enable the separation of system components without introducing contaminants, ensuring the integrity and cleanliness of the system remain intact. This makes them a reliable and efficient choice for maintaining and servicing cryogenic systems. The following

Figure 2 is a typical cross-section illustrating how bayonets are held and sealed together [11].

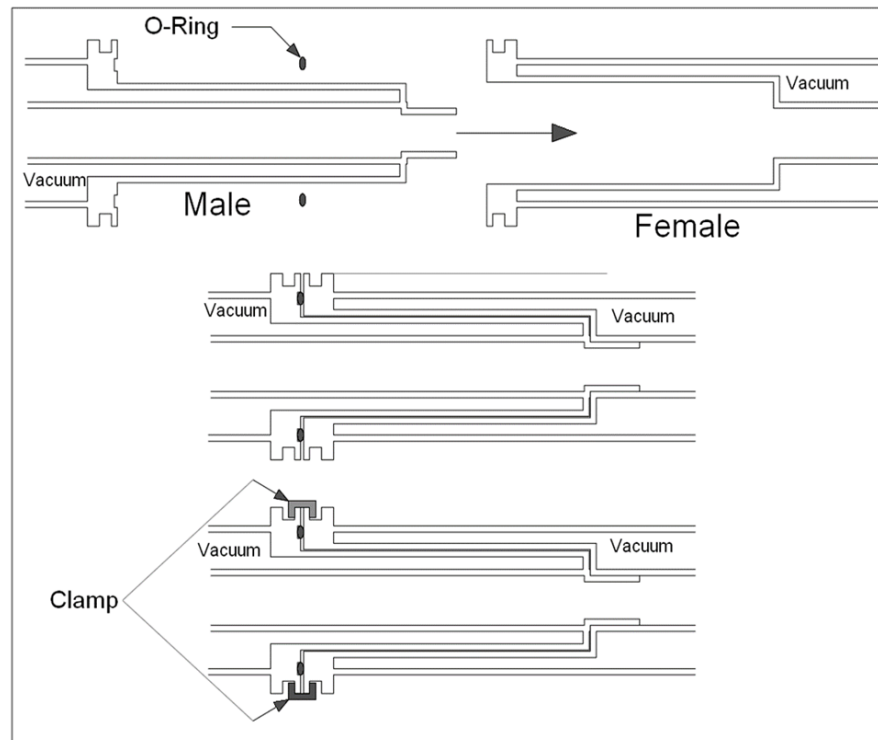


Figure 2: Typical bayonet cross section and joint.

## Valves

To address the unique challenges of handling LH<sub>2</sub>, specialized valve designs and safety measures are essential. Non-metallic seals in valves tend to contract at cryogenic temperatures, which is why extended bonnet valves are often used. These valves position the stem seals in a warmer area, ensuring they remain effective and functional. Additionally, because trapped LH<sub>2</sub> can rapidly warm up and generate extremely high pressures, valves must be designed to avoid trapping liquid when closed. This is a key reason globe valves are widely preferred in such applications. However, if ball valves are used, they must be modified to prevent liquid entrapment. A common modification involves drilling a hole in the ball, which must be installed with the hole facing the high-pressure side when the valve is closed to allow any trapped liquid to escape safely. Furthermore, to minimize the risk of ignition in hydrogen environments, pneumatic

actuators are typically chosen for remotely operated valves, as they keep potential ignition sources away from the valve. If electrical actuators are used instead, they must be specifically rated and certified for safe operation in hydrogen-rich environments. These design considerations and safety practices are critical for ensuring the reliability and safety of LH2 systems, particularly in applications such as storage, transportation, and processing [8], [6], [17], [18].

## **Extended bonnet globe valves**

An extended bonnet is utilized in both low-temperature and high-temperature applications, serving the purpose of safeguarding the stuffing box and preventing leakage from the stem packing. In low-temperature scenarios, extended bonnets are commonly employed for handling mediums such as LNG (liquefied natural gas), liquid ethylene, oxygen, LH2, and other cryogenic fluids [13], [12], [14].

## **Project Objective**

The objective of this project is to identify potential roadblocks, such as insufficient or outdated codes and standards, that may hinder the adoption of LH2 as a low-pressure storage solution at hydrogen refuelling stations in Canada. Consequently, this project will focus on analyzing the components required to store and gasify LH2. A refuelling station that incorporates LH2 storage adds two or three major components, as illustrated in

Figure 3. This project will address these components.

The top part of

Figure 3 illustrates a system that includes a high-pressure LH2 pump, which can significantly raise the pressure, eliminating the need for a compressor. The bottom part of

Figure 3 depicts a system that either uses a low-pressure LH2 pump or lacks a pump, necessitating a hydrogen compressor downstream from the vaporizer. This project will cover the LH2 storage, the low-pressure or high-pressure LH2 pump, and the vaporizer.

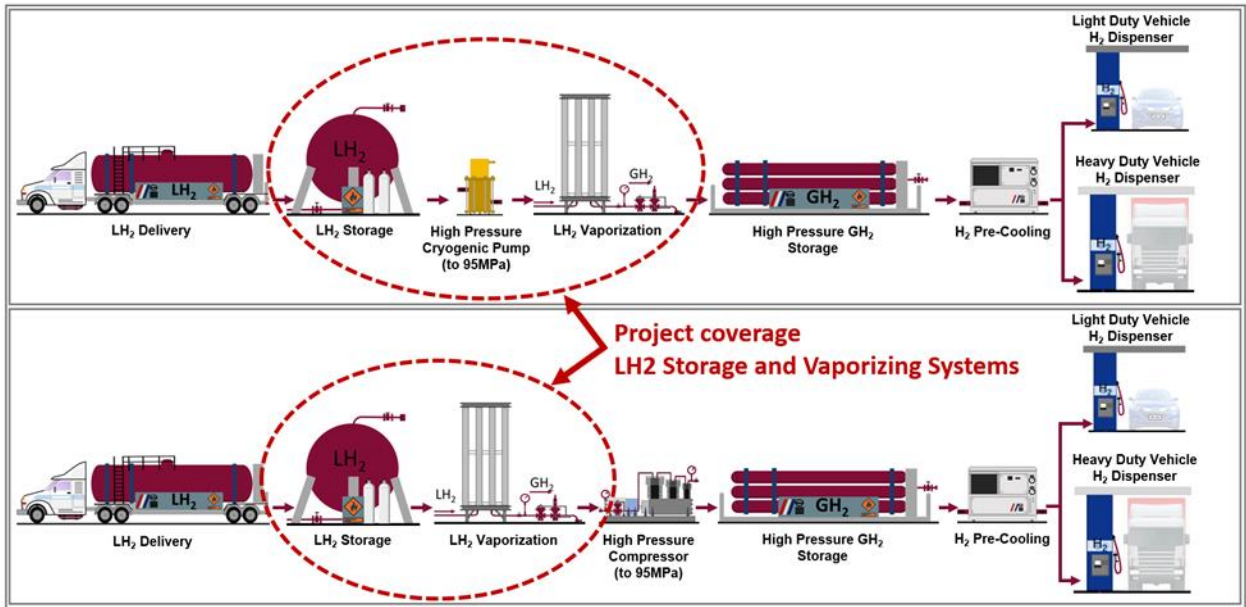


Figure 3: Major components required to store and gasify LH2

More details about the LH2 storage, the low-pressure or high-pressure LH2 pump, and the vaporizer will be provided in the reference design.

This project included a literature review to identify publications detailing LH2 storage installations at hydrogen refuelling stations, including descriptions of plant, vaporization components, and any available piping and instrumentation diagrams. The review also sought reports and publications related to LH2 storage installations and vaporization systems for hydrogen refuelling stations, focusing on relevant regulations, codes, and standards such as ICC, Eurocodes, NFPA, BNQ, CSA, IEC, ISO, and SAE.

Anyone involved with LH2 should grasp the fundamental properties of hydrogen gas, along with all additional considerations specific to LH2.

## Reference Designs and Key Subcomponents

*Various sources from the literature review were helpful in establishing a reference design [19], [20], [21]. The reference design system and its components are described in*

*Figure 4 to*

Figure 9 and Table 1.

*Figure 4 and*

Figure 5 were created from illustrations by Beeson et al. [19] and represent the LH2 cryogenic tank and lines, which include components from the vacuum system lines, safety relief system, tank instrumentation lines, storage filling lines, storage pressure build lines and emergency shutdown lines.

Figure 6 was created from an illustration by Jallais et al. [21] and it illustrates the LH2 cryogenic tank delivery lines.

Figure 7 and

Figure 8 illustrate the LH2 cryogenic tank delivery lines from a publication by Air Products [20] and Linde.

Figure 9 describes the estimated symbols and meanings for figures

Figure 4 to

Figure 8. The legend presented in

Figure 9 is based on an interpretation of the symbols from the referenced P&ID and has not been formally confirmed by the company. It is intended for illustrative purposes only.

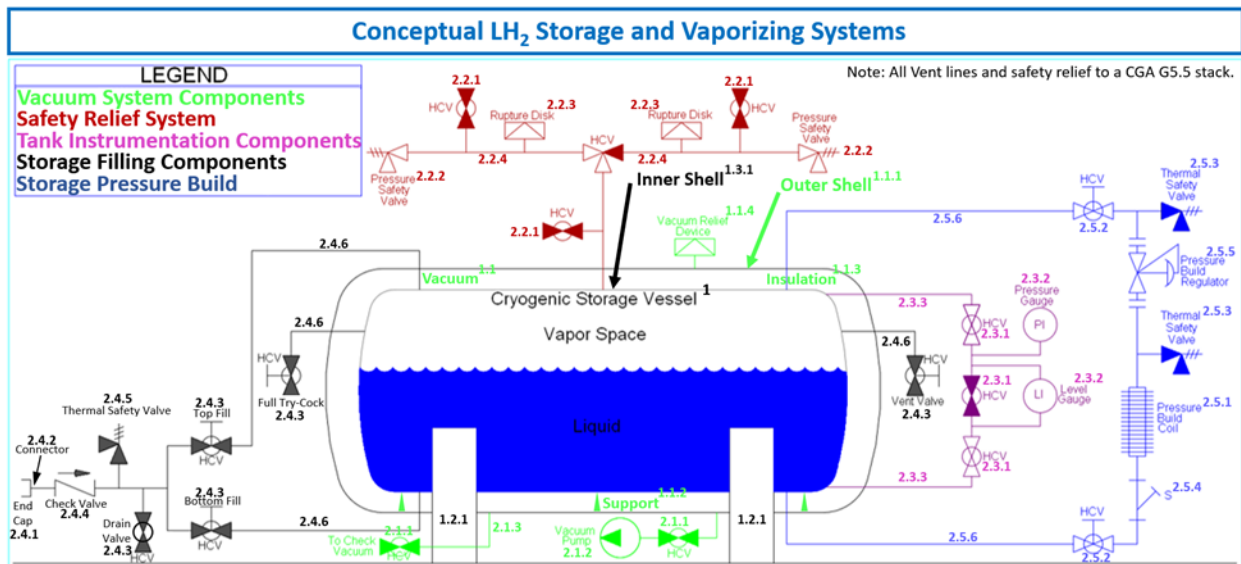


Figure 4: Conceptual LH<sub>2</sub> cryogenic tank and lines [19].

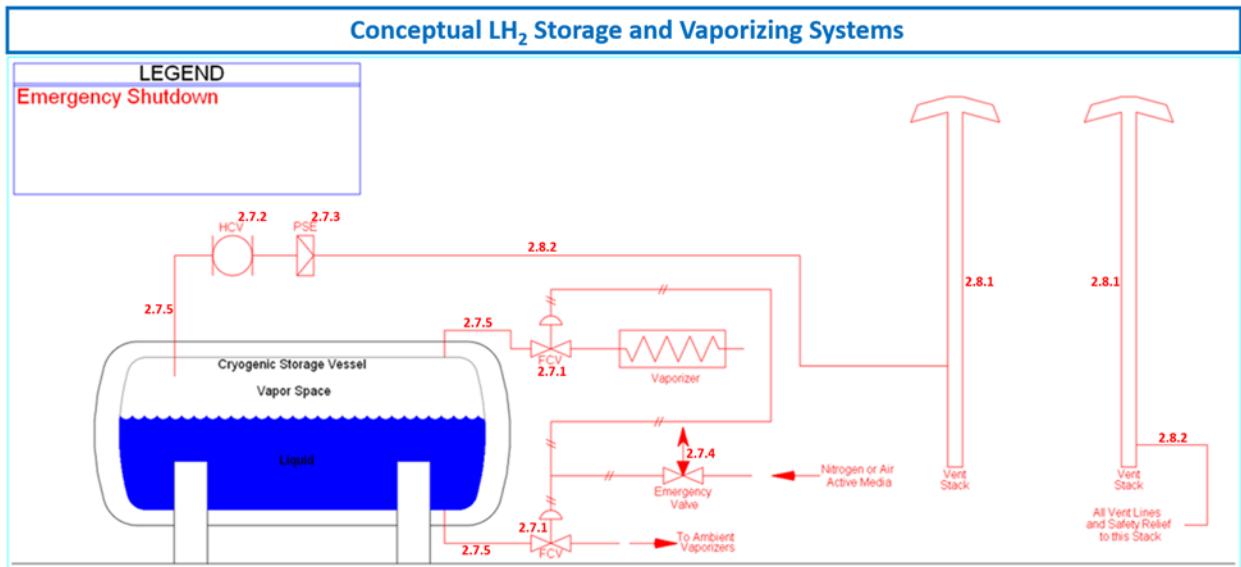


Figure 5: Conceptual LH<sub>2</sub> cryogenic tank emergency shutdown system lines [19].

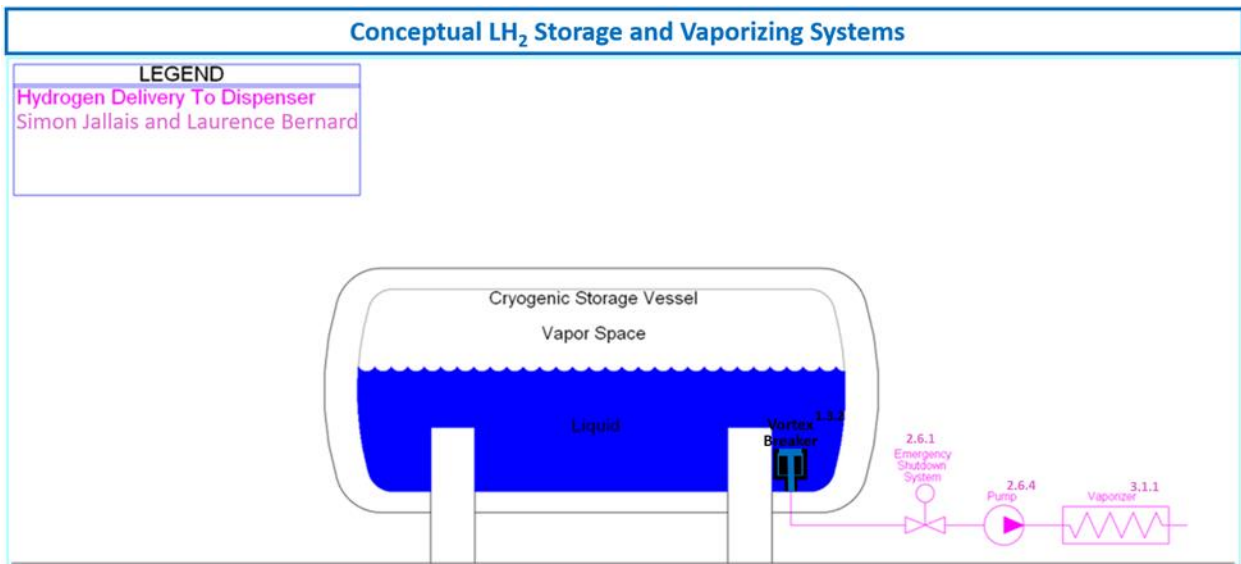


Figure 6: Conceptual LH<sub>2</sub> cryogenic tank delivery lines based on illustration by Jallais et al. [21].

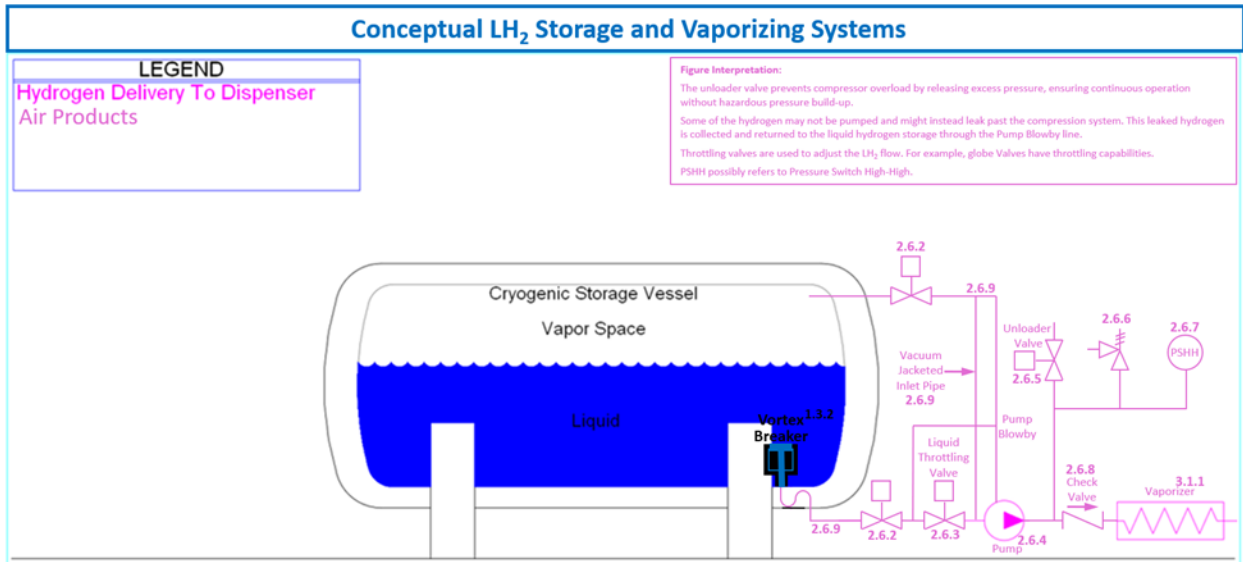


Figure 7: Conceptual LH<sub>2</sub> cryogenic tank delivery lines based on illustration by Air Products [20].

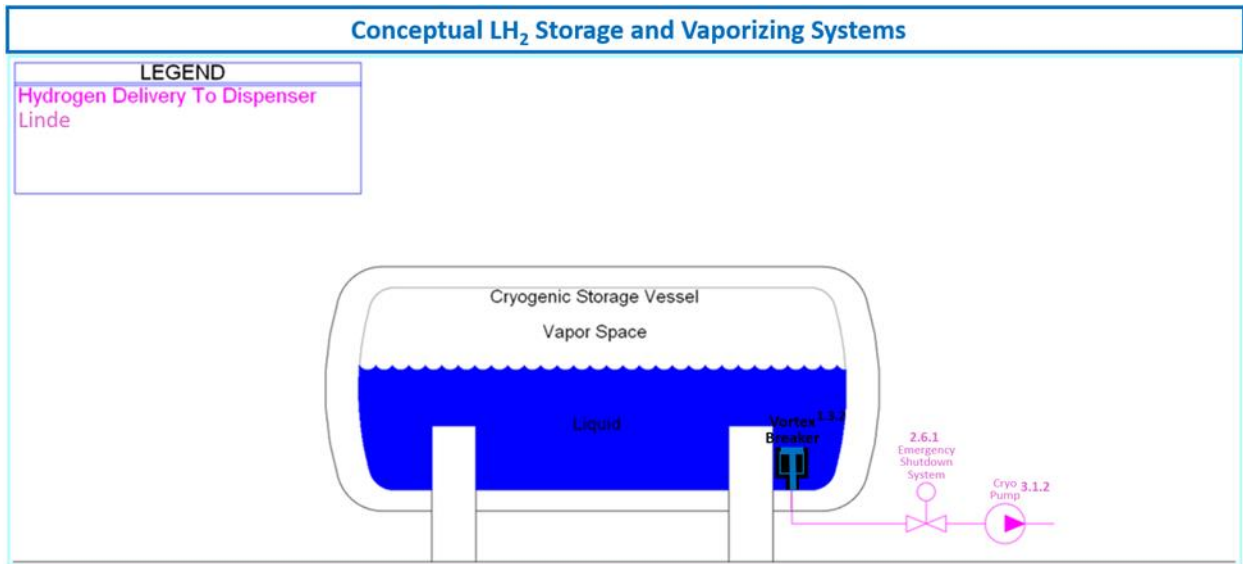























Figure 8: Conceptual LH<sub>2</sub> cryogenic tank delivery lines based on illustration by Linde<sup>7</sup>

<sup>7</sup> Illustration based on publication by Linde Engineering: Dr.-Carl-von-Linde-Strasse 6–14, 82049 Pullach, Germany, [www.linde-engineering.com](http://www.linde-engineering.com), Linde Hydrogen FuelTech Tomorrow's fuel today - H<sub>2</sub> Fuelling - Making our world more productive Linde GmbH K19004\_15\_ TICS\_052020.

Conceptual LH <sub>2</sub> Storage and Vaporizing Systems					
	Three Way Valve Normally Closed as Shown Butt Welded		Thermal Safety Valve		Pressure Indicator
	Ball Valve Normally Closed Butt Welded		Pressure Safety Valve		Level Indicator
	Ball Valve Hand Operated Normally Closed Butt Welded		Check Valve		Y-Type Strainer
	Ball Valve Normally Open Butt Welded		End Cap		Pressure Regulator Flanged
	Ball Valve Hand Operated Normally Open Butt Welded		Rupture Disk		Pressure Build Coil Finned Tubes Heat Exchanger
	Emergency Valve		Flow Control Valve Pneumatic (Diaphragm) Butt Welded		Rupture Disk
	High Pressure Pump Low Pressure Pump Vacuum Pump Cryogenic Pump		Hand Operated Control Valve Butt Welded Rotary Valve		Vaporizer

Note 1: HCV stands for Hand Operated Control Valve. Note 2: The Y-type strainer removes solid particles.

Figure 9: Estimated symbols legends and meanings for figures 4, 5, 6, and 7.

Table 1: Reference design sections and components for LH<sub>2</sub> storage and vaporization systems.

Part	System or Subsection	Components
<b>LH<sub>2</sub> Cryogenic Tank (Part 1)</b>	Vacuum Insulation (Part 1.1)	Outer Shell (Figure 3, Part 1.1.1)
		Annular Space and Supporting structure (Figure 3, Part 1.1.2)
		Annular Space Insulation (Figure 3, Part 1.1.3)
		Annular Space Relief Device (Top Hat) (Figure 3, Part 1.1.4)
	Tank Siting Structure (Part 1.2)	Tank Base (Figure 3, Part 1.2.1)
	LH <sub>2</sub> Container (Part 1.3)	Inner Shell (Figure 3, Part 1.3.1)
		Inner Vessel Vortex Breaker (Figure 5, Figure 6, Figure 7, and Figure 8, Part 1.3.2)
<b>LH<sub>2</sub> Cryogenic Tank Lines (Part 2)</b>	Vacuum Insulation (Part 2.1)	Shutoff Valves (Figure 3, Part 2.1.1)
		Vacuum Pump (Figure 3, Part 2.1.2)
		Piping (Figure 3, Part 2.1.3)
	Safety Relief (Part 2.2)	Shut-off Valves (Figure 3, Part 2.2.1)
		Pressure Safety Valves (Figure 3, Part 2.2.2)

Part	System or Subsection	Components
		Rupture Disk (Figure 3, Part 2.2.3)
		Piping (Figure 3, Part 2.2.4)
	Instrumentation (Part 2.3)	Shut-off Valves (Figure 3, Part 2.3.1)
		Pressure and Level Indicators (Figure 3, Part 2.3.2)
		Piping (Figure 3, Part 2.3.3)
	Fill Line (Part 2.4)	End Cap (Figure 3, Part 2.4.1)
		Connector (Figure 3, Part 2.4.2)
		Shut-off Valves (Figure 3, Part 2.4.3)
		Check Valves (Figure 3, Part 2.4.4)
		Thermal Safety Valve (Figure 3, Part 2.4.5)
		Piping (Figure 3, Part 2.4.6)
	Pressure Build (Part 2.5)	Heat Exchanger (Figure 3, Part 2.5.1)
		Shut-off Valves (Figure 3, Part 2.5.2)
		Thermal Safety Valve (Figure 3, Part 2.5.3)
		Strainers (Figure 3, Part 2.5.4)
		Pressure Build Regulator (Figure 3, Part 2.5.5)
		Piping (Figure 3, Part 2.5.6)
	LH2 Delivery (Part 2.6)	Emergency Shut-off Valve (Figure 5 and Figure 7 and 7, Part 2.6.1)
		Shutoff Valves (Figure 6, Part 2.6.2)
		Throttling Valves (Figure 6, Part 2.6.3)
		Low Pressure Pump (Figure 5 and Figure 6, Part 2.6.4)
		High Pressure Pump (Figure 5 and Figure 6, Part 2.6.4)
		Pump Unloader Valve (Figure 6, Part 2.6.5)
		Pressure Safety Valves (Figure 6, Part 2.6.6)
		Pressure Switches and Limits (Figure 6, Part 2.6.7)
		Check Valves (Figure 6, Part 2.6.8)
		Piping (Figure 6, Part 2.6.9)
	Emergency Shutdown (Part 2.7)	Flow Control Valves (Figure 4, Part 2.7.1)
		Hand Operated Control Valve (Figure 4, Part 2.7.2)
		Rupture Disks (Figure 4, Part 2.7.3)
		Emergency Valves (Figure 4, Part 2.7.4)
		Piping (Figure 4, Part 2.7.5)
	Venting (Part 2.8)	Vent Stack (Figure 4, Part 2.8.1)
		Piping (Figure 4, Part 2.8.2)

Part	System or Subsection	Components
<b>GH2 Delivery to Dispenser (Part 3)</b>	LH2 to GH2 Conversion (Part 3.1)	Vaporizer (Figure 5, and Figure 6, Part 3.1.1)
		Cryo Pump (Figure 7, Part 3.1.2)
<b>Helium Lines</b> (Not represented in the figures)	Purging	Helium Cylinders
		Shut-off Valves
		Pressure Indicators
		Piping
<b>Electrical Installation</b> (Not represented in the figures)	Electrical System	Valves, Switches, etc.
<b>Air/Nitrogen Lines</b> (Not represented in the figures)	Pneumatic Control	Cylinders
		Compressors
		Pressure Indicators
		Control Valves
		Pressure Safety Valves
<b>Site</b> (Not represented in the figures)	Installation	Concrete Paving, Fencing, Footings, etc.

# Review of Codes and Standards for Liquid Hydrogen Tanks, Pumps and Vaporizers at Refuelling Stations

## Cryogenic tanks

There are standards that address cryogenic tanks. For example, the CGA H-3-2019 (Cryogenic Hydrogen Storage) [6] standard specifies the design and performance requirements for vacuum-insulated, above-ground LH2 cryogenic tanks with a maximum allowable working pressure (MAWP) of 1,210 kPa or less. This standard does not cover installation, operation, or emergency response procedures, and it applies only within the United States.

The ISO 21009-1:2022 (Cryogenic vessels — Static vacuum-insulated vessels — Part 1: Design, fabrication, inspection and tests) [22] covers the fabrication, inspection and tests of vacuum-insulated cryogenic vessels with a MAWP of more than 50 kPa but it can be used as a guideline for vessels of lower pressures. The ISO 21009-2:2024 (Cryogenic Vessels — Static Vacuum Insulated Vessels — Part 2: Operational

Requirements) [23] covers the operational requirements for cryogenic vessels. This standard is also meant for vessels with a MAWP of more than 50 kPa but it can be used as a guideline for vessels of lower pressures.

An informative guidance document for cryogenic tanks is the CGA P-40-2017 (Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Tanks with Rupture Disk(s) - 4<sup>th</sup> Edition) [24]. This document includes guidance and calculations to find out if a vessel could be over pressurized while refilling. This document also provides engineering controls for the relief protection from rupture disk(s) in cryogenic storage tanks.

There are other standards that are relevant or can be used for informational purposes (as listed in Appendix A) from Standards Development Organizations such as:

- API, CGA, CSA, EIGA, EN, ISO, SAE, and UN

The informative standards that may cover aspects relevant to cryogenic tanks include themes related to:

- Containers for the transportation of dangerous goods
- Cryogenic vessels for transportation
- Portable cryogenic containers
- Handling of insulated tanks with loss of vacuum
- Insulated cryogenic vessels
- LH2 storage tank of hydrogen ships
- LH2 tanks for land vehicles
- LH2 tanks for aerial vehicles
- LNG standards
- Fuel cell vehicle standards

Chapter 8 of the CAN/BNQ 1784-000/2022 (Canadian Hydrogen Installation Code) defines the LH2 storage installation requirements. This chapter include prescriptions for the inner vessel material selection and temperature ratings. It also specifies the design and registration requirements (ASME BPVC, Section VIII [16], Division 1 or Division 2 and CSA B51 [25], Part 1). This code includes requirements for the materials and pressure ratings of the outer vessel. Similarly, it specifies requirements for the annular space and all circuits that the storage system must include. Additionally, the marking requirements are outlined.

The NFPA 2 standard also has requirements for cryogenic tanks and their installation including setback distances. For instance, NFPA 2 requires tank foundations and supports that are be able to withstand the low temperatures of a LH2 spill. Chapter 8 of the NFPA 2 includes requirements for LH2 and chapter 11 includes requirements for LH2 fuelling facilities including storage. This includes compliance with chapter 6 (general hydrogen requirements) and 8 (liquefied hydrogen) as well as an allowance of ullage space to avoid overfilling of the tank.

The CAN/BNQ 1784-000/2022 and NFPA 2 have requirements for LH2 tanks and their installation. However, a standards gap exists in Canada for cryogenic tanks. As USA and international standards do exist it may be useful to harmonize with the USA standards as well as to adopt the international standards with Canadian deviations in consultation with industry and standards development organizations two examples could be:

- To make the CGA H-3-2019 standard a bi-national standard (USA and Canada).
- To adopt the ISO 21009-1 [22] and ISO 21009-2 [23] in Canada with Canadian deviations.

## Vaporizers

According to Han et al., 2024 [26], the vaporizer supports must be constructed from non-flammable materials. If they are taller than 450 mm, they must comply with the ASTM E1529: 2022 standard (Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies) [27].

The CGA G-19.1: 2020 standard (Standard for Natural Gas Supply Systems, Second Edition) [28] includes a section on vaporizers. Although this standard is intended for natural gas, parts of it may also be applicable to LH2 vaporizers. The CGA P-56: 2022 standard (Cryogenic Vaporization Systems - Prevention of Brittle Fracture of Equipment and Piping) [29] recommends safe design practices for new cryogenic vaporizer systems and aims to prevent brittle fracture in piping and equipment downstream from the vaporization system.

The CSA/ANSI LNG 3.16:22 standard (Road vehicles — Liquefied natural gas (LNG) fuel system components — Part 16: Heat exchanger–vaporizer) [30] could be used useful for LH2 vaporizers. Section 8.6 of the CAN/BNQ 1784-000/2022 (Canadian Hydrogen Installation Code) outlines requirements for LH2 vaporizers. These requirements include selecting LH2 wetted parts in accordance with the CGA H-5 standard [31], specifying the use of austenitic stainless steel, Type 316L.

Additionally, the code mandates that heat be indirectly supplied by air, steam, water, or other water solutions, and that the heating equipment must be classified according to the IEC 60079-10-1 standard [32]. Furthermore, this standard requires measures to prevent the flow of LH2 if the heating medium fails.

Section 8.3.1.2.5 of the NFPA 2 addresses LH2 vaporizers. This code mandates that heat must be indirectly supplied by air, steam, water, or other water solutions. It specifies the proper methods for venting vaporizer pressure relief devices. Additionally, the code outlines the hazards associated with discharging LH2 downstream from the vaporizer due to heating media failure or excess flow. To address these risks, the code requires measures to prevent the flow of LH2 if the heating medium fails and mandates the installation of equipment to prevent flows exceeding the vaporizer's capacity. Furthermore, the standard requires a low-temperature shutoff switch for this purpose. The code also includes provisions for powered vaporizers, including the necessity for reserved heating to ensure continued vaporization following a power interruption.

As can be seen there is no specific standard in Canada for hydrogen vaporizing systems for fuelling stations. However, the NFPA 2, CAN/BNQ 1784-000/2022 and other USA requirements do cover many aspects of vaporizers. Additional details regarding the standards relevant to vaporizers can be found in Appendix B – Standards Relevant to Vaporizers.

## **Cryogenic Pumps**

Cryogenic pumps for LH2 are engineered to operate at extremely low temperatures (-252.9°C) to maintain hydrogen in its liquid state. Various designs can be utilized but reciprocating and centrifugal pumps are among the most commercially available.

To the best of authors' knowledge, there is currently no Canadian standard particularly for cryogenic pumps. However, relevant standards have been published by CGA and ISO, which provide guidance for the design, safety, installation, and operation of cryogenic pumps.

The standard CGA P-96-2023 [33] covers the reciprocating cryogenic pumps for hydrogen and LNG services. It includes the requirements for

- Electrical and mechanical components such as motor, suction filter, piston ring material, and valves;
- Leak detection at gland seals;
- Instrumentation;
- Installation; and

- Operation

Standards CGA H-5 defines the requirements for installation of pumps which are similar to those found in CGA P-96 including secure mounting to concrete foundations and grounding systems.

CGA G-19.1 is specific to natural gas systems, yet outlines useful requirements for both reciprocating and centrifugal pumps such as

- Humidity freezing;
- Vibration;
- Provisions for vapor venting;
- Discharge of unloader valve to vent stack, storage vessel or other safe locations;
- Considerations for unacceptable pressure fluctuations;
- Cavitation;
- Net Positive Suction Head (NPSH)
- Installation and start-up

Standard ISO 24490 [34] specifically applies to centrifugal pumps but can also be used for other types of cryogenic pumps, where applicable. This standard outlines the requirements for

- Materials including compatibility with hydrogen and oxidizing fluids
- Pressure containing parts
- Performance
- Clearances
- Bearing and lubrication
- Shaft seals

Linde has developed a specialized cryogenic pump for LH2 refuelling stations which has two chambers, both immersed in the cryogenic liquid. The first chamber is maintained at  $-252.9^{\circ}\text{C}$ . A piston compresses hydrogen to roughly 6 bars while simultaneously transferring it into the second chamber. The pressure in the second chamber increases to 900 bar and hydrogen becomes gaseous. The temperature is then increased to  $-40^{\circ}\text{C}$  to be ready for fuelling. This pump can deliver gas directly into the car without the need for a vaporizer. Linde claims that it fully complies with the SAE J 2601 [35].

The CAN/BNQ 1784-000/2022 (Canadian Hydrogen Installation Code) does not include specific content for cryogenic pumps but requires the LH2 pump piping to have a

vacuum jacket. Chapter 11 of the NFPA 2 contains design, construction, installation, and operation requirements for various LH2 equipment, including pumps. These requirements address wiring systems and the sealing of process instrumentation connections to prevent the flow of flammable fluids and gases from one electrical section to another. This standard also mandates that emergency shutoff devices must disconnect the pumps from their associated power sources. Additional details regarding the standards relevant to Cryogenic Pumps can be found in Appendix C – Standards Relevant to Cryogenic Pumps.

The standards for cryogenic tanks, vaporizers, and cryogenic pumps reference various standards for most components, such as valves, pipes, and insulation. Appendix D – Codes and Standards Relevant to Installation and Components, provides the codes and standards relevant to some components, along with general installation themes like electrical, building, and gas codes. This report does not delve into the specifics of area classification, as it is not unique to LH2 components. Relevant standards for area classification can be found in other NRC reports.

## Review of Regulations in Canada

In Canada, the regulatory framework for the storage and installation of LH2 involves a combination of federal and provincial/territorial regulations that ensure safety, environmental protection, and compliance with established standards. Regulations related to LH2 installations at both federal and provincial levels are categorized into the following sections:

- **National Building Code:** This code sets the regulatory requirements for buildings used for the storage of hazardous materials, including LH2. This code specifies container types and maximum allowable quantities as well as siting requirements such as minimum distance from other structures and property lines to ensure safety in the event of leaks or explosions. Also, ventilation standards referenced in this code address critical ventilation needs for flammable gases like hydrogen. Further, electrical requirements establish guidelines for wiring and electrical components in hazardous locations. Finally, fire Separation measures for spaces handling flammable materials are outlined in the national building code.
- **National Fire Code:** This code outlines the minimum requirements to ensure fire safety in buildings and facilities including fire prevention, equipment maintenance and emergency planning.
- **National Electrical Code:** This code sets the requirements for the safe installation of electrical components and is specifically applicable to hazardous area classification for LH2 systems.

- **Environmental Protection Legislations:** These legislations outline the rules for emergency responses, authorizations for reviewable projects, and other environmental safeguards to prevent and manage spills or accidents involving LH2.
- **Transportation of Dangerous Goods Legislations:** These regulations define mandatory requirements for the transportation and handling of LH2, ensuring safe transit and minimizing risks associated with its movement.
- **Occupational Health and Safety Legislations:** These regulations specify requirements for workplace safety related to hazardous material handling. They mandate employee training, risk assessments for installations, and other safety protocols to protect workers.

The more specific regulations at both federal and provincial levels include:

- **Oil and Gas Operations and Installation Acts:** These acts apply to hydrogen systems, setting standards for their safe installation and operation within the context of the oil and gas industry. In some of the regulations gas means natural gas and includes all substances, other than oil, that are produced in association with natural gas. Interpretations can be made that gas could also encompass hydrogen produced by the Steam Methane Reforming (SMR) process.
- **Safety Acts:** These acts define the standards that hydrogen systems must comply with, including design, construction, and operational criteria.
- **Pressure Equipment Regulations:** Each province also has a set of regulations for pressure-containing equipment. Provincial authorities, such as Technical Safety BC (TSBC) and the Technical Standards and Safety Authority (TSSA) in Ontario, enforce these standards.

Appendix E – Summary of Legislations at the Federal Level and for Select Provinces provides a detailed summary of these legislations at the federal level and for select provinces.

## Key Requirements

This section outlines the key requirements for tanks, vaporizers, and pumps used in LH2 installations. These requirements are necessary for ensuring safety, efficiency, and compliance with relevant regulations.

## **Cryogenic Tanks**

Standards ISO 21009-1, ISO 21009-2, CGA H-3, CGA H-5 provide requirements for LH2 storage tanks.

## **Personnel Training**

Only authorized and trained individuals are permitted to handle tanks and associated equipment. Training programs must cover operational and maintenance procedures, hazard identification, safe operating limits, and emergency protocols.

## **Safety Requirements**

LH2 tanks must be designed to the ASME Boiler and Pressure Vessel code. Other standards such as CSA B51, CSA B52 [36], CGA H-3 and ISO 21009-1 provide other key design requirements such as minimum ullage volume, wind, seismic, shipping, supports, inner vessel, outer jacket, and the annular space. The requirements in CGA H-3 are like those identified in CGA G-19.1 for Liquefied Natural Gas (LNG). A comprehensive list of standards applicable to cryogenic tanks is provided in Appendix A – Standards Relevant to Cryogenic Tanks.

Tanks must have identification labels, warning signs, and protective equipment displayed. All pressurized components must be depressurized before disconnection, and surfaces in contact with hydrogen must be clean.

Although CGA P-96 is for cryogenic pumps, it covers some basic requirements for insulation of the LH2 tanks.

Contact with LH2 or uninsulated equipment and pipe shall be avoided to prevent cold burns. Considerations must be given to the significant air liquefaction that can occur around uninsulated equipment.

## **Installation**

To allow safe filling and easy inspection tanks shall be installed with safety distances. Gas from pressure relief devices must be safely vented. Canadian Hydrogen Installation Code and CGA H-5 provide other key requirements for installation of the LH2 tanks. Installations must include correct electrical equipment for classified locations as well as proper grounding.

Any unacceptable misalignment or tilting must be avoided during the installation. Vessels shall be installed in well-ventilated areas to avoid explosive gas-air mixtures. Underground installations must be first evaluated by a thorough and appropriate risk assessment conducted by the end user. According to ISO 21009-2 proper space, at least 0.6 meter around installation, must be provided for maintenance and emergency cases.

## **Inspection**

According to ISO 21009-2, there is no need for in-service inspection of either the inner vessel or the interior surface of the outer jacket due to the nature of cryogenic fluids, their temperatures, the metallic materials of construction used, and the fact that the inner vessel is inside an evacuated outer jacket.

Regular inspections, including external visual checks of the vessel, valve functionality, vacuum between inner vessel and outer jacket, and leak tests are mandatory. Inspection of the pressure relief devices must happen within maximum intervals of five years. Replacement of burst discs must follow the manufacturer's instructions. According to CGA H-3, the purchaser may inspect the tank prior to component assembly or at a test station.

## **Maintenance and Repair**

Maintenance ensures conditions remain safe. Repairs must be completed with original or equivalent approved parts. Modifications need proper authorization from Authorities Having Jurisdiction. The responsibility for the maintenance and repair shall be established between the contracting parties. All hazards related to confined spaces such as oxygen enrichment/deficiency or flammability shall have been considered and documented prior for maintenance. Tanks must be fully depressurized before being taken out for service. Taking out of service shall follow a written procedure and the results of the steps involved shall be recorded. Proper tagout/lockout procedure shall be in place to avoid potential hazards especially while authorized personnel are performing maintenance on a Pressure Relief Device connected to a common relief stack.

## **Emergency Procedures**

Plans must be established for fire and other hazardous events. These plans must incorporate local conditions and emergency services. It is recommended to include hydrogen properties, quantities, vessel design and local topography in the procedure. In cases where a fire-fighting system is deployed, it should at a minimum consist of one fire extinguisher appropriate for the surroundings. If water is used to cool equipment during a fire, care must be taken to avoid spraying near relief-device vents due to the risk of ice formation that could obstruct them.

## **Operational Requirements**

Prior to filling the product identification plate, condition of hoses and couplings must be checked. All required measuring equipment should be fully operational and, when applicable, have up-to-date calibration. If the vessel is warm, it should be cooled down gradually according to manufacturer's recommendations or an approved first fill procedure. Filling processes must adhere to applicable standards such as SAE J2578 [37], SAE J2579 [38] , SAE 2601 [35], SAE 2719 [39], SAE 2799 [40] and SAE Air8466 [41]. Filling process must not exceed maximum levels.

Protective caps must be used for fittings and guidelines for purging and filling must be followed.

All surfaces in contact with LH2 shall be kept free from oil and grease.

## **Safety Distances**

Specific minimum safety distances must be observed to mitigate hazards. Annex A of ISO 21009-2 provide specific recommendations based on vessel capacity.

## **Cryogenic Pumps**

ISO 24490 [34] outlines key requirements for pumps used in cryogenic services including LH2.

## **General Requirements**

Cryogenic centrifugal pumps must comply with appropriate general standards. Regulations and specific conditions are the basis for choosing the appropriate general standards. Common standards frequently used include ISO 5199, ISO 13709 (ANSI/API 610) [42], or EN 809 [43].

## **Materials**

Materials for cryogenic hydrogen pumps must be suitable for low temperatures and environments. Considerations for embrittlement should be taken for possible exposure to LH2. Materials must be either resistant to atmospheric corrosion or adequately protected against it. If this is not feasible, an appropriate corrosion allowance should be considered. Metallic materials under stress must achieve minimum toughness values, while non-metallic structural parts should maintain acceptable stress and impact values.

Additionally, all materials should be resistant to, or protected from, atmospheric corrosion to ensure durability and reliability in cryogenic applications. ISO 21010 [44] and ISO 11114 [45] outline the criteria for choosing safe combinations of metallic cylinder and valve materials with the contents of cylinder gases.

Table 2 of CGA P-96 [33] provides a list of materials of construction for different components of reciprocating cryogenic hydrogen pumps.

## **Design**

Pressure-containing parts must be designed to safely withstand defined pressures. Performance must meet specified requirements. Clearances must be large enough for good hydraulic performance. Design should prevent rubbing and ensure secure fastenings. Performance of pump design and installation must comply with the

requirements specified in the data sheet. ISO 5199 [46] and ISO 9908 [47] provide examples of data sheets.

The spaces between moving and stationary parts in the pump should be maximized as much as possible without compromising hydraulic performance and sealing. When choosing materials for components, it is crucial to consider the considerable differences in expansion coefficients to maintain appropriate clearances and interferences at operating temperatures and during cool-down periods. Fasteners must be properly secured, e.g., friction nuts, tab washers, to prevent loosening in service.

International standards for electrical and mechanical components are acceptable if they meet or exceed local regulations

## **Installation**

A risk assessment is required for the overall installation to assess all hazards. If the pump is fully enclosed, additional fire hazards must be considered. The pumps are typically bolted to the concrete floor and bonded to a common ground for electrical continuity. Cables and conduits must be positioned away from the LH2 pump and piping to prevent exposure to potential leaks. It is important to account for the risk of wire insulator embrittlement at low temperatures. The suction line should not be installed horizontally; instead, it should have upward and downward slopes to facilitate the return of gas to the tank or a safe vented area. Similarly, the suction return line should maintain a continuous upward slope for the same purpose.

## **Instrumentation**

At minimum, according to CGA P-96, all reciprocating pumps must be equipped to the following instrumentations:

- Emergency stop buttons
- Loss of prime/cavitation
- High discharge pressure trip
- Vaporizer discharge low temperature
- Fire detection
- Crankcase relief device
- Distance piece (gland) purge – Distance piece is the extended spacer or carrier frame between the cold end and the warm end

- Low Explosive Limit (LEL) detector
- Forced ventilation
- Electrical isolation (a dedicated lockable electrical disconnect)
- Pump cooldown detection
- Casing hot point detection
- Gland leakage low temperature

Additional recommended instrumentations are:

- Gland high temperature
- High vibration
- Pressure control
- Discharge pressure gauges
- Pump prime at start-up
- Liquid vessel isolation

### **Bearings and Lubrication**

Freezing of the lubricating grease or oil for warm bearings must be avoided. Cold bearings shall be designed for cold temperatures and short-term dry runs. The lubricant should typically be suitable for -40 °C. Sealed bearings are recommended. If re-greasing of bearings in-situ is necessary, grease drain plugs should be installed to minimize the risk of grease build-up within the motor housing. Shaft seals should prevent metal-to-metal rubbing and manage leakage effectively.

### **Purging**

Use of dry inert gas purges is recommended to prevent moisture ingress and protect against particle contamination.

### **Flammable Liquids and Over-pressurization**

Design should limit leakage and have pressure relief methods for trapped cryogenic liquid. ISO 24490 [34] specifies the maximum leakage from the pump and its accessories to 1 mm<sup>3</sup>/s at normal conditions. Any leak higher than that must be

captured and vented to a safe location. EN 1779 [48] provides methods for leak testing.

Pump design must not allow any trapped LH2. Overpressure protection shall be in place for any part of the pump that could become inadvertently pressurized, especially the vacuum insulated space.

## **Pump Motors**

Fully enclosed fan-cooled electric motors mounted externally must be used. Additionally, hydraulic motors must be separated from the cryogenic cabinet. The motor must be rated according to relevant standards, such as NFPA 70 [49] or the ATEX Directive 2014/34/EU [50].

## **Insulation**

Insulation requirements depend on LH2 conditions, piping arrangements, type, and material/ compatibility of the insulator. Suction line should be insulated to minimize heat leak.

## **Testing**

Cryogenic pumps must undergo many tests including design evaluation, initial pressure test, cryogenic tests (mechanical integrity, NPSH test) hydrostatic pressure test, and performance test.

## **Operation**

The following instructions are required:

- Drying
- Standby
- Cooldown
- Startup
- Operation
- Shutdown
- Emergency procedures

Before starting operations, purging is necessary to eliminate any air or oxygen from the system. Section 10 of CGA P-96 outlines potential operational issues to be

aware of. Additionally, regular visual inspections of permanently installed flexible metal hoses and bellows should be conducted to confirm they are in good condition.

## **Maintenance and Repair**

A maintenance program must be established following the manufacturer's recommendations. The pump should be purged before and after maintenance on the cold end. Purging the warm end after maintenance is recommended for optimal safety and performance. Repair procedures provided by either the manufacturer or the user, or both, must be adhered to. A work permit is necessary when performing maintenance or repairs on an operational or installed pump, or when working in a classified area. Extra specific precautions must be taken when dealing with confined spaces.

## **Cleanliness**

CGA P-96 and ISO 24490 [34] require cleanliness level and packaging to comply with CGA G-5.3 for hydrogen purity levels and ISO 23208 [51], respectively.

## **Marking**

Marking of the pump shall be visible after installation and compliant with applicable standards.

## **Vaporizer**

### **General**

Ambient vaporizers need to be appropriately sized based on the specific product, flow rate, usage cycle, and anticipated climate conditions. It's important to consider winter conditions when sizing to ensure efficient and reliable operation throughout the year. Vaporizers with an external heat exchanger are suitable for situations where the creation of a water vapor cloud is undesirable or where there is limited space.

### **Design**

CGA G-19.1 includes guidance on vaporizers used for LNG, specifying that they should be designed in accordance with ASME B 31.3 [52], with a minimum design temperature of  $-196^{\circ}\text{C}$ . For LH<sub>2</sub>, this temperature must be adjusted. The user defines the operating temperatures and pressures. The design of the vaporizer requires the following parameters: the flow rate from the tank to be vaporized, the delivery pressure from the vaporizer, the duty cycle (whether it operates continuously or intermittently), and the location details, including ambient temperature and climate data. Trim heaters can be used downstream of the

vaporizer, but only indirect heating units are permitted. This ensures safe and effective temperature regulation of the vaporized product. A temperature sensor should be installed downstream of the vaporizer to prevent cold gas from flowing further down the line, which could lead to embrittlement of materials. This sensor will help ensure that the gas is at an appropriate temperature for safe handling and use.

## **Material**

According to CGA P-96, typical materials used include stainless steel with aluminum fins. This combination is commonly chosen for its durability and efficiency in heat exchange applications.

Part 16 of CSA/ANSI LNG 3.16:22 outlines the following requirements for vaporizers used for liquefied natural gas:

## **Marking**

The marking of the component should include enough information to clearly identify its specifications and ensure proper usage. This typically includes details like size, pressure/electrical rating, manufacturer information, and any relevant standards or certifications.

## **Construction and Assembly**

The heat exchanger-vaporizer must comply with the relevant requirements outlined in ISO 12614-1 Road vehicles — Liquefied natural gas (LNG) fuel system components Part 1: General requirements and definitions as well as ISO 12614-2 Road vehicles — Liquefied natural gas (LNG) fuel system components Part 2: Performance and general test methods. The fittings must comply with CSA B51 and compatible with the rigid fuel line to ensure a secure and leak-proof connection.

## **Testing**

Table 1 of CSA ANSI LNG 3.16 Part 16 summarizes the applicable tests for the vaporizer:

- Hydrostatic strength
- Leakage
- Excess torque resistance
- Bending moment
- Continued operation

- Corrosion resistance
- Oxygen ageing
- Electrical overvoltage
- Non-metallic synthetic immersion
- Vibration resistance
- Brass material compatibility
- Water jacket freezing
- Compatibility with heat exchange fluids of non-metallic parts

## Codes and Standards Gap Analysis

Various standards may be appropriate for different phases of the LH2 system project's life cycle, which is defined as illustrated in the figure below.

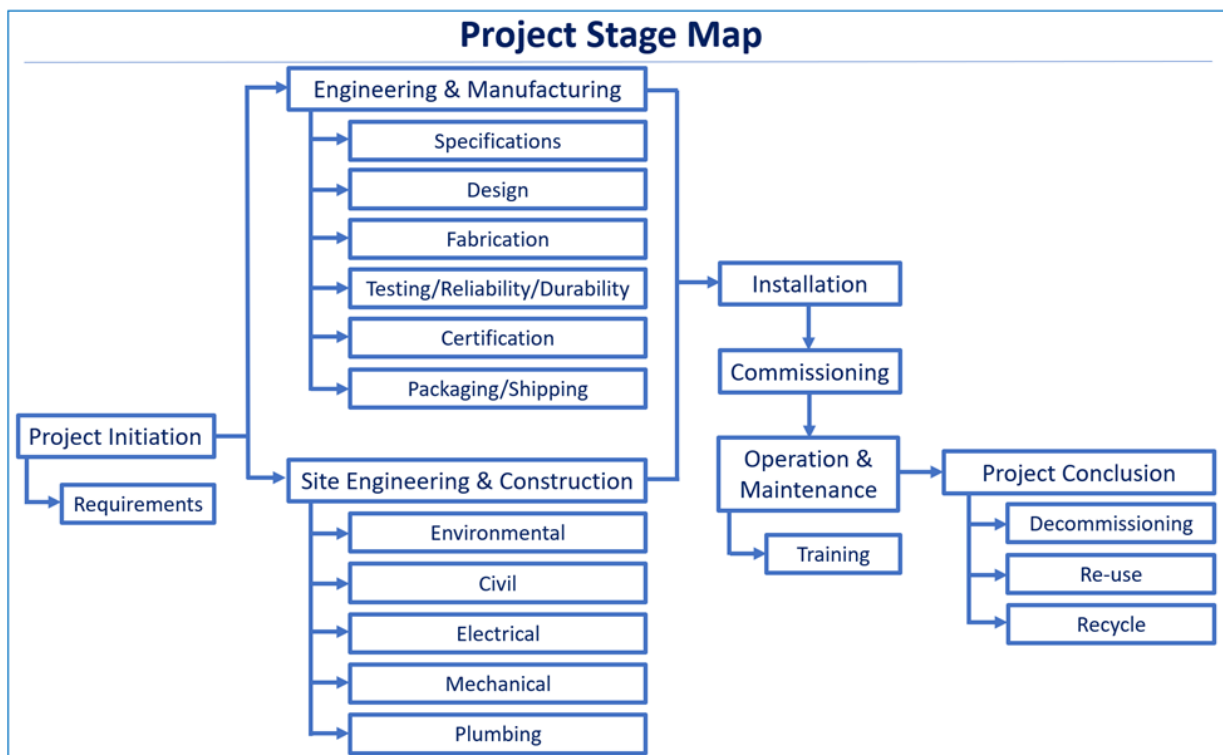


Figure 10: LH2 system project's life cycle.

The standards for key components, including cryogenic tanks, vaporizers, and cryogenic pumps, were classified according to the system project's life cycle. The following table illustrates the number of standards identified for each phase of the project life cycle for the main components. These standards were identified based on their scope. Consequently, some standards that could be used for certification may not have been classified accordingly.

Table 2: Classification of standards for main components according to the project life cycle.

Project Stage	Number of Standards		
	Cryogenic Tanks	Vaporizer	Cryogenic Pumps
Specifications	22	3	5
Design	26	4	5
Fabrication	16	2	1
Testing	22	3	1
Certification	1	0	0
Shipping	4	1	0
Site Engineering & Construction	4	3	2
Installation	9	3	3
Commissioning	5	2	1
Personnel Training	6	2	2
Operation	15	3	3
Maintenance	16	4	3
Decommissioning	2	0	0
Recycle/reuse	0	0	0

This table excludes cross-cutting standards that apply to all components, such as those related to pressure vessels, area classification, functional safety, and other general themes. It only includes standards specific to each component. The following figure summarizes this information.

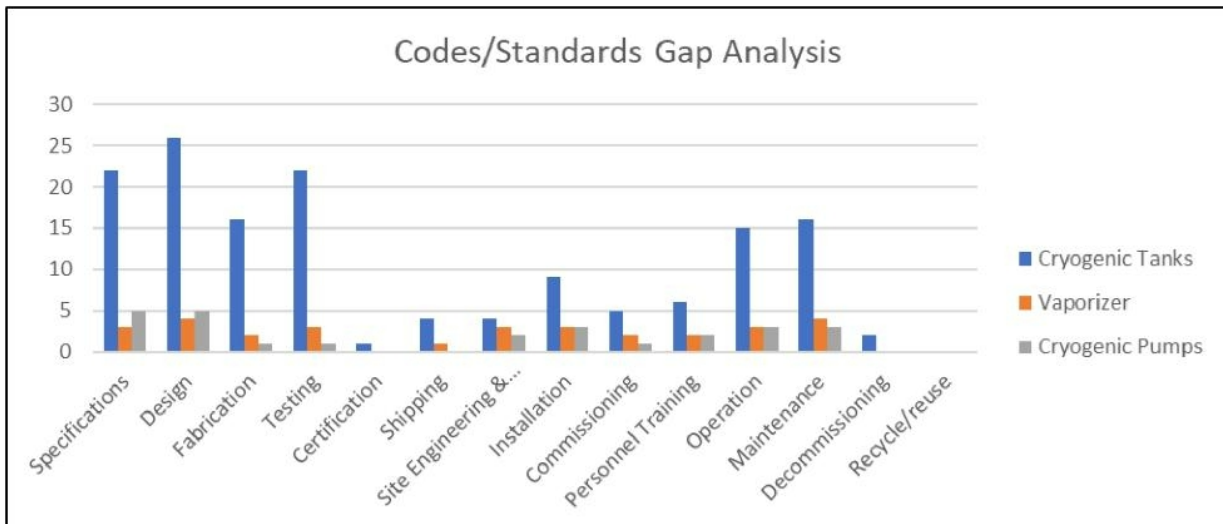


Figure 11: Classification of standards for main components according to the project life cycle.

As shown in this figure, most standards are for specification, design, testing, fabrication, maintenance, and operation, in that respective order. As shown in this figure, there are no standards for recycling or reuse. This could be a topic to discuss with the industry to assess whether a standard is needed.

The CAN/BNQ 1784-000/2022 and NFPA 2 have requirements for LH2 tanks and their installation. However, a standards gap exists in Canada for cryogenic tanks. As USA and international standards do exist it may be useful to harmonize with the USA as well as to adopt the international standards with Canadian deviations in consultation with industry and standards development organizations two examples could be:

To make the CGA H-3-2019 standard a bi-national standard (USA and Canada).

To adopt the ISO 21009-1 and ISO 21009-2 in Canada with Canadian deviations.

Currently, there is no specific standard in Canada for hydrogen vaporizing systems for fuelling stations. However, the NFA 2, CAN/BNQ 1784-000/2022 and other USA requirements do cover many aspects of vaporizers (Appendix B – Standards Relevant to Vaporizers lists the relevant standards). Therefore, for the time being these standards must be used but in the long term a new vaporizer standard should be created.

To the best of authors' knowledge, there is currently no Canadian standard particularly for cryogenic pumps. However, relevant standards have been published by the CGA and the ISO, which provide guidance for the design, safety, installation, and operation of cryogenic pumps. Therefore, for the time being these standards must be used but in the long term a new cryogenic pumps standard should be created (Appendix C – Standards Relevant to Cryogenic Pumps lists the relevant standards).

## TC 197 Work on Fuelling Stations

Generic hydrogen refuelling station (HRS) document (ISO 19886, TBD) will be created from overarching requirements applicable to gaseous and liquid stations coming from ISO 19880-1 Gaseous hydrogen – Fuelling stations. The ISO 19880 series will remain for gaseous stations.

sLH2<sup>8</sup>/LH2 dispensing building upon the existing ISO 13984 series.

CcH2<sup>9</sup> dispensing to be developed under a new ISO series.

ISO 14687 Hydrogen fuel quality – Product specification has liquid requirements.

Vehicles (document currently under development or revision):

- ISO 13984 – Liquid hydrogen – Land vehicle fuelling protocol.
- ISO 13985 – Liquid hydrogen – Land vehicle fuel storage system.

Additional documents are in the planning phases for LH2 components with similar experts:

- ISO 17628-3 – Gaseous hydrogen land vehicle refuelling connection devices – Part 3: Cryo-compressed hydrogen gas.
- ISO 24925 (TBD) – Cryo-compressed hydrogen refuelling protocol.
- ISO 25578 (TBD) – Liquid hydrogen – Land vehicle refuelling connection devices.

## Stakeholder Consultation

Stakeholders were identified from the NRC Codes and Standards website (<https://csres-cnrcse.nrc-cnrc.gc.ca/en/canadian-hydrogen-value-chain-2024>), which includes the complete hydrogen value chain across 72 elements and provides a list of relevant companies active in Canada for each element. The authors focused on elements potentially relevant to LH2. Additionally, the membership from the Hydrogen Codes and Standards Working Group was reviewed to identify other relevant stakeholders.

Twenty stakeholders were identified as companies that were either potentially working with LH2 or possessed the necessary expertise for consultation. The identified

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<sup>8</sup> sLH2 stands for subcooled liquid hydrogen, [https://www.mdpi.com/2032-6653/15/1/22#:~:text=Subcooled%20liquid%20hydrogen%20\(sLH2\)%20is,complexity%20of%20hydrogen%20refuelling%20stations](https://www.mdpi.com/2032-6653/15/1/22#:~:text=Subcooled%20liquid%20hydrogen%20(sLH2)%20is,complexity%20of%20hydrogen%20refuelling%20stations).

<sup>9</sup> CcH2 stands for cryo-compressed hydrogen storage.

stakeholders included industry experts, regulatory bodies, hydrogen refuelling station operators, and other key stakeholders. Twelve of these companies are headquartered in Canada, four are based in the United States, and four are headquartered in France, Germany, Ireland, and Japan, but have subsidiaries in Canada.

The questionnaire outlined in Appendix F – Stakeholder Consultation Questionnaire was distributed to the identified stakeholders for completion. Only 8 stakeholders returned a completed questionnaire, which can be found in Appendix G – Completed Stakeholder Consultation Questionnaire.

The first section of the questionnaire aimed to uncover the respondent's level and type of experience and included four questions. The first and second questions in this section requested the name of the individual completing it and the name of their company. For privacy reasons, the answers to these questions were excluded from the appendices. The third question in this section was:

What is your level of experience with LH2 installations?

- a. First-hand (e.g., you have designed or worked on such systems)
- b. Second-hand (e.g., you have observed others designing or working on such systems)
- c. Third hand (e.g., you have observed others designing or working on such systems)
- d. Other (please provide a brief description)
- e. Not applicable (please provide a brief description)

Some respondents had multiple answers for this question. The following table illustrates the answers:

*Table 3: Respondents' levels of experience.*

Respondent	Level of Experience with LH2 Installations				
	a. Firsthand	b. Second Hand	c. Third Hand	d. Other	e. Not Applicable
A	Yes				
B	Yes	Yes	Yes		
C		Yes			
D			Yes		
E	Yes	Yes	Yes		

F	Yes
G	Yes
H	Yes

As can be seen, most of the respondents had firsthand experience, with 75% of the responses indicating such. Some respondents had second hand and thirdhand experience, as illustrated in the figure below.



Figure 12: Respondents' levels of experience.

The fourth question in this section was:

What is your LH2 experience related to?

- a. Storage
- b. Pumps
- c. Vaporizers
- d. All the above
- e. Other (please provide a brief description)

Some respondents had multiple answers for this question. The following table illustrates the answers:

Table 4: Respondents' component experience.

Respondent	Component Type Experience					Additional Components or Comments
	a. Storage	b. Pumps	c. Vaporizers	d. All	e. Other	
A				Yes		
B				Yes	Yes	Liquefaction plants
C					Yes	LNG Systems
D				Yes	Yes	Experience in all systems (d) but for LNG.
E				Yes		
F	Yes				Yes	Liquefiers
G				Yes	Yes	High Pressure Tubes, Manifolds, Vent Stacks and Pressure Building Systems
H				Yes		Including the development of storage, pumps, and vaporizers.

As shown, most respondents had experience with storage, pumps, and vaporizers, with 87.5%, 75%, and 75% having experience in each area, respectively. Some respondents also had experience with other components, such as liquefaction plants, pressure-building systems, high-pressure tubes, manifolds, vent stacks, and LNG systems (some of which is transferable to LH2). The figure below illustrates these percentages.

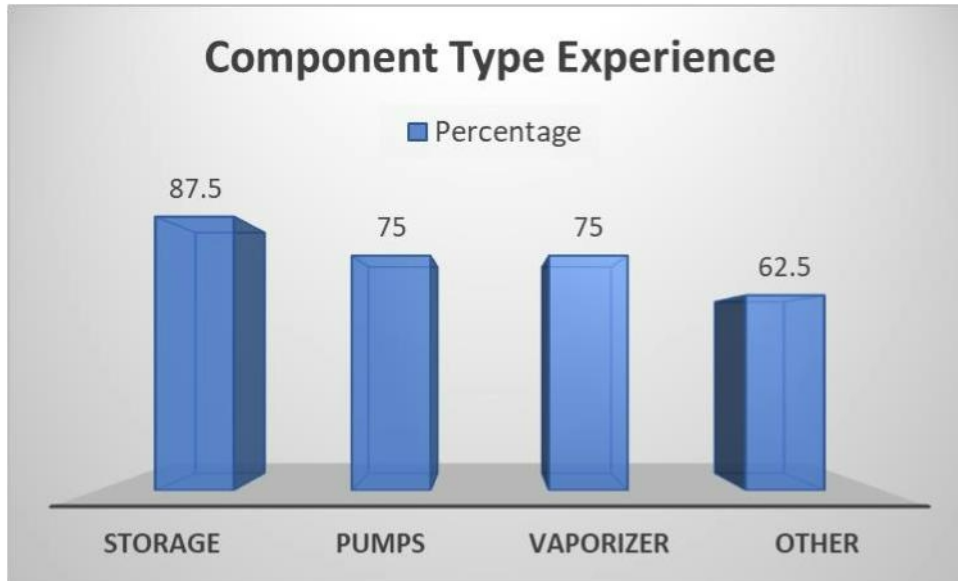


Figure 13: Respondents' component experience.

Section 2 of the questionnaire relates to codes, standards, and regulatory gaps, inconsistencies, and areas needing improvement. This section also addresses current safety measures and risk mitigation strategies. The first question in this section was:

To what extent do you believe there are gaps and inconsistencies in the current regulations for LH2 storage and vaporizing systems, and what areas might require improvement?

- Significant gaps and inconsistencies, with many areas needing improvement
- Some gaps and inconsistencies, with a few areas needing improvement
- Minimal gaps and inconsistencies, with minor areas needing improvement
- No significant gaps or inconsistencies, regulations are comprehensive

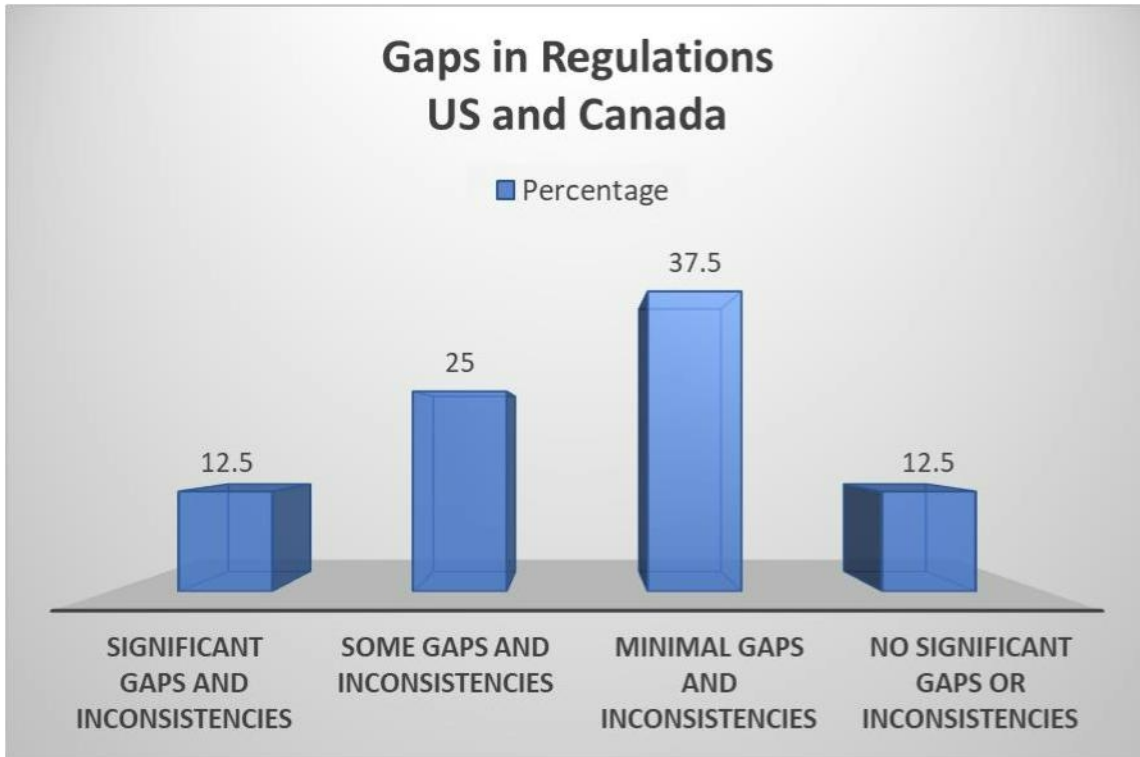
The following table illustrates the answers:

Table 5: Perceived gaps in regulations by US and Canadian respondents.

Respondent	Gaps And Inconsistencies in The Current Regulations				Respondent Company Nationality	Respondent Component Experience
	Significant gaps and conflicts	Some gaps and conflicts	Minimal gaps and conflicts	No significant gaps or conflicts		
A	Yes				US	All

Respondent	Gaps And Inconsistencies in The Current Regulations				Respondent Company Nationality	Respondent Component Experience
	Significant gaps and conflicts	Some gaps and conflicts	Minimal gaps and conflicts	No significant gaps or conflicts		
B			Yes		Canada	All
C		Yes			Canada	LNG
D					Canada	LNG
E		Yes			Canada	All
F			Yes		Canada	Storage
G				Yes	Subsidiary in Canada (from Irish company)	All
H			Yes		US	All

The responses varied based on the respondents' particular experiences and their areas of work. This was especially noticeable in the US, where one respondent identified significant gaps and another reported no gaps. These differences may reflect individual experiences with various authorities having jurisdiction or other factors. In Canada, responses ranged from some gaps and conflicts to no significant gaps and conflicts. The figure below illustrates the percentages for all respondents, both US and Canadian.



*Figure 14: Perceived gaps in regulations by US and Canadian respondents.*

The figure below illustrates the percentages for all Canadian respondents. This again reflects those different respondents have had varying experiences, although not as diverse as in the US. That said, minimal regulatory gaps could be expected in Canada.

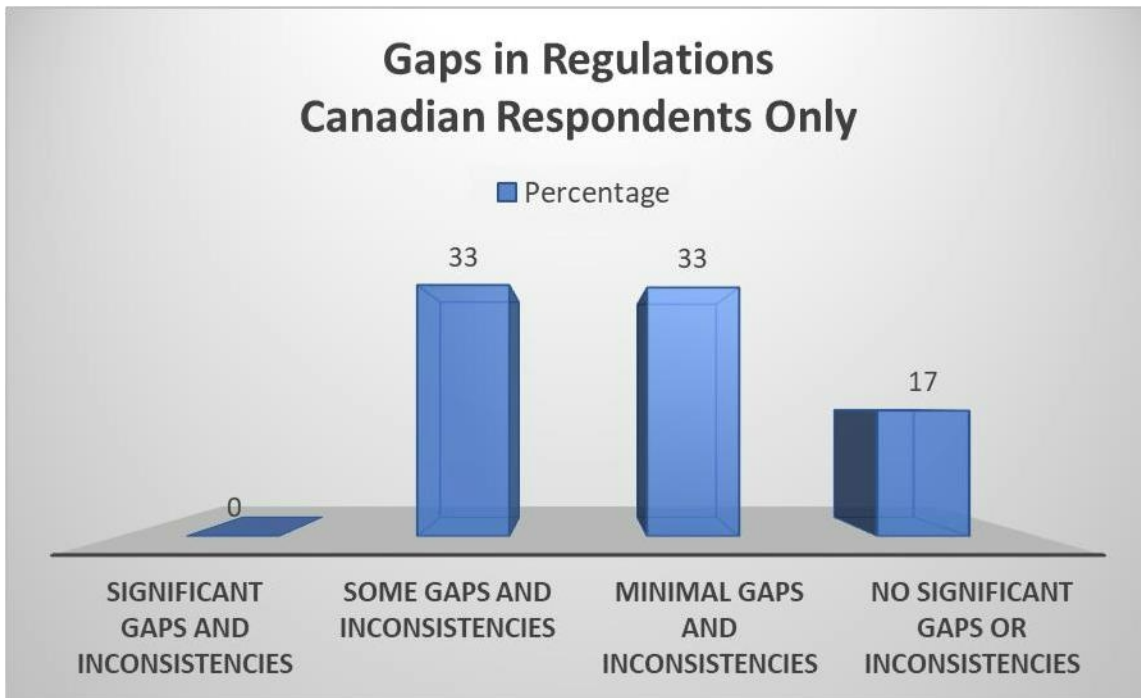


Figure 15: Perceived gaps in regulations by Canadian respondents.

The respondents also provided additional comments or expanded on their answers for this question. For example, Respondent A, who is from the US, has not reviewed the regulations for LH2 in detail but is aware of OSHA regulations and NFPA 2. He also mentioned that the US has a fragmented regulatory framework for hydrogen in general.

Respondent B commented on the potential for LH2 in heavy-duty vehicles, both on and off-road, noting that Europe is interested in this, while Asia is focused on gaseous fuels. Respondent C commented that there are some gaps, but these are currently being addressed through ISO standards under TC 197. This respondent outlined the TC 197 work as follows:

Respondent D had insufficient experience to respond regarding LH2 but had experience with LNG. This respondent felt that more work needs to be done to establish consistent fundamental knowledge about cryogenic fuels and fuel operations among regulatory authorities and policy makers at all levels of government.

Respondent E noted that a few areas require improvement, particularly in small LH2 systems and newer, smaller controls that are not meant for heavy industrial use. Additionally, AHJ need to clarify approval processes across Canada and address code misalignment to eliminate trade barriers.

Respondent F stated that regulations for designing and building LH2 systems do exist; however, it is not always clear what they are and when they need to be followed. The

new roadmap that has been created will help address this issue (<https://natural-resources.canada.ca/energy-sources/clean-fuels/hydrogen-strategy/canadian-hydrogen-codes-standards-roadmap>).

Respondent G indicated that CGA documentation, along with NFPA hydrogen standards and the BNQ-1784 code, provides comprehensive coverage for the design and installation of LH2 systems. The standards are written in a way that minimizes interpretation issues, although no standard, whether for hydrogen or any other product, is entirely 'interpretation-proof'.

Respondent H noted that most experience with LH2 is found in the USA, where NFPA and CGA standards are the leading frameworks. These standards have been iteratively updated to accommodate changes in the hydrogen industry over the years. The two entities collaborate to minimize gaps, inconsistencies, and overlaps.

The second question from Section 2 was as follows:

To what extent do you believe there are gaps and inconsistencies in the current codes and standards for LH2 storage and vaporizing systems, and what areas might require improvement?

- a. Significant gaps and inconsistencies, with many areas needing improvement
- b. Some gaps and inconsistencies, with a few areas needing improvement
- c. Minimal gaps and inconsistencies, with minor areas needing improvement
- d. No significant gaps or inconsistencies, regulations are comprehensive

The following table summarizes the answers:

Table 6: Perceived gaps in codes and standards by US and Canadian respondents.

Respondent	Gaps and Inconsistencies in the Current Codes and Standards				Respondent Company Nationality	Respondent Component Experience
	Significant gaps and conflicts	Some gaps and conflicts	Minimal gaps and conflicts	No significant gaps or conflicts		
A	Yes				US	All
B		Yes			Canada	All
C		Yes			Canada	LNG
D					Canada	LNG

Respondent	Gaps and Inconsistencies in the Current Codes and Standards				Respondent Company Nationality	Respondent Component Experience
	Significant gaps and conflicts	Some gaps and conflicts	Minimal gaps and conflicts	No significant gaps or conflicts		
E	Yes				Canada	All
F	Yes				Canada	Storage
G	Yes				Subsidiary in Canada (from Irish company)	All
H	Yes				US	All

The responses varied based on the respondents' particular experiences and their areas of work. These differences may reflect individual experiences with various authorities having jurisdiction or other factors. In Canada, responses ranged from some gaps and conflicts to no significant gaps and conflicts. The figure below illustrates the percentages for all respondents, both US and Canadian.

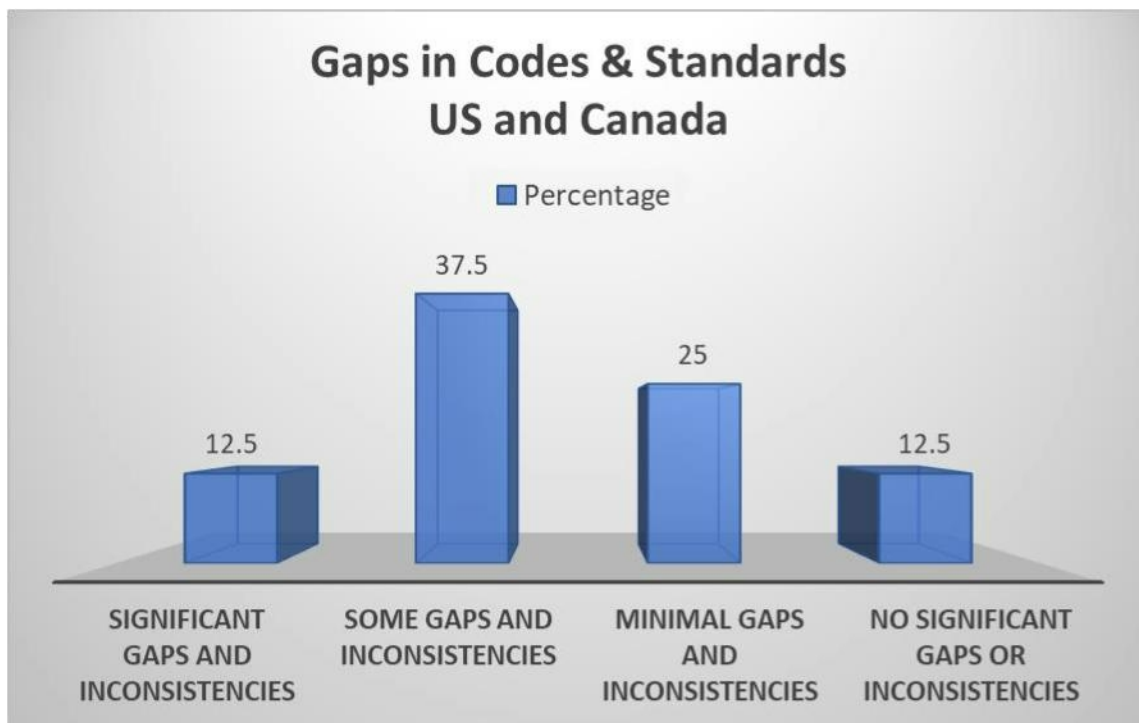


Figure 16: Perceived gaps in codes and standards by US and Canadian respondents.

The figure below illustrates the percentages of all Canadian respondents for whom minimal or some gaps could be expected in Canada.

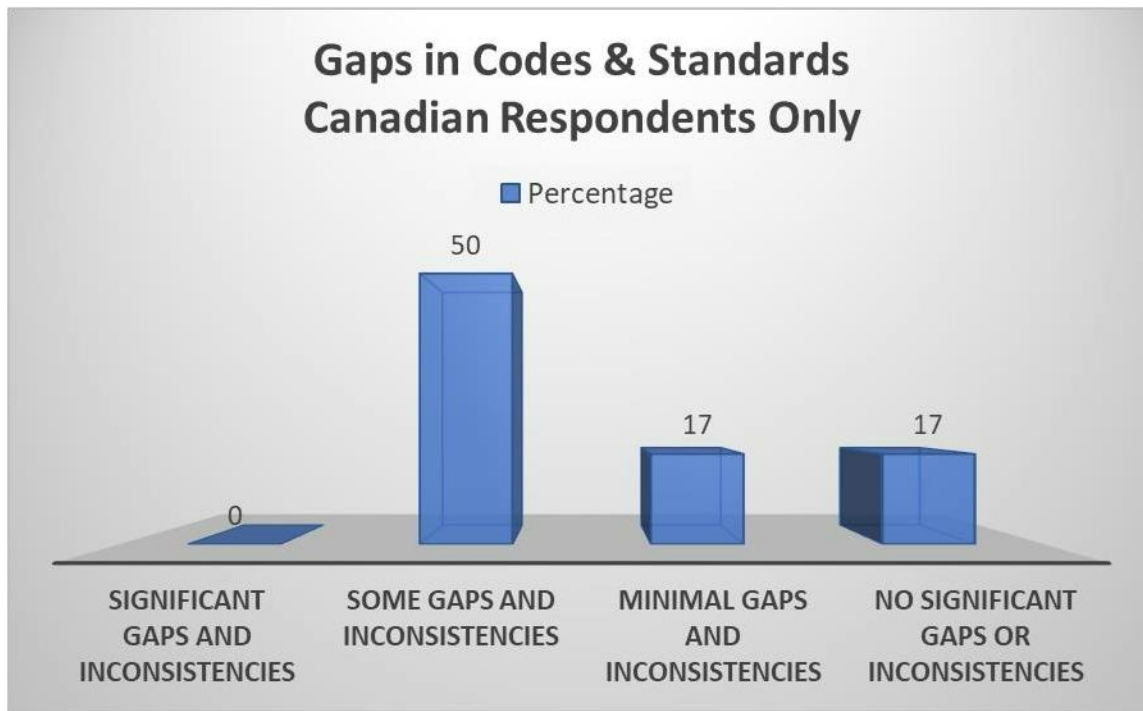


Figure 17: Perceived gaps in codes and standards by Canadian respondents.

The respondents also provided additional comments or expanded on their answers for this question. For instance, respondent A, who is from the United States, explained that NFPA 2 is one of the primary codes covering safety for LH2. It has seen significant updates on the gaseous hydrogen side to account for additional research performed by Sandia and the HYRAM+ project for dispensers.

The liquid side has far less attention. NFPA 497/IEC 60079-10-1 “electrical classification” need more attention for hydrogen in general. NFPA 497 [53] is still using prescribed distances and IEC 60079-10-1 secondary release areas are not based on any real-world data. IEC 60079-10-1 area calculations are known to be very conservative for hydrogen releases. NFPA 2 and other codes should consider mandating requirements for some level of leak detection, gas detection and flame sensors as would help reduce risk. Also, ASME B31.12 “hydrogen piping code” has many aspects that are contrary to existing codes like B31.3 “process piping” [52] and B31.8 “pipelines” [54]. This code is expected to be cancelled in several years with its content being placed into B31.3 and B31.8.

Respondent B stated that the BNQ-1784 and NFPA 2 standards are expected to be aligned by 2025 or 2026. Additionally, the BNQ-1784 has significant gaps concerning

LH2, leading them to collaborate with the AHJ to bypass the BNQ-1784 standard in favor of NFPA 2 standard. The respondent also highlighted the need for harmonization of CRN across the country to avoid constant reapplication. Furthermore, there are likely discrepancies between CSA B51 (all parts) and the guidance provided by BNQ-1784 and NFPA 2 concerning temperatures and pressure tests, where each document has different requirements. Other areas that need improvement include:

- The CSA-HGV standard series regarding station design, particularly in relation to liquid sources and new technology involving high-pressure direct fill liquid pumps.
- Acceptance of third-party listing and labeling of equipment for design registration, with national acceptance as well.

Respondent C mentioned that there are some gaps, but these are being addressed by ISO/TC 197. Respondent D, who specializes in LNG, noted that based on their experience with LNG, the existing suite of codes and standards appears quite adequate. They suggested that there should be a one-to-one mapping of codes and standards of equivalent depth and quality from LNG to LH2.

Respondent F mentioned that while there are often good codes and standards available for reference when designing and building LH2 systems, they can be difficult to locate and determine which ones are applicable. The new roadmap that has been created will assist with this (<https://natural-resources.canada.ca/energy-sources/clean-fuels/hydrogen-strategy/canadian-hydrogen-codes-standards-roadmap>).

Additionally, they face the challenge of being a company that frequently builds hydrogen systems in Canada and then exports the equipment overseas to other jurisdictions, making it difficult to determine which codes and standards must be adhered to.

The third question from Section 2 was as follows:

To what extent do current safety measures and risk mitigation strategies employed adequately address the LH2 systems?

- a. Fully adequate
- b. Partially adequate (minor gaps)
- c. Partially adequate (significant gaps)
- d. Not adequate

The following table summarizes the answers:

*Table 7: Assessment of safety measures and risk mitigation strategies by US and Canadian respondents.*

Respondent	Adequacy of Safety Measures and Risk Mitigation Strategies				Respondent Company Nationality	Respondent Component Experience
	Fully adequate	Partially adequate (minor gaps)	Partially adequate (major gaps)	Not adequate		
A				Yes	US	All
B		Yes			Canada	All
C		Yes			Canada	LNG
D	Yes				Canada	LNG
E	Yes				Canada	All
F	Yes				Canada	Storage
G	Yes				Subsidiary in Canada (from Irish company)	All
H	Yes				US	All

With the exception of respondent A, all answers were quite similar, as most felt that the safety measures and risk mitigation strategies employed were either adequate or had minor gaps. Respondent A answered this question solely from the perspective of existing codes and standards, while other respondents interpreted it more broadly, noting that additional factors, such as experience and the availability of a strong pool of (QRA) consultants, are necessary. Some respondents focused primarily on codes and standards, while others did not specify their perspective. The additional comments provided by the respondents help clarify their points of view and the differences in their answers. The figure below illustrates the percentages for all respondents, both from the USA and Canada.



*Figure 18: Assessment of safety measures and risk mitigation strategies by US and Canadian respondents.*

The figure below illustrates the percentages of all Canadian respondents, most of whom feel that we have adequate safety measures, although some believe there are minor gaps.



Figure 19: Assessment of safety measures and risk mitigation strategies by Canadian respondents.

The respondents also provided additional comments or expanded on their answers for this question. For instance, respondent A feels that safety measures are primarily the responsibility of the company and facility. While there are general guidelines in the code, simply adhering to codes and standards will not guarantee that the resulting system is safe or operated safely. Respondent B mentioned that NFPA 2 and ISO 19880 provide a solid framework, with significant industry involvement and an appropriate revision/update cycle to address issues as they arise.

However, BNQ-1784 does not offer this. This respondent also stated that there is a reasonable pool of QRA consultants available to help conduct studies and model scenarios. Nevertheless, getting AHJ on board is more challenging. Additionally, more data is needed to better validate the models. Although Sandia has been working on this, there is an opportunity for Canada to take a leadership role. The Centre for Hydrogen Safety in USA is also a valuable resource for aggregating industry experience, knowledge, and best practices.

Respondent C explained that the Canadian Hydrogen Installation Code (CAN/BNQ 1784-000/2022) includes requirements for LH2 installations, while ISO standards are

currently addressing gaps for fuelling stations and vehicle systems. Additionally, ISO/TS 15916 (Work in Progress) Hydrogen Technologies – Basic considerations for the safety of hydrogen systems, includes safety-related details for LH2.

Respondent D based their answer to this question on the industry's strong safety record to date. Respondent E believes that an exception to the safety measures and risk mitigation strategies exists in the economic integration of smaller systems.

Respondent F believes that the existing safety measures and risk mitigation strategies are fully adequate when paired with an experienced team, and they can effectively address all concerns related to LH2 systems.

Respondent G believes that a LH2 installation is quite safe, provided all piping, components, and materials are selected according to NFPA and BNQ codes, in conjunction with CGA guidance. The safe distances seem reasonable, and the requirement for actuated shutoff valves is a sound addition.

Section 3 of the questionnaire focuses on industry insights regarding trends, best practices, and technological advancements in LH2 storage systems, as well as the limitations and challenges of this technology. The first question in this section was:

What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?

The answers covered different topics and can be summarized as follows:

## **Emerging trends and technological advancements**

- Glass bead insulation in vacuum anulus of the vessels has greatly reduced the boil off rate.
- High pressure liquid pumps for direct filling of gaseous hydrogen vehicles.
- Standards for emerging liquefaction technologies.
- Liquid H2 is being used for bulk transportation and other applications are being developed (e.g., ISO/TC 197/SC 1 has a new working group, WG 2 – Aerial vehicle LH2 fuel storage system).
- Systems that mitigate the losses from thermal shock by precooling the hydrogen in storage.
- BMW – German LH2 tanks for cars.
- Zero boil-off LH2 storage systems. See link: <https://quantum-technology.com/quantum-technology-secures-500000-from-cice-for-groundbreaking-zero-boil-off-liquid-hydrogen-delivery-system/>.

- Greater focus on reducing / eliminating product losses at LH2 stations, which today can be significant but need to be reduced to reach a sustainable level.

## Best practices

- Heightened focus on H2 vent stack releases and safe distances for surrounding hazards (welding, flames, etc.). This is important work and should continue to be built upon.
- Treating all the hydrogen equipment as a system will yield the best results, vs piecemealing out various subsystems to integrate them all in a customized solution.

## Other topics

- If CGA and NFPA guidelines are followed, LH2 storage systems can be designed in a safe and effective manner.
- Refinement of setbacks in NFPA 2-2024 related specifically to LH2 that means BNQ-1784 is no longer in sync and makes sighting of equipment much more difficult in the Canadian context.

The second question in this section was:

What are some of the limitations or challenges you have encountered with the use of LH2 systems?

Again, the answers covered different topics and can be summarized as follows:

- Losses and boil-off:
  - Operational losses can be significant if not addressed in the design.
  - High boil off rate on custom LH2 storage vessels due to inadequate insulation on vent piping for an aerospace application. Equivalent to 7% boil-off a day.
- Setback requirements:
  - Dealing with minimum separation distances and electrical standards required to mitigate an explosion has been very challenging. However, safe solutions have always been achieved.
  - The main issue is always finding a space which adheres to the distances from BNQ-1784 and NFPA. That being said, those safe distances are in place for

a very good reason and alternative measures can be taken to ensure safety in limited spaces.

- Long-term storage and intermittent use remain technical and physical limitations. Addressing these issues functionally is challenging, as codes may be optimized for one condition but not for all, leading to technical overdesign and higher costs.
- Insufficient production capabilities in the US, with production facilities located too far away, result in a 16-hour travel time for each truck. This leads to a peak usage of 10 trucks per week due to inadequate on-site storage.
- Handling procedures.
- Costs.
- Challenges typical of cryogenic gases.

One general comment was:

- We have designed and manufactured very large LH2 systems and with the proper precautions and a well-designed scope and project we see relevance in a variety of applications, however the market will determine what the best use-case for LH2 is.

# Recommendations

Efforts should continue by reviewing use cases of refuelling stations that utilize LH2 storage, to gather more information and analyze current practices, challenges, and advancements in LH2 storage systems used at refuelling stations.

To the best of the author's knowledge, there are no Canadian standards that fully address the main components, such as the cryogenic tanks, cryogenic pumps, and vaporizers. However, various US and international standards cover many aspects of these components and their installation. Also, some of the gaps not covered by the existing standards are currently being addressed through ISO standards under TC 197 (the SCC is the secretariat). The existing standards can be utilized to mitigate some or most of the safety hazards associated with the main components. However, it is recommended to assess the risks and hazards associated with the reference design by performing a risk analysis. This analysis may include methodologies such as failure mode and effects analysis (FMEA), bow tie hazard analysis, or other appropriate techniques. The team assigned to this work should include regulators, LH2 authorities, codes, and standards experts, and fuelling station industrial partners. This work will identify risks and hazards that may not be addressed by existing codes and standards, highlight the highest risks, and potentially uncover methodologies to mitigate these risks to an acceptable level.

Eventually, Canadian standards that cover cryogenic tanks, cryogenic pumps, and vaporizers should be developed. These standards should either be bi-national (US and Canada) or involve the adoption of international standards with Canadian deviations. For example, to cover cryogenic tanks, the CGA H-3-2019 standard could be adopted as a bi-national standard (US and Canada). Additionally, ISO 21009-1 and ISO 21009-2 could be adopted in Canada with Canadian deviations. Currently, there is no specific standard in Canada for hydrogen vaporizing systems for fuelling stations. However, the NFPA 2, ASME B 31.3, CAN/BNQ 1784-000/2022 and other US requirements do cover many aspects of vaporizers. Therefore, for the time being these standards must be used but in the long term a new vaporizer standard should be created. To the best of authors' knowledge, there is currently no Canadian standard particularly for cryogenic pumps. However, relevant standards have been published by the Compressed Gas Association (CGA) and International Organization for Standardization (ISO), which provide guidance for the design, safety, installation, and operation of cryogenic pumps. Therefore, for the time being these standards must be used but in the long term a new cryogenic pumps standard should be created.

Comprehensive risk reduction safety strategies can be developed based on existing codes and standards, as well as the results of the risk analysis. These strategies may lead to a general product safety evaluation and certification pathway, in consultation

with industry. Additionally, this work may aid in harmonizing approvals across all provinces. In other words, this work may streamline the approval process for manufacturers, suppliers, and AHJ by establishing a harmonized methodology across Canada. It should also incorporate international standards as much as possible to facilitate exports.

## **Recommendations from the stakeholders that were consulted include:**

### 1. Cross-Canada Harmonization and Fundamental Knowledge Development:

- Additional work is needed to establish consistent fundamental knowledge about cryogenic fuels and fuel operations among regulatory authorities and policymakers at all levels of government. This may be in the form of a guidance document.
- Authorities having jurisdiction need to clarify approval processes across Canada and address code misalignment to eliminate trade barriers.
- Regulations for designing and building LH2 systems do exist; however, it is not always clear what they are and when they need to be followed. The new roadmap that has been created will help address this issue (<https://natural-resources.canada.ca/energy-sources/clean-fuels/hydrogen-strategy/canadian-hydrogen-codes-standards-roadmap>).
- At the present time, harmonization of Canadian Registration Numbers across the country is required to avoid constant reapplication.
- It would help manufacturers, suppliers and AHJ to have acceptance of third-party listing and labeling of equipment for design registration, with national acceptance.
- LH2 codes and standards would benefit from having a one-to-one mapping of equivalent depth and quality with the more established LNG codes and standards.

### 2. Updating the CAN/BNQ 1784-000/2022:

- NFPA, ISO and CGA standards are the leading frameworks. These standards have been iteratively updated to accommodate changes in the hydrogen industry over the years. In fact, NFPA 2 and ISO 19880 provide a solid framework, with significant industry involvement and an appropriate revision/update cycle to address issues as they arise. On the other hand, the BNQ-1784 has significant gaps concerning LH2, leading industry to collaborate with the AHJ to bypass the BNQ-1784 standard in favor of the NFPA 2 standard. Furthermore, refinement of setbacks distances in the NFPA 2-2024 related specifically to LH2 means that

the BNQ-1784 is no longer harmonized with NFPA 2, which makes siting of equipment much more difficult in the Canadian context. Additionally, discrepancies between CSA B51 and the guidance provided by BNQ-1784 and NFPA 2 concerning temperatures and pressure tests, where each document has different requirements need to be fixed. However, the BNQ-1784 and NFPA 2 standards are expected to be aligned by 2025 or 2026.

3. Risk Assessment studies and model scenarios:

- There is a reasonable pool of QRA consultants available to help conduct studies and model scenarios. Similarly, the CAN/BNQ 1784-000/2022 references risk assessment standards such as ISO 31000, ISO/IEC 31010, or ISO 12100. However, getting AHJ on board is more challenging because there is a lack of widely accepted guidance, which results in each installation being assessed differently. Additionally, more data is needed to better validate the models. Although Sandia has been working on this, there is an opportunity for Canada to take a leadership role.

4. Other areas that need improvement include:

- The CSA-HGV standard series could include more requirements regarding station design, particularly in relation to liquid sources and new technology involving high-pressure direct fill liquid pumps.
- Some areas in small LH2 systems and newer, smaller controls that are not meant for heavy industrial use require additional requirements.
- Long-term storage and intermittent use remain technical and physical limitations. Addressing these issues functionally is challenging, as codes may be optimized for one condition but not for all, leading to technical overdesign and higher costs.

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# Appendix A – Standards Relevant to Cryogenic Tanks

Number	Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
1	API STD 620: 2013 (2025)	Design and Construction of Large, Welded, Low-Pressure Storage Tanks, Twelfth Edition, Includes Addendum 1 (2014), Addendum 2 (2018), Addendum 3 (2021), and Addendum 4 (2025)	API	USA	Standard	Current	Relevant
2	CAN/CGSB-43.149-2023	Ton Containers for the Transportation of Dangerous Goods	The Canadian General Standards Board (CGSB)	Canada	Standard	Current	Informative
3	CGA H-3: 2024	Cryogenic Hydrogen Storage	CGA	USA	Standard	Current	Relevant
4	CGA P-30: 2024	Guideline For Portable Cryogenic Liquid Containers - Use, Care, And Disposal	CGA	USA	Standard	Current	Informative
5	CGA P-40: 2017	Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Tanks with Rupture Disk(S) - 4th Edition	CGA	USA	Standard	Current	Informative
6	CGA P-56-2022	Cryogenic Vaporization Systems - Prevention of Brittle Fracture of Equipment and Piping	CGA	USA	Guidance Document	Current	Relevant
7	CGA P-59: 2023	Prevention Of Excessive Pressure During Filling of Cryogenic Vessels - 3rd Edition	CGA	USA	Standard	Current	Relevant
8	CGA P-68: 2016 (R2021)	Standard For Roadside Inspections of Vehicles Transporting Class 2 Hazardous Materials (Formerly CGA SB-40)	CGA	USA	Standard	Current	Informative
9	CGA P-75: 2023	Standard for Proper Handling of Insulated Tanks That Are in Obvious Signs of Loss of Vacuum - 2nd Edition	CGA	USA	Standard	Current	Informative
10	CGA P-88: 2020	Guideline For the Maintenance Of Bulk Delivery Equipment Containing Class 2 Hazardous Materials (Formerly CGA SB-41)	CGA	USA	Guidance Document	Current	Informative
11	CSA B339-2025	Cylinders, spheres, and tubes for the transportation of dangerous goods	CSA	Canada	Standard	Current	Informative
12	CSA B340-2025	Selection and use of cylinders, spheres, tubes, and other containers for the transportation of dangerous goods, Class 2	CSA	Canada	Standard	Current	Informative
13	CSA B52-2023	Mechanical Refrigeration Code	CSA	Canada	Code	Current	Informative
14	CSA B620:20	Highway tanks and TC portable tanks for the transportation of dangerous goods	CSA	Canada	Standard	Current	Informative
15	CSA B622:20	Selection and use of highway tanks and TC portable tanks for the transportation of dangerous goods, Class 2	CSA	Canada	Standard	Current	Informative
16	CSA B625:20	Portable tanks for the transport of dangerous goods	CSA	Canada	Standard	Current	Informative
17	EIGA Doc 224/20	Static vacuum insulated cryogenic vessels operation and inspection	EIGA	Europe	Guidance Document	Current	Informative

Number	Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
18	EN 13530-1:2002	Cryogenic vessels - Large transportable vacuum insulated vessels - Part 1: Fundamental requirements	CEN	Europe	Standard	Current	Informative
19	EN 13530-2:2003	Cryogenic vessels - Large transportable vacuum insulated vessels - Part 2: Design, fabrication, inspection and testing	CEN	Europe	Standard	Current	Informative
20	GTR 13	Global Technical Regulations GTR 13 - Hydrogen and Fuel Cell Vehicles	UN	International	Regulation	Current	Informative
21	ISO 11326:2024	Ships and marine technology — Test procedures for liquid hydrogen storage tank of hydrogen ships	ISO	International	Standard	Current	Informative
22	ISO 13985:2006 (Confirmed 2021)	Liquid hydrogen — Land vehicle fuel tanks	ISO	International	Standard	Current	Informative
23	ISO 20421-1:2019	Cryogenic vessels — Large transportable vacuum-insulated vessels — Part 1: Design, fabrication, inspection and testing	ISO	International	Standard	Current	Informative
24	ISO 20421-1:2019 /Amd 1:2022	Cryogenic vessels — Large transportable vacuum-insulated vessels — Part 1: Design, fabrication, inspection and testing — Amendment 1	ISO	International	Standard	Current	Informative
25	ISO 20421-2:2017	Cryogenic vessels — Large transportable vacuum-insulated vessels — Part 2: Operational requirements	ISO	International	Standard	Current	Informative
26	ISO 21009-1:2022	Cryogenic vessels — Static vacuum-insulated vessels — Part 1: Design, fabrication, inspection and tests	ISO	International	Standard	Current	Relevant
27	ISO 21009-2:2024	Cryogenic vessels — Static vacuum insulated vessels — Part 2: Operational requirements	ISO	International	Standard	Current	Relevant
28	ISO 21028-1:2016 (Confirmed 2021)	Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below -80 degrees C	ISO	International	Standard	Current	Relevant
29	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	ISO	International	Standard	Current	Informative
30	ISO 21029-1:2018/Amd 1:2019	Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 1: Design, fabrication, inspection and tests — Amendment 1	ISO	International	Standard	Current	Informative
31	ISO 21029-2:2015 (Confirmed 2020)	Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 2: Operational requirements	ISO	International	Standard	Current	Informative
32	ISO/AWI 19888-1	Hydrogen Technologies — Aerial Vehicles — Part 1: Liquid Hydrogen Fuel Storage System	ISO	International	Standard (Under Development)	Under development	Informative
33	NFPA 52: 2023	Vehicular Natural Gas Fuel Systems Code 2019 Edition	NFPA	USA	Code	Current	Informative

Number	Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
34	SAE AIR8466: 2024	Hydrogen Fuelling Stations for Airports, in Both Gaseous and Liquid Form	SAE	USA	Standard	Current	Informative
35	SAE J2343 201802	Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles (STABILIZED Feb 2018)	SAE	USA	Recommended Practice	Current	Informative
36	SAE J2578 202301	Recommended Practice for General Fuel Cell Vehicle Safety	SAE	USA	Recommended Practice	Current	Informative
37	SAE J2579 201806	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	SAE	USA	Standard	Current	Informative
38	United Nations - Working Party 29	United Nations - Working Party 29 - Global Regulations on Pollution and the Environment Global Technical Regulations (GTR) Hydrogen Vehicles - Liquid Hydrogen, Gaseous Hydrogen	UN	International	Regulation	Not Assessed	Informative
39	CAN/BNQ 1784-000/2022	Canadian Hydrogen Installation Code	BNQ	Canada	Code	Current	Relevant
40	NFPA 2: 2023	Hydrogen Technologies Code	NFPA	USA	Standard	Current	Relevant

## Appendix B – Standards Relevant to Vaporizers

Number	Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
1	ASTM E1529: 2022	Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies	ASTM	USA	Standard	Current	Relevant
2	CGA G-19.1: 2020	Standard For Natural Gas Supply Systems Second Edition	CGA	USA	Standard	Current	Informative
3	CGA P-56: 2022	Cryogenic Vaporization Systems - Prevention of Brittle Fracture of Equipment and Piping	CGA	USA	Standard	Current	Relevant
4	CSA/ANSI LNG 3.16:22	Road vehicles — Liquefied natural gas (LNG) fuel system components — Part 16: Heat exchanger–vaporizer (Adopted ISO 12614-16:2021, second edition, 2021-06, with North American deviations)	CSA	Canada/USA	Standard	Current	Informative
5	CAN/BNQ 1784-000/2022	Canadian Hydrogen Installation Code	BNQ	Canada	Code	Current	Relevant
6	NFPA 2: 2023	Hydrogen Technologies Code	NFPA	USA	Standard	Current	Relevant

## Appendix C – Standards Relevant to Cryogenic Pumps

Number	Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
1	CGA P-96: 2023	Reciprocating Cryogenic Pumps and Pump Installations for Hydrogen and Liquefied Natural Gas	CGA	USA	Standard	Current	Relevant
2	ISO 24490:2016 (Confirmed 2021)	Cryogenic vessels — Pumps for cryogenic service	ISO	International	Standard	Current	Relevant
3	SAE J2601 202005	Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles	SAE	USA	Standard	Current	Relevant
4	CAN/BNQ 1784-000/2022	Canadian Hydrogen Installation Code	BNQ	Canada	Code	Current	Relevant
5	NFPA 2: 2023	Hydrogen Technologies Code	NFPA	USA	Standard	Current	Relevant

# Appendix D – Codes and Standards Relevant to Installation and Components

## Site Installation Items: Concrete Paving, Fencing, Footings, Buildings, Fire Protection, Ventilation, Setback Distances, etc.

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>CAN/BNQ 1784-000/2022</b>	Canadian Hydrogen Installation Code	BNQ	Canada	Code	Current	Relevant
<b>NFPA 2: 2023</b>	Hydrogen Technologies Code	NFPA	USA	Standard	Current	Relevant
<b>NFPA 55: 2023</b>	Compressed Gases and Cryogenic Fluids Code	NFPA	USA	Code	Current	Relevant
<b>ACGIH</b>	Industrial Ventilation: A manual of Recommended Practice for Design (28th edition)	ACGIH	USA	Book	Current	Informative
<b>ANSI/AIHA Z9.5</b>	Laboratory Ventilation	AIHA	USA	Standard	Current	Informative
<b>BC Building Code (2018)</b>	BC Building Code (2018)	BC	Canada	Code	Current	Relevant
<b>BC Fire Code (2018)</b>	BC Fire Code (2018)	BC	Canada	Code	Current	Relevant
<b>CAN/ULC-S524:2019</b>	Standard for Installation of Fire Alarm Systems	ULC	Canada/USA	Standard	Current	Relevant
<b>ULC 526: 2023</b>	Visible Signaling Devices for Fire Alarm and Signaling Systems, Including Accessories	ULC	Canada/USA	Standard	Current	Relevant
<b>ULC 537: 2019</b>	Standard for Verification of Fire Alarm Systems	ULC	Canada/USA	Standard	Withdrawn	Relevant
<b>CGA PS-48: 2024</b>	CGA Position Statement on Clarification of Existing Hydrogen Setback Distances and Development of New Hydrogen Setback Distances in NFPA 2	CGA	USA	Position Statement	Current	Relevant
<b>CGA PS-69: 2022</b>	CGA Position Statement on Liquefied Hydrogen Supply System Separation Distances	CGA	USA	Position Statement	Current	Relevant
<b>CSA-B108.2-21</b>	Liquefied natural gas refuelling stations installation code	CSA	Canada	Code	Current	Informative
<b>International Fire Code: 2024</b>	Chapter 50	ICC	International	Code	Current	Informative
<b>ISO 7240-19:2007 (Confirmed 2018)</b>	Fire detection and alarm systems – Part 19: Design,	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	installation, commissioning, and service of sound systems for emergency purposes					
<b>ISO/TR 20491:2019</b>	Fasteners -- Fundamentals of hydrogen embrittlement in steel fasteners	ISO	International	Technical Report	Current	Informative
<b>NBC</b>	National Building Code of Canada (2020)	NRC	Canada	Code	Current	Relevant
<b>NFC</b>	National Fire Code of Canada (2020)	NRC	Canada	Code	Current	Relevant
<b>NFPA 2010 Edition</b>	Fire Protection Guide to Hazardous Materials	NFPA	USA	Guidance Document	Current	Informative
<b>NFPA 30: 2024</b>	Flammable and Combustible Liquids Code	NFPA	USA	Code	Current	Informative
<b>NFPA 45: 2024</b>	Standard on Fire Protection for Laboratories Using Chemicals	NFPA	USA	Standard	Current	Informative
<b>NFPA 497: 2024</b>	Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas	NFPA	USA	Recommended Practice	Current	Informative
<b>NFPA 50B</b>	Standard for Liquefied Hydrogen Systems at Consumer Sites	NFPA	USA	Code	Current	Informative
<b>NFPA 68: 2023</b>	Standard on Explosion Protection by Deflagration Venting	NFPA	USA	Standard	Current	Informative
<b>NFPA 69: 2024</b>	Standard on Explosion Prevention Systems	NFPA	USA	Standard	Current	Informative
<b>NFPA 72: 2025</b>	National Fire Alarm and Signaling Code	NFPA	USA	Code	Current	Informative
<b>CSA B72:20</b>	Installation code for lightning protection systems	CSA	Canada	Code	Current	Informative
<b>NFPA 91: 2020</b>	Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids	NFPA	USA	Standard	Current	Informative

# Electrical Installations

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>API RP505: 2025</b>	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2, Third Edition	API	USA	Recommended Practice	Current	Informative
<b>CSA C22.1:24</b>	Canadian Electrical Code	CSA	Canada	Standard	Current	Relevant
<b>IEC 60079-10-1:2020</b>	Explosive Atmospheres - Part 10-1: Classification of Areas - Explosive Gas Atmospheres	IEC	International	Standard	Current	Relevant
<b>NFPA 70: 2023</b>	National Electrical Code (NEC)	NFPA	USA	Code	Current	Relevant
<b>CSA SPE-1000-2021</b>	Model Code for the field evaluation of electrical equipment	CSA	Canada	Code	Current	Informative

# Hardware and Software (Functional Safety)

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>CGA PS-55-2019</b>	CGA Position Statement on Use of Nonsparking Tools	CGA	USA	Position Statement	Current	Relevant
<b>IEC 61508-1:2010</b>	Functional safety of electrical / electronic / programmable electronic safety-related systems - Part 1: General requirements	IEC	International	Standard	Current	Relevant
<b>CSA C22.2 NO. 61511-1:17 (R2022)</b>	Functional Safety - Safety Instrumented Systems for the Process Industry Sector - Part 1: Framework, Definitions, System, Hardware, and Application Programming Requirements (Adopted IEC 61511-1:2016, 2nd Edition, 2016-02, with Canadian Deviations)	CSA	Canada	Standard	Current	Relevant
<b>IEC 62061:2024</b>	Safety of machinery – Functional safety of safety-related control systems	IEC	International	Standard	Current	Relevant
<b>ISO 13849-1:2023</b>	Safety of machinery — Safety-related parts of control systems Part 1: General principles for design	ISO	International	Standard	Current	Relevant
<b>SAE J2799_201912</b>	Hydrogen Surface vehicle to station	SAE	USA	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	communications hardware and software					

## Hydrogen Quality

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>CGA G-5.3: 2024</b>	Commodity Specification for Hydrogen	CGA	USA	Standard	Current	Informative
<b>CGA PS-31: 2007 (R 2019)</b>	CGA position statement on cleanliness for proton exchange membranes hydrogen piping/components	CGA	USA	Position Statement	Current	Informative
<b>ISO 14687: 2025</b>	Hydrogen fuel quality - Product specification	ISO	International	Standard	Current	Informative
<b>ISO 15859-2:2004 (Confirmed 2020)</b>	Space systems -- Fluid characteristics, sampling and test methods -- Part 2: Hydrogen	ISO	International	Standard	Current	Informative
<b>ISO 23208:2017 (Confirmed 2022)</b>	Cryogenic vessels — Cleanliness for cryogenic service	ISO	International	Standard	Current	Informative
<b>ISO 23208:2017/Amd 1:2020</b>	Cryogenic vessels — Cleanliness for cryogenic service — Amendment 1: Cryogenic vessels — Cleanliness for cryogenic service — Amendment 1	ISO	International	Standard	Current	Informative
<b>SAE J2719 202003</b>	Hydrogen fuel quality for fuel cell vehicles	SAE	USA	Standard	Current	Informative

## Valves

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ASME B16.5: 2020</b>	Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24, Metric/Inch Standard	ASME	USA	Standard	Current	Relevant
<b>ISO 12614-4:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 4: Manual valve	ISO	International	Standard	Current	Informative
<b>ISO 12614-8:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 8: Excess flow valve	ISO	International	Standard	Current	Informative
<b>ISO 21011:2008 (confirmed in 2023)</b>	Cryogenic vessels — Valves for cryogenic service	ISO	International	Standard	Current	Relevant

## Check Valves

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ISO 12614-3:2021	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 3: Check valve	ISO	International	Standard	Current	Informative

## Control Valves

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ISO 12614-19:2021	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 19: Automatic valve	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
GTR 13	Global Technical Regulations GTR 13 - Hydrogen and Fuel Cell Vehicles	UN	International	Regulation	Current	Informative
ISO 21012:2024	Cryogenic vessels — Hoses	ISO	International	Standard	Current	Relevant
ISO 21028-1:2016 (Confirmed 2021)	Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below -80 degrees C	ISO	International	Standard	Current	Relevant
NFPA 52: 2023	Vehicular Natural Gas Fuel Systems Code 2019 Edition	NFPA	USA	Code	Current	Informative
SAE AIR8466: 2024	Hydrogen Fuelling Stations for Airports, in Both Gaseous and Liquid Form	SAE	USA	Standard	Current	Informative
SAE J2343 201802	Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles (STABILIZED Feb 2018)	SAE	USA	Recommended Practice	Current	Informative
SAE J2578 202301	Recommended Practice for General Fuel Cell Vehicle Safety	SAE	USA	Recommended Practice	Current	Informative
SAE J2579 201806	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	SAE	USA	Standard	Current	Informative
United Nations - Working Party 29	United Nations - Working Party 29 - Global Regulations on Pollution and the	UN	International	Regulation	Not Assessed	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	Environment Global Technical Regulations (GTR) Hydrogen Vehicles - Liquid Hydrogen, Gaseous Hydrogen					

## LH2 Cryogenic Tank Lines-Fill Line

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 13984:1999 (Confirmed 2021)</b>	Liquid hydrogen — Land vehicle fuelling system interface	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Fill Line-Connector

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>CGA V-23-2020</b>	Standard for Cylinder Connections on Portable Cryogenic Liquid Cylinders (Formerly SB-26)	CGA	Canada	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Instrumentation

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 12614-5:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 5: Tank pressure gauge	ISO	International	Standard	Current	Informative
<b>ISO 12614-13:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 13: Tank pressure control regulator	ISO	International	Standard	Current	Informative
<b>ISO 12614-14:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 14: Differential pressure fuel content gauge	ISO	International	Standard	Current	Informative
<b>ISO 12614-15:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 15: Capacitance fuel content gauge	ISO	International	Standard	Current	Informative
<b>NIST HDBK 44: 2018</b>	Specifications, Tolerances, and Other	NIST	USA	Book	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	Technical Requirements for Weighing and Measuring Devices					
<b>CSA/ANSI B107:24</b>	Enclosed hydrogen equipment — Safety	CSA	Canada/USA	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Instrumentation-Pressure and Level Indicators

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>OIML R 81:1998</b>	Dynamic measuring devices and systems for cryogenic liquids	OIML	International	Recommended Practice	Current	Informative

## LH2 Cryogenic Tank Lines-LH2 Delivery

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 24132:2024</b>	Ships and marine technology — Design and testing of marine transfer arms for liquefied hydrogen	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-LH2 Delivery-High Pressure Pump

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 24490:2016 (Confirmed 2021)</b>	Cryogenic vessels — Pumps for cryogenic service	ISO	International	Standard	Current	Relevant

## LH2 Cryogenic Tank Lines-Safety Relief

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 21013-1:2021</b>	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves	ISO	International	Standard	Current	Relevant
<b>ISO 21013-1:2021/Amd 1:2024</b>	Cryogenic vessels — Pressure-relief	ISO	International	Standard	Current	Relevant

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	accessories for cryogenic service — Part 1: Reclosable pressure-relief valves - Amendment 1					
<b>ISO 21013-2:2007 (Confirmed 2021)</b>	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices	ISO	International	Standard	Current	Relevant
<b>ISO 21013-2:2007/Amd 1:2018</b>	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices — Amendment 1	ISO	International	Standard	Current	Relevant
<b>ISO 21013-3:2016 (Confirmed 2021)</b>	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination	ISO	International	Standard	Current	Relevant
<b>ISO 21013-4:2012 (Confirmed 2017)</b>	Cryogenic vessels — Pilot operated pressure relief devices — Part 4: Pressure-relief accessories for cryogenic service	ISO	International	Standard	Current	Relevant
<b>ISO 21013-4:2012/Amd 1:2019</b>	Cryogenic vessels — Pilot operated pressure relief devices — Part 4: Pressure-relief accessories for cryogenic service — Amendment 1	ISO	International	Standard	Current	Relevant

## LH2 Cryogenic Tank Lines-Safety Relief-Pressure Safety Valves

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>API STD 520 - Part 1: 2020</b>	Sizing, Selection, and Installation of Pressure-relieving Devices Part I - Sizing and Selection, Tenth Edition, Includes Errata 1 (2023)	API	USA	Standard	Current	Informative
<b>API STD 520 - Part 2: 2020</b>	Sizing, Selection, and Installation of Pressure-relieving Devices: Part II - Installation, Seventh Edition	API	USA	Standard	Current	Informative
<b>API STD 521</b>	Pressure-relieving and Depressuring Systems,	API	USA	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	Seventh Edition, Includes Errata 1 (2022)					
<b>EN 13648-1:2008</b>	Cryogenic vessels - Safety devices for protection against excessive pressure - Part 1: Safety valves for cryogenic service	CEN	Europe	Standard	Current	Informative
<b>EN 13648-2:2002</b>	Cryogenic vessels - Safety devices for protection against excessive pressure - Part 2: Bursting disc safety devices for cryogenic service	CEN	Europe	Standard	Current	Informative
<b>ISO 12614-7:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 7: Pressure relief valve (PRV)	ISO	International	Standard	Current	Informative
<b>ISO 4126-1:2013 (Confirmed 2025)</b>	Safety devices for protection against excessive pressure -- Part 1: Safety valves	ISO	International	Standard	Current	Informative
<b>ISO 21013-1:2021/Amd 1:2024</b>	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves - Amendment 1	ISO	International	Standard	Current	Relevant
<b>ISO 4126-1:2013/Amd 1:2016</b>	Safety devices for protection against excessive pressure — Part 1: Safety valves Amendment 1	ISO	International	Standard	Current	Informative
<b>ISO 4126-10:2024</b>	Safety devices for protection against excessive pressure — Part 10: Sizing of safety valves and bursting discs for gas/liquid two-phase flow	ISO	International	Standard	Current	Informative
<b>ISO 4126-2:2018 (Confirmed 2024)</b>	Safety devices for protection against excessive pressure -- Part 2: Bursting disc safety devices	ISO	International	Standard	Current	Informative
<b>ISO 4126-3:2020</b>	Safety devices for protection against excessive pressure — Part 3: Safety valves and bursting disc safety devices in combination	ISO	International	Standard	Current	Informative
<b>ISO 4126-6:2014 (Confirmed 2022)</b>	Safety devices for protection against excessive pressure --	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	Part 6: Application, selection and installation of bursting disc safety devices					
<b>ISO 4126-9:2008 (Confirmed 2020)</b>	Safety devices for protection against excessive pressure -- Part 9: Application and installation of safety devices excluding stand-alone bursting disc safety devices	ISO	International	Standard	Current	Informative
<b>EIGA Doc 24/18</b>	Vacuum insulated cryogenic storage tank systems pressure protection devices	EIGA	Europe	Guidance Document	Current	Informative

## LH2 Cryogenic Tank Lines-Safety Relief-Rupture Disk

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>EN 13648-2:2002</b>	Cryogenic vessels - Safety devices for protection against excessive pressure - Part 2: Bursting disc safety devices for cryogenic service	CEN	Europe	Standard	Current	Informative
<b>ISO 4126-2:2018 (Confirmed 2024)</b>	Safety devices for protection against excessive pressure -- Part 2: Bursting disc safety devices	ISO	International	Standard	Current	Informative
<b>ISO 4126-3:2020</b>	Safety devices for protection against excessive pressure — Part 3: Safety valves and bursting disc safety devices in combination	ISO	International	Standard	Current	Informative
<b>ISO 4126-6:2014 (Confirmed 2022)</b>	Safety devices for protection against excessive pressure -- Part 6: Application, selection and installation of bursting disc safety devices	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Vacuum Insulation

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 20088-1:2016 (Confirmed 2022)</b>	Determination of the resistance to cryogenic spillage of insulation	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	materials — Part 1: Liquid phase					
ISO 20088-2:2020	Determination of the resistance to cryogenic spill of insulation materials — Part 2: Vapour exposure	ISO	International	Standard	Current	Informative
ISO 20088-3:2018 (Confirmed 2024)	Determination of the resistance to cryogenic spillage of insulation materials -- Part 3: Jet release	ISO	International	Standard	Current	Informative
ISO 2861:2020	Vacuum technology — Dimensions of clamped-type quick-release couplings	ISO	International	Standard	Current	Informative
ISO 9803-1:2020	Vacuum technology — Mounting dimensions of pipeline fittings — Part 1: Non knife-edge flange type	ISO	International	Standard	Current	Informative
ISO 9803-2:2020	Vacuum technology — Mounting dimensions of pipeline fittings — Part 2: Knife-edge flange type	ISO	International	Standard	Current	Informative
ISO/TS 6737:2023	Vacuum technology — Vacuum gauges — Characteristics for a stable ionisation vacuum gauge	ISO	International	Technical Specification	Current	Informative

## LH2 Cryogenic Tank Lines-Vacuum Insulation-Shutoff Valves

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ISO 21358:2020	Vacuum technology — Right-angle valve — Dimensions and interfaces for pneumatic actuator	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Vacuum Insulation-Vacuum Pump

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ISO 21360-2:2020	Vacuum technology — Standard methods for measuring vacuum-pump performance — Part 2: Positive	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	displacement vacuum pumps					
<b>ISO 21360-6:2023</b>	Vacuum technology — Standard methods for measuring vacuum-pump performance — Part 6: Cryogenic vacuum pumps	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Emergency Shutdown

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>EN 13648-1:2008</b>	Cryogenic vessels - Safety devices for protection against excessive pressure - Part 1: Safety valves for cryogenic service	CEN	Europe	Standard	Current	Informative

## LH2 Cryogenic Tank Lines-Venting

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>CGA G-5.5: 2021</b>	Standard for Hydrogen Vent Systems	CGA	USA	Standard	Current	Relevant
<b>EIGA Doc. 211/24</b>	European Industrial Gas Association (EIGA) - Hydrogen Vent Systems for Customer Applications	EIGA	Europe	Recommended Practice	Current	Relevant

## LH2 Cryogenic Tank-Vacuum Insulation

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>EN 13458-1:2002</b>	Cryogenic vessels - Static vacuum insulated vessels - Part 1: Fundamental requirements	CEN	Europe	Standard	Current	Informative
<b>EN 13458-2:2003</b>	Cryogenic vessels - Static vacuum insulated vessels - Part 2: Design, fabrication, inspection and testing	CEN	Europe	Standard	Current	Informative
<b>ISO 20088-1:2016 (Confirmed 2022)</b>	Determination of the resistance to cryogenic spillage of insulation materials — Part 1: Liquid phase	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ISO 20088-2:2020</b>	Determination of the resistance to cryogenic spill of insulation materials — Part 2: Vapour exposure	ISO	International	Standard	Current	Informative
<b>ISO 20088-3:2018 (Confirmed 2024)</b>	Determination of the resistance to cryogenic spillage of insulation materials -- Part 3: Jet release	ISO	International	Standard	Current	Informative
<b>ISO 2861:2020</b>	Vacuum technology — Dimensions of clamped-type quick-release couplings	ISO	International	Standard	Current	Informative
<b>ISO 9803-1:2020</b>	Vacuum technology — Mounting dimensions of pipeline fittings — Part 1: Non knife-edge flange type	ISO	International	Standard	Current	Informative
<b>ISO 9803-2:2020</b>	Vacuum technology — Mounting dimensions of pipeline fittings — Part 2: Knife-edge flange type	ISO	International	Standard	Current	Informative
<b>ISO/TS 6737:2023</b>	Vacuum technology — Vacuum gauges — Characteristics for a stable ionisation vacuum gauge	ISO	International	Technical Specification	Current	Informative
<b>ISO 21029-1:2018</b>	Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 1: Design, fabrication, inspection and tests	ISO	International	Standard	Current	Informative
<b>ISO 21029-1:2018/Amd 1:2019</b>	Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 1: Design, fabrication, inspection and tests — Amendment 1	ISO	International	Standard	Current	Informative
<b>ISO 21029-2:2015 (Confirmed 2020)</b>	Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 2: Operational requirements	ISO	International	Standard	Current	Informative

## LH2 Cryogenic Tank-Vacuum Insulation-Annular Space-Insulation

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ISO 21014:2019	Cryogenic vessels — Cryogenic insulation performance	ISO	International	Standard	Current	Relevant
ISO 21014:2019/Amd 1:2022	Cryogenic vessels — Cryogenic insulation performance — Amendment 1	ISO	International	Standard	Current	Relevant

## LH2 Cryogenic Tank-Vacuum Insulation-Annular Space-Relief Device (Top Hat)

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
EIGA Doc 24/18	Vacuum insulated cryogenic storage tank systems pressure protection devices	EIGA	Europe	Guidance Document	Current	Informative

## LH2 Cryogenic Tank Lines-Pressure Build-Heat Exchanger

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
CSA/ANSI LNG 3.16:22	Road vehicles — Liquefied natural gas (LNG) fuel system components — Part 16: Heat exchanger–vaporizer (Adopted ISO 12614-16:2021, second edition, 2021-06, with North American deviations)	CSA	Canada/USA	Standard	Current	Informative

## Piping

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
ASME B31.12 - 2023	Hydrogen Piping and Pipelines	ASME	USA	Standard	Current	Relevant
ASME B31.3: 2024	Process Piping	ASME	USA	Standard	Current	Relevant
ASME B31.5: 2022	Refrigeration Piping and Heat Transfer Components	ASME	USA	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ASME B16.5: 2020</b>	Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24, Metric/Inch Standard	ASME	USA	Standard	Current	Relevant
<b>CGA G-5.4: 2019</b>	Hydrogen Piping	CGA	USA	Standard	Current	Informative
<b>CGA G-5.6-2005 (R2013)</b>	Hydrogen Pipeline Systems	CGA	USA	Standard	Current	Relevant
<b>CGA P-93: 2023</b>	Guideline for Piping Failure Rates in Nontoxic Cryogenic Gas Supply Systems	CGA	USA	Guidance Document	Current	Informative
<b>ISO 12614-9:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 9: Gas-tight housing and ventilation hose	ISO	International	Standard	Current	Informative
<b>ISO 12614-10:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 10: Rigid fuel line in stainless steel	ISO	International	Standard	Current	Informative
<b>ISO 12614-11:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 11: Fittings	ISO	International	Standard	Current	Informative
<b>ISO 12614-20:2023</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 20: Flexible fuel or vent lines	ISO	International	Standard	Current	Informative

## All Components

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
<b>ANSI/AIAA G-095</b>	Guide to Safety of Hydrogen and Hydrogen Systems	AIAA	USA	Standard	Current	Informative
<b>ANSI/CGA G-5-2024</b>	Hydrogen	ANSI	USA	Guidance Document	Current	Relevant
<b>ASME BPVC VIII: 2023</b>	ASME Boiler and Pressure Vessel Code, Section VIII: Rules for Construction of Pressure Vessels - Division 1	ASME	USA	Code	Current	Informative
<b>CAN/BNQ 1784-000/2022</b>	Canadian Hydrogen Installation Code	BNQ	Canada	Code	Current	Relevant
<b>CGA H-4-2020</b>	Terminology Associated with Hydrogen Fuel Technologies	CGA	USA	Standard	Inactive	Relevant
<b>CGA H-5: 2020</b>	Standard for Bulk Hydrogen Supply	CGA	USA	Standard	Current	Relevant

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	Systems (an American National Standard)					
<b>CGA H-7: 2024</b>	Standard Procedures For Hydrogen Supply Systems	CGA	USA	Standard	Current	Informative
<b>CGA P-12: 2021</b>	Safe Handling Of Cryogenic Liquid	CGA	USA	Standard	Current	Relevant
<b>CGA P-28: 2022</b>	OHSA Process safety management and EPA risk management plan guidance document for bulk liquid hydrogen supply systems	CGA	Canada	Standard	Current	Relevant
<b>CGA P-41: 2023</b>	Locating bulk liquid storage systems in courts	CGA	Canada	Standard	Current	Relevant
<b>CGA P-61: 2023</b>	Ergonomic Guideline for the Compressed and Cryogenic Gas Industry	CGA	USA	Standard	Current	Informative
<b>CGA P-69: 2018</b>	Guideline for Emergency Response to Cryogenic Liquid Releases - 1st Edition	CGA	USA	Standard	Current	Informative
<b>CGA P-86: 2020</b>	Guideline for Process Safety Management	CGA	USA	Guidance Document	Current	Informative
<b>CSA B51-2024</b>	Boiler, pressure vessel, and pressure piping code	CSA	Canada	Code	Current	Relevant
<b>CSA/ANSI B107:24</b>	Enclosed hydrogen equipment — Safety	CSA	Canada/USA	Standard	Current	Informative
<b>EIGA Doc 6/19</b>	European Industrial Gas Association (EIGA) - Safety in Storage, Handling and Distribution of Liquid Hydrogen (Revision of Doc 6/02)	EIGA	Europe	Guidance Document	Current	Relevant
<b>ISO 12614-1:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 1: General requirements and definitions	ISO	International	Standard	Current	Informative
<b>ISO 12614-2:2021</b>	Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 2: Performance and general test methods	ISO	International	Standard	Current	Informative
<b>ISO 23208:2017 (Confirmed 2022)</b>	Cryogenic vessels — Cleanliness for cryogenic service	ISO	International	Standard	Current	Informative
<b>ISO 23208:2017/Amd 1:2020</b>	Cryogenic vessels — Cleanliness for cryogenic service — Amendment 1: Cryogenic vessels — Cleanliness for	ISO	International	Standard	Current	Informative

Document Number	Document Name	SDO	Document Nationality	Document Type	Status	Rating
	cryogenic service — Amendment 1					
<b>ISO/TR 15916:2015</b>	Basic consideration for the Safety of Hydrogen Systems	ISO	International	Technical Report	Standard to be revised	Relevant
<b>NFPA 2: 2023</b>	Hydrogen Technologies Code	NFPA	USA	Standard	Current	Relevant
<b>NFPA 55: 2023</b>	Compressed Gases and Cryogenic Fluids Code	NFPA	USA	Code	Current	Relevant

## Appendix E – Summary of Legislations at the Federal Level and for Select Provinces

In Canada, the regulatory framework for the storage and installation of LH2 involves a combination of federal and provincial regulations that ensure safety, environmental protection, and compliance with established standards. Details of the applicable acts and regulations both at the federal and provincial levels can be found in the following table.

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
FEDERAL	Canada Oil and Gas Operations Act (R.S.C., 1985, c. O-7) Canada Oil and Gas Installations Regulations (SOR/96-118) Canada Oil and Gas Operations Regulations (SOR/83-149)	Minister of Natural Resources Minister of Northern Affairs Canada Energy Regulator (CER)	Definition of "gas" in the ACT: gas: means natural gas and includes all substances, other than oil, that are produced in association with natural gas; (gaz) hydrogen can be produced by steam methane reforming (SMR). Need to clarify if the definition covers hydrogen either as gas or liquid.
	Canada Occupational Health and Safety Regulations	Minister of Labour	Safety concerns related to handling of hazardous material (LH2). Workplace Hazardous Materials Information System (WHMIS) guidelines to ensure workers are informed of the risks associated with LH2. Mandates hazard assessment for LH2 installations and storage systems.
	National Building Code of Canada	Federal Government that owns and operates the building on federal land Public Services and Procurement Canada (PSPC) Canadian Commission on Building and Fire Codes (CCBFC)	Safety guidelines for structures handling hazardous material, e.g., LH2. Table 1.3.1.2. lists all the reference standards in the code.
	National Fire Code of Canada		Safety rules for facilities storing and dispensing flammable gases like hydrogen. Does not directly apply to LH2 as it is not flammable.
	National Energy Code of Canada for Buildings 2020		Technical provisions to address energy efficiency in the design and construction of new buildings and additions to existing buildings.
	Canadian Electrical Code	Federal Government that owns and operates the building on federal land	Safety requirements for electrical installations.
	Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33) Clean Fuel Regulations (SOR/2022-140) Environmental Emergency Regulations, 2019 (SOR/2019-51)	Minister of the Environment	Set the rules for preventing pollution and protecting the environment.
	Transportation of Dangerous Goods Act, 1992 (S.C. 1992, c. 34) Transportation of Dangerous Goods Regulations (SOR/2001-286)	Transport Canada	Hydrogen Class 2.1, UN 1966 Liquid Hydrogen. Part 5.10 of the regulation mandates compliance with CSA and CGSB and TC standards for container utilization.
Information from: <a href="https://laws-lois.justice.gc.ca/eng/">https://laws-lois.justice.gc.ca/eng/</a>			

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
ALBERTA	Safety Codes Act, S-1 RSA 2000 Building Code Regulation, 5/2024 Certification and Permit Regulation, 295/2009 Fire Code Regulation, 351/2003 Gas Code Regulation, 111/2020 Permit Regulation, 204/2007 Power Engineers Regulation, 85/2003 Pressure Equipment Exemption Order, 56/2006 Pressure Equipment Safety Regulation, 49/2006 Pressure Welders Regulation, 169/2002	Alberta Municipal Affairs Safety Codes Council Alberta Boilers Safety Association (ABSA)	This set of legislation defines the requirements for pressurized systems, permits and design registration. In the Safety Codes Act, "gas" means any gas or compressed gas or any mixture or dilution of gases and includes any combustible or flammable fluid, but does not include any gas, mixture or dilution of gases or combustible or flammable fluid excluded by the regulations from the definition of gas.
	Occupational Health and Safety (OHS) Act, O-2.2 2020 Occupational Health and Safety Code, 191/2021 Occupational Health and Safety Regulation, 184/2021	Alberta Labour - OHS division	Defines the workplace hazardous material handling requirements.
	National Fire Code - 2023 Alberta Edition	Alberta Municipal Affairs	Regulatory requirements for fire prevention and safety.
	National Building Code - 2023 Alberta Edition	Alberta Municipal Affairs	Regulatory requirements for buildings including the ones used for storage of LH2.
	National Energy Code of Canada for Buildings 2020	Alberta Municipal Affairs	
	Dangerous Goods Transportation and Handling Act, D-4 RSA 2000 Dangerous Goods Transportation and Handling Regulation, 157/1997	Ministry of Transportation and Economic Corridors	The act imposes the duties and penalties for any person who handles or transports LH2 (dangerous goods). The Regulation sets out the form and contents of permits and applications for permits issued under the Dangerous Goods Transportation and Handling Act.
	Environmental Protection and Enhancement Act, E-12 RSA 2000 Activities Designation Regulation, 276/2003 Approvals and Registrations Procedure Regulation, 113/1993 Code of Practice for Compressor and Pumping Stations and Sweet Gas Processing Plants, 1996 Environmental Assessment (Mandatory and Exempted Activities) Regulation, 111/1993 Environmental Assessment Regulation, 112/1993 Environmental Protection and Enhancement (Miscellaneous) Regulation, 118/1993 Release Reporting Regulation, 117/1993 Waste Control Regulation, 192/1996	Alberta Environment and Protected Areas (AEPA)	The Act serves as the main legislative framework in Alberta for regulating air, water, land, and biodiversity. It aims to protect, enhance, and responsibly utilize the environment by specifying which proposed activities require approval or registration.
Information from: <a href="https://kings-printer.alberta.ca/Laws_Online.cfm">https://kings-printer.alberta.ca/Laws_Online.cfm</a>			

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
BRITISH COLUMBIA	Low Carbon Fuels Act, [SBC 2022] C. 21 Low Carbon Fuels (Technical) Regulation, 295/2023 Low Carbon Fuels (General) Regulation, 282/2023	Ministry of Energy and Climate Solutions	From the Act, "fuel" means a fuel or other energy source: "type A fuel" means a fuel other than a type B fuel; "type B fuel" means any of the following: (a) electricity; (b) natural gas; (c) propane; (d) a prescribed fuel. From the General Regulation: Type B fuel — hydrogen 3 For the purposes of paragraph (d) of the definition of "type B fuel" in section 1 of the Act, hydrogen is prescribed.  The Low Carbon Fuels Act and its regulations are together known as British Columbia's Low Carbon Fuel Standard (LCFS). This policy offers financial incentives for adopting low-carbon fuels, with rewards based on the greenhouse gas reductions achieved by replacing traditional fuels.
	Clean Energy Act, [SBC 2010] C. 22 Clean or Renewable Resource Regulation - 291/2010 Greenhouse Gas Reduction (Clean Energy) Regulation - 102/2012	Ministry of Energy and Climate Solutions BC Utilities Commission (BCUC)	The act is developed to help meet BC's energy objectives such as reducing BC greenhouse gas emissions and foster technologies that support energy conservation and efficiency and the use of clean or renewable resources.
	Safety Standards Act [SBC 2003] C. 38 Gas Safety Regulation, 103/2004 Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation - 104/2004 Safety Standards General Regulation - 105/2004	Attorney General and Deputy Premier (Part 8 of the act) Ministry of Housing and Municipal Affairs Technical Safety BC (TSBC)	Provision of the requirements for safe design, manufacture, operation and maintenance of pressure containing equipment. Directive D-GA 2014-03 of TSBC asserts that refuelling station design registration applications are to demonstrate compliance towards the following associated adopted code(s): CAN/BNQ – 1784-000 Canadian hydrogen installation code. CSA B108 – Compressed natural gas fuelling stations installation code. CSA B149.1 – Natural gas and propane installation code. CSA - Z662 Oil and gas pipeline systems code.
	Building Act [SBC 2015] c. 2 Building Act General Regulation - 131/2016	Ministry of Housing and Municipal Affairs Attorney General and Deputy Premier (Part 4 of the act)	The Building Act standardizes technical building requirements across BC and gives the province primary authority while allowing local governments to set additional rules in 'unrestricted' areas.
	2024 BC Building Code	Ministry of Housing and Municipal Affairs	Adopted the National Building Code.
	2024 BC Fire Code	Ministry of Housing and Municipal Affairs Local Fire Departments	Adopted the National Fire Code.

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
	Energy Resource Activities Act, [SBC 2008] C. 36 Liquefied Natural Gas Facility Regulation - 146/2014 Energy Resource Activities General Regulation - 187/2023 Requirements for Consultation and Notification Regulation - 202/2023 Environmental Protection and Management Regulation - 219/2024 Emergency Management Regulation - 202/2023	Ministry of Energy and Climate Solutions (the Act except Division 2 of Part 2) Attorney General and Deputy Premier (Division 2 of Part 2 of the act) BC Energy Regulator (BCER)	The act expanded the BCER's responsibilities to include the regulation of hydrogen, ammonia, and methanol. BCER is the one-stop permitting authority for hydrogen projects in BC.
	Environmental Assessment Act, [SBC 2018] C. 51 Reviewable Projects Regulation - 243/2019	Ministry of Environment and Parks Ministry of Water, Land and Resource Stewardship (Section 5 (f)) Attorney General and Deputy Premier (Division 1 of Part 8 of the act)	Referenced under Energy Resource Activities Act. Assesses the environmental, economic and social sustainability of major (reviewable) projects. The reviewable projects are prescribed in the Reviewable Projects Regulation.
	Federal Port Development Act, [SBC 2015] C. 3	Ministry of Energy and Climate Solutions	Sets the authority and implementation for provincial officials to comply with Canada Marine Act (SC 1998, c. 10). Might be relevant if the refuelling station is to be constructed at a port for marine applications.
	Fire Safety Act, [SBC 2016] C. 19 Fire Safety Regulation - 248/2024 Fire Safety (Risk Analysis for Compliance Monitoring) Regulation - 249/2024	Ministry of Housing and Municipal Affairs Public Safety and Solicitor General	Includes requirements for regular fire safety inspections and effective enforcement to prevent fire-related tragedies and preserve human life and protect property and economic loss due to fires.
	Greenhouse Gas Industrial Reporting and Control Act, [SBC 2014] C. 29 BC Carbon Registry Regulation - 25/2024 Emission Offset Project Regulation - 250/2015 Greenhouse Gas Emission Administrative Penalties and Appeals Regulation - 248/2015 Greenhouse Gas Emission Reporting Regulation - 249/2015	Ministry of Energy and Climate Solutions	Provides emission offset units and credits for producers who achieve emissions reductions.
	Petroleum and Natural Gas Act, [RSBC 1996] C. 361 Petroleum and Natural Gas General Regulation - 357/98 Petroleum and Natural Gas Storage Reservoir Regulation - 192/2023	Ministry of Energy and Climate Solutions Attorney General and Deputy Premier (Sections 146, 148-153, 155 and 156) BC Energy Regulator (BCER)	Per Act Definitions: "natural gas" means (a) all fluid hydrocarbons, before and after processing, that are not defined as petroleum, and (b) any of the following that is produced from a well: (i) carbon dioxide; (ii) helium; <b>(iii) hydrogen;</b> (iv) hydrogen sulphide;
	Transport of Dangerous Goods Act, [RSBC 1996] C. 458 Transport of Dangerous Goods Regulation - 203/85	Ministry of Transportation and Transit	Sets an agreement with the federal government with respect to administration and enforcement of the provincial and federal acts.

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
	Utilities Commission Act, [RSBC 1996] C. 473 Public Utility Regulation - 174/2006	Attorney General and Deputy Premier British Columbia Utilities Commission (BCUC)	Does not directly apply to the hydrogen refuelling stations according to the following definitions in the act: "petroleum industry" includes the carrying on within British Columbia of any of the following industries or businesses: (a) the distillation, refining or blending of petroleum; (b) the manufacture, refining, preparation or blending of products obtained from petroleum; (c) the storage of petroleum or petroleum products; (d) the wholesale or retail distribution or sale of petroleum products; (e) the wholesale or retail distribution or sale of liquefied or compressed natural gas;  "petroleum products" includes gasoline, naphtha, benzene, kerosene, lubricating oils, stove oil, fuel oil, furnace oil, paraffin, aviation fuels, liquid butane, liquid propane and other liquefied petroleum gas and all derivatives of petroleum and all products obtained from petroleum, whether or not blended with or added to other things;  "public utility" does not include (e) a person not otherwise a public utility who is engaged in the petroleum industry or in the wellhead production of oil, natural gas or other natural petroleum substances,
	Zero-Emission Vehicles Act, [SBC 2019] C. 29 Zero-Emission Vehicles Regulation - 196/2020	Ministry of Energy and Climate Solutions	Although hydrogen is mentioned as a source for propulsion of the Zero Emission Vehicles, the intention of the act is to: a) increase the number of Zero Emission Vehicles (ZEVs) available in the province; b) support the affordability of ZEVs; and, c) ensure provincial greenhouse gas reduction targets are met. Therefore, it is not relevant to the refuelling stations.
	Fuel Price Transparency Act, [SBC 2019] C. 46 Fuel Price Transparency Regulation - 52/2020	BC Utilities Commission (BCUC)	Sets the requirement for the fuel price. Not relevant to the storage and installation systems.
Information from: <a href="https://www.bclaws.gov.bc.ca/">https://www.bclaws.gov.bc.ca/</a>			
<b>ONTARIO</b>	Ontario's Building Act Ontario's Building Code Building Code Act, 1992, S.O. 1992, c. 23 Planning Act, section 34, 38, 41, 44 Public Transportation and Highway Improvement Act, section 34, 38	Minister of Municipal Affairs and Housing	Building code establishes detailed technical and administrative requirements and minimum standards for building construction. Planning act requires compliance with the Zoning By-laws. Public transportation and highway improvement act requires a Building and Land Use Permit from the Ministry of Transportation where construction is adjacent to a highway

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
	Fire Protection and Prevention Act, 1997, S.O. 1997, c. 4 Ontario's Fire Code	Municipal Fire Departments	provides the standards commercial and residential buildings must follow in terms of fire safety.
	Occupational Health and Safety Act, R.S.O. 1990, c. O.1	Minister of Labour	Refers to the following standards: CSA B149.1 Natural Gas and Propane Installation Code CSA B149.2 Propane Storage and Handling Code NFPA 2 Hydrogen Technologies Code NFPA 55 Compressed Gases and Cryogenic Fluids Code
	Dangerous Goods Transportation and Handling Act, D-4 RSA 2000 Dangerous Goods Transportation and Handling Regulation, 157/1997	Ministry of Transportation and Economic Corridors	The act imposes the duties and penalties for any person who handles or transports liquid hydrogen (dangerous goods). The Regulation sets out the form and contents of permits and applications for permits issued under the Dangerous Goods Transportation and Handling Act.
	Technical Standards and Safety Act, S.O. 2000, c. 16 Fuel Industry Certificates, O. Reg. 215/01 Liquid Fuels, O. Reg. 217/01 Operating Engineers Regulation, O. Reg. 219/01 Boilers and Pressure Vessels Regulation, O. Reg. 220/01	Ministry of Public and Business Service Delivery and Procurement Technical Standards and Safety Authority (TSSA)	Provides efficient and flexible administration of technical standards with respect to the matters such as pressure vessels, fuels, and operating engineers, which could apply to LH2.
	Environmental Protection Act, R.S.O. 1990, c. E.19 Greenhouse Gas Emissions: Quantification, Reporting, and Verification Regulations, O. Reg. 390/18 Spill Prevention and Contingency Plans Regulations, O. Reg. 224/07	Minister of the Environment and Climate Change	Requires a Record of Site Condition, filed with the Ministry of the Environment and Climate Change. Requires confirmation of waste disposal site at a building.
Information from: <a href="https://www.ontario.ca/laws">https://www.ontario.ca/laws</a>			
QUEBEC	Building Act (Loi sur le bâtiment, RLRQ c B-1.1) Safety Code for the Construction Industry (Code de sécurité pour les travaux de construction, S-2.1, r. 4) National Building Code of Canada (Code national du bâtiment - Canada) Regulation respecting pressure installations	Régie du bâtiment du Québec (RBQ) Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST)	The purpose of the act is to ensure the quality and safety of construction work and facilities, protect public safety, and verify the qualifications, integrity, and financial stability of contractors, owner-builders, and building inspectors. It is specifically related to LH2 refuelling stations as it applies to the to facilities intended for use by the public, installations intended to use, store or distribute gas; and pressure installations. The Safety Code for the Construction Industry applies to any work conducted on a construction site as defined by the Act respecting occupational health and safety (chapter S-2.1), where foundation, erection, maintenance, renovation, repair, alteration or demolition work is carried out in respect of a building or of civil engineering works, on and at the site itself, including the preparatory work of land clearing or earth moving and any other work determined by regulation, and the lodging, eating or recreational facilities put at the disposal of the construction workers by the employer

Jurisdiction	Act/Regulation/Code	Authorities Having Jurisdiction	Comments
	Fire Safety Act (Loi sur la sécurité incendie, RLRQ c S-3.4) National Fire Code of Canada (Code national de prévention des incendies - Canada)	Ministère de la Sécurité publique (MSP)	Fire prevention and safety requirements.
	Environmental Quality Act (Loi sur la qualité de l'environnement, RLRQ c Q-2) Regulation respecting hazardous materials (Règlement sur les matières dangereuses, RLRQ c Q-2, r. 32)	Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs (MELCCFP)	Environmental protection requirements and handling hazardous materials including LH2.
	Occupational Health and Safety Act (Loi sur la santé et la sécurité du travail, RLRQ c S-2.1)	Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST)	Workplace safety requirements.
	Transportation of Dangerous Goods Act, 1992 (Loi de 1992 sur le transport des marchandises dangereuses, LC 1992, c 34) Transportation of Dangerous Substances Regulation, chapter C-24.2, r. 43	The Ministère du Transport du Québec's	Requirements for handling and transportation of liquid hydrogen.
Information from: <a href="https://www.legisquebec.gouv.qc.ca/en/">https://www.legisquebec.gouv.qc.ca/en/</a>			

# Appendix F – Stakeholder Consultation Questionnaire

Section 1: Stakeholders' Information		
No	Questions	Answers or Comments
1	First and Last Names	
2	Company Name	
3	What is your level of experience with LH2 installations? a. First-hand (e.g., you have designed or worked on such systems) b. Second-hand (e.g., you have observed others designing or working on such systems) c. Third hand (e.g., you have learned from others with first-hand or second-hand experience) d. Other (please provide a brief description) e. Not applicable (please provide a brief description)	
4	What is your LH2 experience related to? a. Storage b. Pumps c. Vaporizers d. All of the above e. Other (please provide a brief description)	

**Section 2: Evaluation of Current Regulations and Standards**

<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>d. No significant gaps or inconsistencies, regulations are comprehensive</li> </ul> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>d. No significant gaps or inconsistencies, regulations are comprehensive</li> </ul> <p>Would you like to please expand on this?</p>	
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <ul style="list-style-type: none"> <li>a. Fully adequate</li> <li>b. Partially adequate (significant gaps)</li> <li>c. Partially adequate (minor gaps)</li> <li>d. Not adequate</li> </ul> <p>Would you like to please expand on this?</p>	

Section 3: Industry Insights		
No.	Questions	Answers or Comments
1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	
<p align="center"><b>Section 4: Additional Comments and Feedback (if any)</b></p> <p><i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i></p>		
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# Appendix G – Completed Stakeholder Consultation Questionnaire

## Respondent A

Section 1: Stakeholders' Information		
No.	Questions	Answers or Comments
3	<p>What is your level of experience with LH2 installations?</p> <p>a. First-hand (e.g., you have designed or worked on such systems)</p> <p>b. Second-hand (e.g., you have observed others designing or working on such systems)</p> <p>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</p> <p>d. Other (please provide a brief description)</p> <p>e. Not applicable (please provide a brief description)</p>	a
4	<p>What is your LH2 experience related to?</p> <p>a. Storage</p> <p>b. Pumps</p> <p>c. Vaporizers</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>	d

Section 2: Evaluation of Current Regulations and Standards		
No.	Questions	Answers or Comments
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p>	<p>I do not spend much time reviewing regulations for LH2. OSHA regulations were generated in the 1960s and have only minor changes since that time so do not align with current codes like NFPA 2. The US has a very fragmented framework setup for hydrogen in general. So I would guess that there are significant gaps (A)</p>

	<p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	<p>NFPA 2 is one of the primary general codes covering safety for LH2. It has seen significant updates on the gaseous hydrogen side to account for additional research performed by Sandia and the HYRAM+ project for dispensers. The liquid side has far less attention. NFPA 497/IEC 60079-10-1 “electrical classification” need more attention for hydrogen in general. NFPA 497 is still using prescribed distances and IEC 60079-10-1 secondary release areas are not based on any real world data. IEC 60079-10-1 area calculations are known to be very conservative for hydrogen releases.</p> <p>NFPA 2 and other codes should consider mandating requirements for some level of leak detection, gas detection and flame sensors as would help reduce risk</p> <p>ASME B31.12 “hydrogen piping code” has many aspects that are contrary to existing codes like B31.3 “process piping” and B31.8 “pipelines”. This code is expected to be cancelled in several years with its content being placed into B31.3 and B31.8.</p> <p>So likely I would call this an (A).</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <p>a. Fully adequate</p> <p>b. Partially adequate (significant gaps)</p> <p>c. Partially adequate (minor gaps)</p> <p>d. Not adequate</p> <p>Would you like to please expand on this?</p>	<p>Safety measures are really up to company and facility, while there are general guide lines in the code, just following the codes and standard will not ensure the resulting system is safe or that it is operated safely.</p> <p>So I do not think the current code and standards are at all adequate, so this would be a (D)</p>
<b>Section 3: Industry Insights</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>

1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	Glas bead insulation in vacuum anulus of the vessels has greatly reduce the boil off rate.
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	<p>High boil off rate on custom LH2 storage vessel due to inadequate insulation on vent piping for an aerospace application. Equivalent to 7% boil-off a day.</p> <p>Insufficient production capabilities in the US with production facilities to far away. This lead to 16 hour travel time for each truck with peak usage of 10 trucks a week due to insufficient storage at the site</p>
<p style="text-align: center;"><b>Section 4: Additional Comments and Feedback (if any)</b></p> <p><i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i></p>		
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**Respondent B**

Section 1: Stakeholders' Information		
No.	Questions	Answers or Comments
3	<p>What is your level of experience with LH2 installations?</p> <p>a. First-hand (e.g., you have designed or worked on such systems)</p> <p>b. Second-hand (e.g., you have observed others designing or working on such systems)</p> <p>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</p> <p>d. Other (please provide a brief description)</p> <p>e. Not applicable (please provide a brief description)</p>	<p>Some variation of a, b, and c. I'm probably not supposed to use a calculator anymore, so A is a bit of a stretch, but I have certainly participated in HAZOPs, a lot of equipment and installation reviews, vendor evaluations and code reviews.</p> <p>We have designed, installed and commissioned our first LH2 to gas transfer facility in Canada. We are using it to fill gaseous distribution assets to 450bar to service our refuelling network in BC. We are the operators for the facility, so have been working hard on our procedures and processes to run and maintain this equipment.</p>
4	<p>What is your LH2 experience related to?</p> <p>a. Storage</p> <p>b. Pumps</p> <p>c. Vaporizers</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>	<p>D) and E) all the above, and liquefaction plants as well.</p> <p>Evaluation of liquid front ends for gaseous H2 stations, as well a liquid-to-gas direct pumping systems/technology, boil off gas management, storage systems, vacuum jacketed piping and liquefaction equipment.</p>

Section 2: Evaluation of Current Regulations and Standards		
No.	Questions	Answers or Comments
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p>	<p>Potential for liquid on board systems (so mobile tanks on heavy duty vehicles, both on and off road). Interest coming from Europe on HD truck side for this approach (NA and Asia more focused on gaseous storage). We are working on some off-road applications as demonstration fleets.</p> <p>Otherwise (D)</p>

	Would you like to please expand on this?	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ol style="list-style-type: none"> <li>Significant gaps and inconsistencies, with many areas needing improvement</li> <li>Some gaps and inconsistencies, with a few areas needing improvement</li> <li>Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>No significant gaps or inconsistencies, regulations are comprehensive</li> </ol> <p>Would you like to please expand on this?</p>	<p>BNQ-1784 and NFPA 2 alignment to 2025/26(?) edition which is coming very soon. Large gaps to 2024 on LH2 as well. To the point that we would work with the AHJ to ignore BNQ-1784 and work with NFPA2.</p> <p>CSA-HGV series as it relates to station design specifically considering liquid sources and newer technology with high pressure direct fill liquid pumps.</p> <p>Harmonization of CRN across the country so we're not having to constantly reapply.</p> <p>Acceptance of 3<sup>rd</sup> party listing and labelling of equipment for design registration. National acceptance as well.</p> <p>Likely gaps between CSA B51 (all parts) and guidance with BNQ-1784 and NFPA2 temperatures, pressure tests (each document requires something different).</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <ol style="list-style-type: none"> <li>Fully adequate</li> <li>Partially adequate (significant gaps)</li> <li>Partially adequate (minor gaps)</li> <li>Not adequate</li> </ol> <p>Would you like to please expand on this?</p>	<p>(C)</p> <p>NFPA 2 and ISO 19880 provide a decent framework, with significant industry involvement and an appropriate revision/update cycle to address issues as they arise. BNQ-1784 does not have this, and it is showing.</p> <p>There is a reasonable pool of QRA consultants which can be access to help conduct the studies and model scenarios. Getting AHJ on board is more difficult. More data is needed to better validate the models. Sandia has been working on this, but there is an opportunity for Canada to provide some leadership here.</p> <p>Centre for Hydrogen Safety is also a great resource to aggregate industry experience/knowledge and best practice.</p>
<b>Section 3: Industry Insights</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>

1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	<p>High pressure liquid pumps for direct filling of gaseous hydrogen vehicles</p> <p>Refinement of setbacks in NFPA 2-2024 related specifically to LH2 that means BNQ-1784 is no longer in sync and makes sighting of equipment much more difficult in the Canadian context.</p> <p>Greater focus on reducing / eliminating product losses at LH2 stations, which today can be significant but need to be reduced to reach a sustainable level.</p>
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	Operational losses can be significant if not addressed in design
<p style="text-align: center;"><b>Section 4: Additional Comments and Feedback (if any)</b></p> <p><i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i></p>		
Empty space for additional comments		

**Respondent C**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <ul style="list-style-type: none"> <li>a. First-hand (e.g., you have designed or worked on such systems)</li> <li>b. Second-hand (e.g., you have observed others designing or working on such systems)</li> <li>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</li> <li>d. Other (please provide a brief description)</li> <li>e. Not applicable (please provide a brief description)</li> </ul>	b. Second hand
4	<p>What is your LH2 experience related to?</p> <ul style="list-style-type: none"> <li>a. Storage</li> <li>b. Pumps</li> <li>c. Vaporizers</li> <li>d. All of the above</li> <li>e. Other (please provide a brief description)</li> </ul>	Minimal for all categories. We supported another company division with LNG systems so some of the cryogenic aspects crossover.

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>d. No significant gaps or inconsistencies, regulations are comprehensive</li> </ul> <p>Would you like to please expand on this?</p>	Some gaps, but these are currently being addressed through ISO standards under TC 197 (see below).

2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ol style="list-style-type: none"> <li>Significant gaps and inconsistencies, with many areas needing improvement</li> <li>Some gaps and inconsistencies, with a few areas needing improvement</li> <li>Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>No significant gaps or inconsistencies, regulations are comprehensive</li> </ol> <p>Would you like to please expand on this?</p>	<p>Some gaps, but these are being addressed by ISO/TC 197 including the following:</p> <p><u>Station:</u>  Generic hydrogen refuelling station (HRS) document (ISO 19886, TBD) will be created from overarching requirements applicable to gaseous and liquid stations coming from ISO 19880-1 <i>Gaseous hydrogen – Fuelling stations</i>. Note: ISO 19880 series will remain for gaseous stations. sLH2/LH2 dispensing building upon the existing ISO 13984 series  CcH2 dispensing to be developed under a new ISO series  ISO 14687 <i>Hydrogen fuel quality – Product specification</i> has liquid requirements</p> <p><u>Vehicles</u> (document currently under development or revision):  ISO 13984 – Liquid hydrogen – Land vehicle fuelling protocol  ISO 13985 – Liquid hydrogen – Land vehicle fuel storage system  Note: additional document in planning phases for LH2 components with similar experts  ISO 17628-3 – Gaseous hydrogen land vehicle refuelling connection devices – Part 3: Cryo-compressed hydrogen gas  ISO 24925 (TBD) – Cryo-compressed hydrogen refuelling protocol  ISO 25578 (TBD) – Liquid hydrogen – Land vehicle refuelling connection devices</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <ol style="list-style-type: none"> <li>Fully adequate</li> <li>Partially adequate (significant gaps)</li> <li>Partially adequate (minor gaps)</li> <li>Not adequate</li> </ol> <p>Would you like to please expand on this?</p>	<p>c. Partially adequate (minor gaps)  Canadian Hydrogen Installation Code (CAN/BNQ 1784-000/2022) has requirements for LH2 installations  ISO standards are addressing gaps for fuelling stations and vehicle systems  Also, ISO/TS 15916 (WIP) <i>Hydrogen Technologies – Basic considerations for the safety of hydrogen systems</i> includes safety related details for LH2</p>
<b>Section 3: Industry Insights</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>

1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	In addition to details described above, liquid H2 is being used for bulk transportation and other applications are being developed (e.g. ISO/TC 197/SC 1 has a new working group, WG 2 – <i>Aerial vehicle liquid hydrogen fuel storage system</i> ).
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	Challenges typical of cryogenic gases
<p style="text-align: center;"><b>Section 4: Additional Comments and Feedback (if any)</b></p> <p><i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i></p>		
<div style="border: 1px solid black; height: 80px;"></div>		

**Respondent D**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <ul style="list-style-type: none"> <li>a. First-hand (e.g., you have designed or worked on such systems)</li> <li>b. Second-hand (e.g., you have observed others designing or working on such systems)</li> <li>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</li> <li>d. Other (please provide a brief description)</li> <li>e. Not applicable (please provide a brief description)</li> </ul>	c.
4	<p>What is your LH2 experience related to?</p> <ul style="list-style-type: none"> <li>a. Storage</li> <li>b. Pumps</li> <li>c. Vaporizers</li> <li>d. All of the above</li> <li>e. Other (please provide a brief description)</li> </ul>	d.

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>d. No significant gaps or inconsistencies, regulations are comprehensive</li> </ul> <p>Would you like to please expand on this?</p>	<p>Insufficient experience to respond with regard to LH2.</p> <p>My experience with LNG indicate that more work needs to be done to establish consistent fundamental knowledge about cryogenic fuels and fuel operations among regulatory authorities and policy makers at all levels of government.</p>

2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> <li>d. No significant gaps or inconsistencies, regulations are comprehensive</li> </ul> <p>Would you like to please expand on this?</p>	<p>Insufficient experience to respond Based on my experience with LNG the suite of codes and standards seems quite adequate. There should be a one to one mapping of Codes and Standards of equivalent depth and quality (LNG to LH2)</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <ul style="list-style-type: none"> <li>a. Fully adequate</li> <li>b. Partially adequate (significant gaps)</li> <li>c. Partially adequate (minor gaps)</li> <li>d. Not adequate</li> </ul> <p>Would you like to please expand on this?</p>	<ul style="list-style-type: none"> <li>a. (based on the fact that the industry exists and has a good safety record)</li> </ul>
<b>Section 3: Industry Insights</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	Systems that mitigate the losses from thermal shock by precooling the hydrogen in storage Standards for emerging liquefaction technologies
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	Expense Handling procedures Setback requirements
<b>Section 4: Additional Comments and Feedback (if any)</b> <i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i>		

**Respondent E**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <p>a. First-hand (e.g., you have designed or worked on such systems)</p> <p>b. Second-hand (e.g., you have observed others designing or working on such systems)</p> <p>c. Third hand (e.g., you have observed others designing or working on such systems)</p> <p>d. Other (please provide a brief description)</p> <p>e. Not applicable (please provide a brief description)</p>	<p>c) First hand – I have personally designed and worked on LH2 systems</p> <p>c) I have observed others designing or working on such systems</p> <p>c) I have also observed others designing or working on such systems</p>
4	<p>What is your LH2 experience related to?</p> <p>a. Storage</p> <p>b. Pumps</p> <p>c. Vaporizers</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>	<p>a. Storage – I have personally worked with design and installation review of LH2 systems</p> <p>b. Pumps – I have personally worked with design and installation review of LH2 systems</p> <p>c. Vaporizers– I have personally worked with design and installation review of LH2 systems</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p>	<p>b. Some gaps and inconsistencies, with a few areas needing improvement – particularly in small liquid H2 systems and new smaller controls (less heavy industrial)</p> <p>c. Approval of new technology installation</p> <p>d. AHJ clarify cross Canada easy approvals – remove code misalignment trade barriers</p>

	<p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	<p>a. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>Some gaps and inconsistencies, with a few areas needing improvement – particularly in small liquid H2 systems and new smaller controls (less heavy industrial)</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <p>a. Fully adequate</p> <p>b. Partially adequate (significant gaps)</p> <p>c. Partially adequate (minor gaps)</p> <p>d. Not adequate</p> <p>Would you like to please expand on this?</p>	<p>a. Fully adequate – with the exception of how to integrate smaller systems economically</p>
<b>Section 3: Industry Insights</b>		
No.	Questions	Answers or Comments
1	What are some of the emerging trends, best practices, and technological	BMW – German LH2 tanks for cars

	advancements in LH2 storage systems that you have observed?	
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	The long term storage and intermittent use is still a technical and physical limitation. It is difficult to address functionally and codes are better for one condition but usually not all conditions which leads to technical overdesign and higher costs.
<b>Section 4: Additional Comments and Feedback (if any)</b>		
<i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i>		

**Respondent F**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <p>a. First-hand (e.g., you have designed or worked on such systems)</p> <p>b. Second-hand (e.g., you have observed others designing or working on such systems)</p> <p>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</p> <p>d. Other (please provide a brief description)</p> <p>e. Not applicable (please provide a brief description)</p>	<p>a. First hand – I have designed and worked on LH2 projects.</p>
4	<p>What is your LH2 experience related to?</p> <p>a. Storage</p> <p>b. Pumps</p> <p>c. Vaporizers</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>	<p>a. Storage</p> <p>e. Liquefiers</p>

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p>	<p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>We have found that the regulations when designing and building LH2 systems exists, however it isn't always clear what they are and when they need to be followed. The new roadmap that has been created will help with this.</p>

	<p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	<p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>We have found that there often are good codes and standards to reference when designing and building LH2 systems, however they have been tricky to find and hard to determine which ones apply to us. The new roadmap that has been created will help with this.</p> <p>An added challenge for us (and I'm sure some others) is that we are company that often builds hydrogen systems in Canada and then exports the equipment overseas to various other jurisdictions. This makes is difficult to determine which codes and standards must be adhered to.</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <p>a. Fully adequate</p> <p>b. Partially adequate (significant gaps)</p> <p>c. Partially adequate (minor gaps)</p> <p>d. Not adequate</p> <p>Would you like to please expand on this?</p>	<p>a. Fully adequate</p> <p>When paired with an experienced team, the current safety measures and risk mitigation strategies can adequately address all concerns with LH2 systems.</p>
<b>Section 3: Industry Insights</b>		
No.	Questions	Answers or Comments
1	<p>What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?</p>	<p>Zero boil-off LH2 storage systems. See link: <a href="https://quantum-technology.com/quantum-technology-secures-500000-from-cice-for-groundbreaking-zero-boil-off-liquid-hydrogen-delivery-system/">https://quantum-technology.com/quantum-technology-secures-500000-from-cice-for-groundbreaking-zero-boil-off-liquid-hydrogen-delivery-system/</a></p>

2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	Dealing with minimum separation distances and electrical standards required to mitigate explosion has been very challenging. However, we have always been able to figure out safe solutions.
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**Section 4: Additional Comments and Feedback (if any)**

*Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.*

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**Respondent G**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <p>a. First-hand (e.g., you have designed or worked on such systems)</p> <p>b. Second-hand (e.g., you have observed others designing or working on such systems)</p> <p>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</p> <p>d. Other (please provide a brief description)</p> <p>e. Not applicable (please provide a brief description)</p>	Firsthand
4	<p>What is your LH2 experience related to?</p> <p>a. Storage</p> <p>b. Pumps</p> <p>c. Vaporizers</p> <p>d. All of the above</p> <p>e. Other (please provide a brief description)</p>	Storage, Pumps, Vaporizers, High Pressure Tubes, Manifolds, Vent Stacks, Pressure Building Systems

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p>	<p>D - No significant gaps or inconsistencies, regulations are comprehensive</p> <p>The existence of CGA documentation along with NFPA H2 standards and the BNQ-1784 code allows for fairly comprehensive coverage for the design and installation of LH2 systems. The standards themselves are written that minimal interpretation issues could arise, although no standard (H2 or any product) is perfect in terms of being "interpretation proof".</p>

	<p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	<p>D - No significant gaps or inconsistencies, regulations are comprehensive</p> <p>See above</p>
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <p>a. Fully adequate</p> <p>b. Partially adequate (significant gaps)</p> <p>c. Partially adequate (minor gaps)</p> <p>d. Not adequate</p> <p>Would you like to please expand on this?</p>	<p>a. Fully adequate.</p> <p>I feel that an LH2 installation is quite safe as long as all the piping, components and materials selected are as per NFPA and BNQ codes in conjunction with CGA guidance. The safe distances seem reasonable and the actuated shutoff valve requirement is sound addition.</p>
<b>Section 3: Industry Insights</b>		
No.	Questions	Answers or Comments
1	<p>What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?</p>	<p>There seems to be a heightened focus on H2 vent stack releases and safe distances for surrounding hazards (welding, flames, etc). I believe this is important work and should be continued to be built upon.</p>

2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	The main issue is always finding a space which adheres to the distances from BNQ-784 and NFPA. That being said, those safe distances are in place for a very good reason and alternative measures can be taken to ensure safety in limited spaces.
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**Section 4: Additional Comments and Feedback (if any)**

*Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.*

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**Respondent H**

<b>Section 1: Stakeholders' Information</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
3	<p>What is your level of experience with LH2 installations?</p> <ul style="list-style-type: none"> <li>a. First-hand (e.g., you have designed or worked on such systems)</li> <li>b. Second-hand (e.g., you have observed others designing or working on such systems)</li> <li>c. Third hand (e.g., you have learned from others with first-hand or second-hand experience)</li> <li>d. Other (please provide a brief description)</li> <li>e. Not applicable (please provide a brief description)</li> </ul>	<p>We have first-hand experience working on hydrogen systems in which Chart has full responsibilities for the LH2 installation.</p>
4	<p>What is your LH2 experience related to?</p> <ul style="list-style-type: none"> <li>a. Storage</li> <li>b. Pumps</li> <li>c. Vaporizers</li> <li>d. All of the above</li> <li>e. Other (please provide a brief description)</li> </ul>	<p>All of the above including development of LH2 storage systems, development of pumps and vaporizers.</p>

<b>Section 2: Evaluation of Current Regulations and Standards</b>		
<b>No.</b>	<b>Questions</b>	<b>Answers or Comments</b>
1	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>regulations</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <ul style="list-style-type: none"> <li>a. Significant gaps and inconsistencies, with many areas needing improvement</li> <li>b. Some gaps and inconsistencies, with a few areas needing improvement</li> <li>c. Minimal gaps and inconsistencies, with minor areas needing improvement</li> </ul>	<p>Most of the experience in LH2 is in the US where NFPA and CGA standards are the leading standards and have been iterating standards to accommodate changes in hydrogen industry over the years. These two entities work together to minimize gaps, inconsistencies and overlaps.</p>

	<p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	
2	<p>To what extent do you believe there are gaps and inconsistencies in the current <u>codes and standards</u> for LH2 storage and vaporizing systems, and what areas might require improvement?</p> <p>a. Significant gaps and inconsistencies, with many areas needing improvement</p> <p>b. Some gaps and inconsistencies, with a few areas needing improvement</p> <p>c. Minimal gaps and inconsistencies, with minor areas needing improvement</p> <p>d. No significant gaps or inconsistencies, regulations are comprehensive</p> <p>Would you like to please expand on this?</p>	Minimal gaps and inconsistencies, with minor areas needing improvement
3	<p>To what extent do current <u>safety measures and risk mitigation strategies</u> employed adequately address the LH2 systems?</p> <p>a. Fully adequate</p> <p>b. Partially adequate (significant gaps)</p> <p>c. Partially adequate (minor gaps)</p> <p>d. Not adequate</p> <p>Would you like to please expand on this?</p>	Fully adequate
<b>Section 3: Industry Insights</b>		
No.	Questions	Answers or Comments
1	What are some of the emerging trends, best practices, and technological advancements in LH2 storage systems that you have observed?	Chart has been supporting the LH2 industry for over 60 years. If CGA and NFPA guidelines are followed LH2 storage systems can be designed in a safe and effective manner. A best practice we can share is

		treating all of the hydrogen equipment as a system will yield the best results, vs piecemealing out various subsystems in an attempt to integrate them all in a customized solution.
2	What are some of the limitations or challenges you have encountered with the use of LH2 systems?	Chart has designed and manufactured very large LH2 systems and with the proper precautions and a well-designed scope and project we see applicability in a variety of applications; however, the market will determine what the best use-case for LH2 is.
<b>Section 4: Additional Comments and Feedback (if any)</b> <i>Please provide any additional comments or feedback you may have regarding LH2 storage and vaporizing systems.</i>		