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Technical Report

Risk Assessment of Hydrogen and Battery Power in Locomotives – Part 3 – Codes and Standards

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Abstract

A review of codes and standards that are applicable to hydrail applications was conducted. Two complementary reports were produced: a literature review (Part 1), and a risks and hazards analysis (Part 2). The codes and standards were selected based on their applicability within North America, grouped according to the key sub-systems and components which comprise a hydrogen fuel cell and lithium battery system. The applicability and user for each code and standard was identified, and they were sorted and colour-coded according to their suitability for use in Canada. Specific Canadian risks (i.e., due to extreme weather conditions) and the associated shortcomings of the applicable standards were discussed. A summary of the gaps in the codes and standards landscape was presented.

Executive Summary

The purpose of this report was to identify and assess the adequacy of codes and standards applicable to the hydrogen fuel cell and lithium battery systems that will be central to hydrail implementation. The findings were tabulated to highlight areas where existing codes and standards are considered adequate, and where gaps in the codes and standards landscape exist. Two complementary reports were produced: a literature review on the subject (M. Hernandez, I. Jimenez, D. Chuang, E. Toma, C. Rabbitt and S. Mackie, "Risk assessment of hydrogen and battery power in locomotives - Part 1 – Literature review," National Research Council of Canada, Ottawa, 2022.), and an analysis of the risks and hazards associated with the operation of a hydrail locomotive (M. Hernandez, I. Jimenez, C. Rabbitt and E. Toma, "Risk assessment of hydrogen and battery power in locomotives – Part 2 - Risks and hazards assessment," National Research Council of Canada, Ottawa, 2022.).

The codes and standards were selected based on their applicability within North America, with a focus on Canadian context, and their specific relevance to the major systems which comprise a hydrogen fuel cell and lithium battery system. The codes and standards identified are broad reaching, in some cases applying to other transportation sectors outside of rail, or to industrial sectors which use hydrogen or lithium battery systems.

The codes and standards were mapped with respect to ground equipment and locomotive systems, as well as lithium batteries, natural gas transport, and railway bulk transport. Since many of the codes and standards are applicable to both ground equipment and locomotive systems, they were referred to as overarching standards. The relevant codes and standards were tabulated for each system, component or application, identifying their name/title, their country of origin, their application (e.g., safety, performance, terminology, hydrogen quality, guide, recommended practice, act), and the expected user of the code/ standard (e.g., manufacturer, designer, installer, integrator, authority having jurisdiction (AHJ), and/or equipment user). A colour coding scheme was applied to assist the reader in quickly identifying the usefulness and applicability of each code or standard for the hydrail application. A complete list of all of the referenced codes and standards was also presented as an appendix.

To assist in assessing the adequacy of the identified codes and standards, and identifying gaps, a summary of unique Canadian risks was presented. The cold temperatures experienced in Canada are often outside the temperature ranges detailed in existing standards. Snow accumulation and potential for icing conditions also present additional challenges. These unique Canadian risks could affect the safety and functionality of hydrail systems.

An assessment of the gaps in the codes and standards landscape, as it relates to hydrail, was performed. Again, a colour coding scheme was used to identify areas that are well covered by existing codes and standards, areas that are well covered but where improvements are recommended, and areas that require work to provide the necessary coverage. Areas that are well covered but require improvement include area classification, electromagnetic compatibility, enclosures, and solid-state hydrogen storage. Areas where existing standards would need to be evaluated for adequacy for a rail environment include hydrogen sensors, pressure relief devices, fire alarm systems, air compressors (specific to fuel cell systems), hydrogen compressors, hydrogen dispensers, locomotive hydrogen storage systems,

locomotive fuel cell power systems and associated equipment (ventilation, heat exchanger, water treatment), and batteries.

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1 Introduction

This report presents a review of codes and standards that are applicable to hydrail applications. It is Part 3 of a three-part set of reports, where Part 1 is a literature review [1], and Part 2 is a review of the risks and hazards, and a risk analysis, for a hypothetical hydrogen fuel cell powered locomotive [2]. The purpose, background, objectives, and scope of the overall project are detailed in the literature review report.

A previous study conducted by Sandia National Laboratories and published by the U.S. Department of Transportation Federal Railroad Administration (FRA), titled *Study of hydrogen fuel cell technology for rail propulsion and review of relevant industry standards* [3], focused on the codes and standards within the rail industry which may apply to hydrogen use in rail applications, specifically identifying the sections of the Association of American Railroads (AAR) Manual of Standards and Recommended Practices which may require revision. This report builds on those findings by including codes and standards from outside the rail industry that are seen to be applicable to the hydrogen fuel cell and lithium battery system that will be central to hydrail implementation. The codes and standards identified encompass all the major systems which are envisioned to be present in a hydrogen fuel cell powered rail vehicle.

The codes and standards were selected based on their applicability within North America, with a focus on Canadian context, and their specific relevance to the major systems which comprise a hydrogen fuel cell and lithium battery system. The codes and standards identified are broad reaching, in some cases applying to other transportation sectors outside of rail, or to industrial sectors which use hydrogen or lithium battery systems.

2 Standards development organizations

It is important to understand the difference between codes, standards and regulations. The Standards Council of Canada (SCC) provides the following definition of a standard [4]:

> *A standard is a document that provides a set of agreed-upon rules, guidelines or characteristics for activities or their results. Standards establish accepted practices, technical requirements, and terminologies for diverse fields.*

The SCC also provides the following distinction between a standard and an act, regulation or code [4]:

- *An act is a statute that establishes control or directives based on legal authority.*
- *A regulation is a statutory instrument made by exercising a legislative power conferred by an Act of Parliament. Regulations have binding legal effects. If a voluntary standard is referenced in a regulation, it becomes mandatory.*
- *A code is broad in scope and is intended to carry the force of law when adopted by a provincial, territorial or municipal authority. A code may include any number of referenced standards.*

Standards development organizations (SDO) are bodies that specialize in the development of standards through the process of consensus, and they participate in the regional and international standardization process [5]. The following SDOs are responsible for standards referred to in the tables of this report:

- American Institute of Aeronautics and Astronautics (AIAA)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineers (ASME)
- American Society for Testing and Materials (ASTM)
- Bureau de normalisation du Québec (BNQ)
- Compressed Air and Gas Institute (CAGI)
- Compressed Gas Association (CGA)
- Canadian Standards Association (CSA)
- European Committee for Standardization (CEN) (European standards (EN))
- General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) (Chinese Guobiao (GB) standards)
- International Electrotechnical Commission (IEC)
- International Organization for Standardization (ISO)
- Japanese Standards Association (JSA) (Japanese Industrial Standards (JIS))
- National Association of Corrosion Engineers (NACE)
- National Fire Protection Association (NFPA)
- International Organization of Legal Metrology (OIML)
- Radio Technical Committee for Aeronautics (RTCA)
- Society of Automotive Engineers (SAE)

- Underwriters Laboratories (UL)
- Underwriters Laboratories of Canada (ULC)

3 Codes and standards relevant to hydrail

The following subsections list and discuss existing codes and standards which are considered relevant for a hydrail locomotive. They are mapped with respect to ground equipment and locomotive systems as shown in Figure 1. Some standards are applicable to ground equipment and locomotive systems and are therefore referred to as overarching standards. The major subsections and grouping of the codes and standards are as follows:

- overarching standards;
- ground equipment standards;
- locomotive standards;
- lithium battery standards;
- natural gas transport standards; and
- railway bulk transport standards.

In Section 3.3.1, current locomotive safety rules and regulations are also presented.

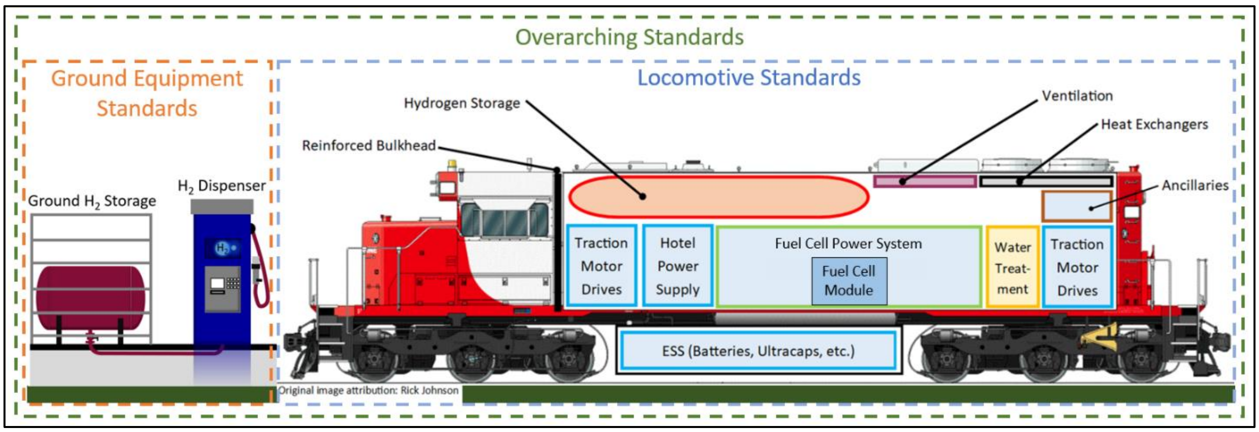

Figure 1: Codes and standards mapping

The tables in the following subsections identify specific codes and standards, their country of origin, their application (e.g., safety, performance, terminology, hydrogen quality, guide, recommended practice, act), and user (e.g., manufacturer, designer, installer, integrator, authority having jurisdiction (AHJ), and/or equipment user). The entries in each of the tables have been sorted first by application, and then by code/standard. To assist the reader in quickly identifying the usefulness of each code or standard, the following colour coding scheme was used:

GREEN: a code or standard that is well established within the industry, and provides a good starting point;

BLUE: a Canadian code or standard that is well established and could be used in Canada, although it may need to be supplemented with other standards;

YELLOW: a foreign or international (intl) standard that could be used in the absence of a Canadian standard (in whole or in part). It may be a good candidate for harmonization or adoption; and

No colour: a code, standard or rule/regulation/act that is provided for information.

All of the codes and standards (including rules, regulations and acts) listed in the individual tables are consolidated in Appendix A as a summary of the codes and standards that are applicable to hydrail applications. They are sorted by SDO, and then by code/standard.

3.1 Overarching standards

This section lists common standards which are applicable to all hydrogen and fuel cell installations and equipment, addressing hydrogen hazards such as material embrittlement, flammability, low ignition energy, high pressures, etc. These standards also cover hydrogen terminology, hydrogen quality, and material flammability testing (to assess the required flammability ratings from different hydrogen product standards). They are typically referenced in the equipment or installation requirements.

The standards were grouped as follows:

1. general hydrogen standards;
2. hydrogen quality standards;
3. standards for pressurized hydrogen containing or conveying components;
4. standards for area classification and for equipment for use in classified areas;
5. standards for hydrogen venting;
6. standards for static electricity;
7. standards for hydrogen material compatibility;
8. standards for hydrogen sensors;
9. standards for pressure relief devices;
10. standards for electrical equipment;
11. standard for control equipment;
12. standards for functional safety (safety programmable controls);
13. electromagnetic compatibility;
14. material properties and fire ratings;
15. standards for fire alarm systems;
16. standards for enclosures;
17. standards for protection against lightning;
18. standards for air compressors;
19. standards for hydrogen compressors; and
20. standards for risk assessments.

Applicable standards for each of the categories are listed in Table 1 through Table 20.

3.1.1 General hydrogen standards

The standards listed in Table 1 cover topics of a general nature such as terminology, general hydrogen safety guidelines, risk management, etc. There is no colour coding applied to the table since the standards are provided for information only. However, system designers, manufacturers, installers and users should familiarize themselves with ANSI/AIAA G-095A-2017 and ISO/TR 15916. Similarly, liquid hydrogen system designers, manufacturers, installers and users should familiarize themselves with CGA P-28.

Code / standard	Title (and adoption notes)	Country	Application	User
ANSI/AIAA G-095A-2017	Guide to safety of hydrogen and hydrogen systems	US	Guide	All
CGA P-6	Standard density data, atmospheric gases and hydrogen	US	Guide	All
ISO/TR 15916	Basic considerations for the safety of hydrogen systems	Intl	Guide	All
CGA G-5.3	Commodity specification for hydrogen	US	Hydrogen quality	Users
CGA P-28	OSHA process safety management and EPA risk management plan guidance document for bulk liquid hydrogen supply systems	US	Safety	All
NFPA 2	Hydrogen technologies code	US	Safety	Installers AHJ
CGA H-4	Terminology associated with hydrogen fuel technologies	US	Terminology	All

Table 1: General hydrogen standards

3.1.2 Hydrogen quality standards

The standards listed in Table 2 are used to specify the required hydrogen quality for different types of fuel cell equipment in order not to poison the catalyst layer and degrade the performance over time. Although these standards are not Canadian, they can nonetheless be used in Canada. CGA PS-31 specifies the cleanliness that is required for proton exchange membrane piping systems and components to avoid impurities from contaminating the hydrogen supply system. Therefore, this standard is also relevant for hydrogen quality.

Code / standard	Title (and adoption notes)	Country	Application	User
CGA G-5.3	Commodity specification for hydrogen	US	Hydrogen quality	All
CGA PS-31	CGA position statement on cleanliness for proton exchange membranes hydrogen piping/components	US	Hydrogen quality	Manufacturers
ISO 14687	Hydrogen fuel quality - Product specification	Intl	Hydrogen quality	Users
SAE J2719	Hydrogen fuel quality for fuel cell vehicles	US	Hydrogen quality	Users

Table 2: Hydrogen quality standards

3.1.3 Standards for components containing or conveying pressurized hydrogen

The standards listed in Table 3 provide guidelines for components containing or conveying pressurized hydrogen. CSA B51 is used to register pressure vessels or fittings with a Canadian Registration Number (CRN). This table also lists the equivalent ISO standard (ISO 16528-1).

Code / standard	Title (and adoption notes)	Country	Application	User
ASME STP-PT-006	Design guidelines for hydrogen piping and pipelines	US	Guide	Designers
ISO 16528-1	Boilers and pressure vessels - Part 1: Performance requirements	Intl	Performance	Designers Manufacturers AHJ
ASME B31.12	Hydrogen piping and pipelines	US	Safety	Designers Manufacturers AHJ
ASME BPVC	Boiler and pressure vessel code	US	Safety	Designers Manufacturers AHJ
CSA B51	Boiler, pressure vessel, and pressure piping code	CAN	Safety	Designers Manufacturers AHJ

Table 3: Standards for pressurized hydrogen containing or conveying components

3.1.4 Standards for area classification and for equipment for use in classified areas

The standards listed in Table 4 are used for area classification, and to ensure that different types of enclosures and techniques are evaluated, for the equipment to be deemed adequate for use in classified areas. Note that IEC 60079-10-1 is the main standard used in Canada to do this as it has not been harmonized yet. Normal practice in Canada is to have a professional engineer apply this standard to classify the areas inside equipment or in installations. However, IEC 60079-10-1 may not effectively mitigate the risks. The methods described in this standard are complex and too dependent on the assumptions and leak rates used. Therefore, if the person working with this standard is too optimistic or too conservative when estimating the assumptions, the classified area may not be of the right size resulting in extra costs or compromised safety. It is recommended that prescriptive area classifications be provided in a manner similar to that used for compressed natural gas (CNG) and liquefied natural gas (LNG), with IEC 60079-10-1 used as an alternative method where the prescriptive methods are not practical.

Section 18 of the Canadian electrical code describes the different zone classifications for explosive gas atmospheres (0, 1 and 2) depending on the likelihood of a flammable gas release and proximity to classified areas. This chapter also describes the different groups for various types of flammable gases (IIC, IIB, IIA and XXXXX[1]), where hydrogen is classified as IIC. Similarly, section 18 of the Canadian Electrical Code also lists the types of equipment that can be used in each type of area.

[1] "XXXXX" represents a chemical formula or chemical name suitable for the specific gas or vapour.

Code / standard	Title (and adoption notes)	Country	Application	User
IEC TS 60079-32-1	Explosive atmospheres - Part 32-1: Electrostatic hazards - guidance	Intl	Guide	Designers Manufacturers
CAN/CSA C22.2 No. 60079-29-1	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases (Adopted IEC 60079-29-1:2016, second edition, 2016-07, with Canadian deviations)	CAN	Performance	Manufacturers
CAN/CSA C22.2 No. 60079-29-4	Explosive atmospheres - Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases (Adopted IEC 60079-29-4:2009, first edition, 2009-11, with Canadian deviations)	CAN	Performance	Manufacturers
CAN/CSA 60079-2	Explosive atmospheres - Part 2: Equipment protection by pressurized enclosure "p" (Adopted IEC 60079-2:2014, sixth edition, 2014-07, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA 60079-30-1	Explosive atmospheres - Part 30-1: Electrical resistance trace heating - General and testing requirements (Adopted IEC/IEEE 60079-30-1:2015, first edition, 2015-09, with Canadian deviations)	CAN	Safety	Manufacturers
CAN/CSA C22.2 No. 60079-1	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d" (Adopted IEC 60079-1:2014, seventh edition, 2014-06, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-11	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i" (Adopted IEC 60079-11:2011, sixth edition, 2011-06, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-15	Explosive atmospheres - Part 15: Equipment protection by type of protection "n" (Adopted IEC 60079-15:2017, fifth edition, 2017-12, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-25	Explosive atmospheres - Part 25: Intrinsically safe electrical systems (Adopted IEC 60079-25:2020, third edition, 2020-06, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-5	Explosive atmospheres - Part 5: Equipment protection by powder filling "q" (Adopted IEC 60079-5:2015, fourth edition, 2015-02, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-6	Explosive atmospheres - Part 6: Equipment protection by liquid immersion "o" (Adopted IEC 60079-6:2015, fourth edition, 2015-02, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 60079-7	Explosive atmospheres - Part 7: Equipment protection by increased safety "e" (Adopted IEC 60079-7:2015, fifth edition, 2015-06, with Canadian deviations)	CAN	Safety	Designers Manufacturers

Code / standard	Title (and adoption notes)	Country	Application	User
CSA 60079-40	Explosive atmospheres - Part 40: Requirements for process sealing between flammable process fluids and electrical systems (Adopted IEC 60079-40:2015, first edition, 2015-02, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CSA C22.1 - Section 18	Canadian electrical code, Part I (25th edition), Safety standard for electrical installations	CAN	Safety	Designers Manufacturers AHJ
CSA C22.2 No. 60079-0	Explosive atmospheres - Part 0: Equipment - General requirements (Adopted IEC 60079-0:2017, seventh edition, 2017-12, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CSA C22.2 No. 60079-46	Explosive atmospheres - Part 46: Equipment assemblies (Adopted IEC TS 60079-46:2017, first edition, 2017-08, with Canadian deviations)	CAN	Safety	Manufacturers
CSA C60079-13	Explosive atmospheres - Part 13: Equipment protection by pressurized room "p" and artificially ventilated room "v" (Adopted IEC 60079-13:2017, second edition, 2017-05, with Canadian deviations)	CAN	Safety	Designers Manufacturers
IEC 60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres	Intl	Safety	Designers Manufacturers
IEC 60079-14	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	Intl	Safety	Designers Manufacturers
IEC 60079-18	Explosive atmospheres - Part 18: Equipment protection by encapsulation "m"	Intl	Safety	Manufacturers
IEC 60079-26	Explosive atmospheres - Part 26: Equipment with separation elements or combined levels of protection	Intl	Safety	Designers Manufacturer

Table 4: Standards for area classification and for equipment for use in classified areas

3.1.5 Standards for hydrogen venting systems

All installations need a dedicated vent line to allow hydrogen to discharge into the atmosphere for different reasons. These vent lines are primarily used during hydrogen gas valve train purging with nitrogen (to get rid of the oxygen from the air) as the nitrogen is released to the atmosphere many times after the system is pressurized. This is followed by purging the nitrogen with hydrogen to get the equipment ready for use. Vent lines are also used for purging water that accumulates in the fuel cell stack channels, which would otherwise cause performance degradation. When the fuel cells are purged, high hydrogen concentrations are released for short periods of time. These vent lines may also be used to empty hydrogen from equipment during emergency situations (e.g., “double block and bleed” systems). To avoid ignition inside the vent lines, it is imperative to reduce the possibility of static electricity generation. Consequently, materials with high electrical conductivity are required. However, vent lines are also required to be able to handle hydrogen fires inside by the use of materials with high temperature ratings. Table 5 lists the required standard for hydrogen venting systems in Canada.

Code / standard	Title (and adoption notes)	Country	Application	User
CGA G-5.5	Standard for hydrogen vent systems	US	Safety	Designers Manufacturers

Table 5: Standards for hydrogen venting systems

3.1.6 Standards for static electricity

The standards listed in Table 6 are generally applicable (for the US and Canada) for hydrogen fuel cell equipment, to manage the risk of static electricity. However, rail applications might require additional requirements than those detailed in these standards. These requirements would need to be developed through careful and deliberate testing. For example, aerospace applications, where high altitude, dry environments and cold temperatures are expected, require deviations and additional requirements. High altitudes result in lower air density (and thus lower electrical resistance), which increases the static discharge gap threshold. CSA C22.2 No. 0.4 addresses grounding and bonding only (and thus it is colour-coded blue in the table below). In fact, at this time, Canadian standards do not have adequate static electricity requirements for hydrogen appliances. Therefore, in Canada, NFPA 77 must be used to address hazards related to static electricity.

Code / standard	Title (and adoption notes)	Country	Application	User
CSA C22.2 No. 0.4	Bonding of electrical equipment	CAN	Safety	Manufacturers
NFPA 77	Recommended practice on static electricity	US	Safety	Manufacturers

Table 6: Standards for static electricity

3.1.7 Standards for hydrogen material compatibility

The standards listed in Table 7 are currently used to test materials for hydrogen compatibility. In Canada, ANSI/CSA CHMC 1 and CSA/ANSI CHMC 2 are becoming more popular. These standards can be used to test wetted parts of valves, regulators and other components as well as gaskets and elastomeric materials. Although the scope of these standards do not specify the pressure, ASTM G142-98 provides guidance for high pressures and high temperatures. ISO 21010 covers gaseous material compatibility including chemical resistance for cryogenic vessels; however, it does not cover low-temperature mechanical property requirements. But ISO 21028-1 covers toughness requirements for materials at cryogenic temperature for temperatures below -80°C. At this time, it is not clear to the authors of this report if liquid hydrogen compatibility is well covered for metals and non-metals. A listing of all materials that have been proven to be compatible for hydrogen use would benefit manufacturers and AHJs, helping to reduce duplication of work.

Code / standard	Title (and adoption notes)	Country	Application	User
ANSI/CSA CHMC 1-2014	Test methods for evaluating material compatibility in compressed hydrogen applications - Metals	CAN US	Safety	Manufacturers
ANSI/NACE TM0284-2016	Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-induced cracking	US	Safety	Manufacturers
ASTM B577-19	Standard test methods for detection of cuprous oxide (hydrogen embrittlement susceptibility) in copper	US	Safety	Manufacturers

Code / standard	Title (and adoption notes)	Country	Application	User
ASTM F1459-06	Standard test method for determination of the susceptibility of metallic materials to hydrogen gas embrittlement (HGE)	US	Safety	Manufacturers
ASTM F1624-12	Standard test method for measurement of hydrogen embrittlement threshold in steel by the incremental step loading technique	US	Safety	Manufacturers
ASTM F519-18	Standard test method for mechanical hydrogen embrittlement evaluation of plating/coating processes and service environments	US	Safety	Manufacturers
ASTM G142-98	Standard test method for determination of susceptibility of metals to embrittlement in hydrogen containing environments at high pressure, high temperature, or both	US	Safety	Manufacturers
CSA/ANSI CHMC 2	Test methods for evaluating material compatibility in compressed hydrogen applications - Polymers	CAN US	Safety	Manufacturers
ISO 11114-4	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	Intl	Safety	Manufacturers
ISO 21010	Cryogenic vessels - Gas/material compatibility	Intl	Safety	Manufacturers

Table 7: Standards for hydrogen material compatibility

3.1.8 Standards for hydrogen sensors

Most hydrogen equipment and installations have hydrogen sensing systems to detect leaks and subsequently shut off the hydrogen gas supply to stop leaks. Table 8 lists the current standards used to evaluate the performance of these sensors. Sensors may drift their response to hydrogen when exposed to some vapours and under certain conditions, and thus it is very important that they comply with these standards and that they are periodically checked or re-calibrated if required. A standard specific to hydrogen does not exist in Canada and thus the CAN/CSA C22.2 No. 60079-29-1 (for flammable gas detectors) is colour-coded blue. Hydrogen-specific clauses from ISO 26142 could complement the evaluation of sensors. UL 2075 is a well-established standard and many sensors are certified to this standard.

Code / standard	Title (and adoption notes)	Country	Application	User
CAN/CSA C22.2 No. 60079-29-1	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases (Adopted IEC 60079-29-1:2016, second edition, 2016-07, with Canadian deviations)	CAN	Performance	Manufacturers
ISO 26142	Hydrogen detection apparatus - Stationary applications	Intl	Performance	Manufacturers
UL 2075	Gas and vapor detectors and sensors	US	Performance	Manufacturers

Table 8: Standards for hydrogen sensors

3.1.9 Standards for pressure relief devices

If the equipment standard does not reference a suitable standard, then the standards listed in Table 9 can be used for pressure relief devices for specific applications.

Code / standard	Title (and adoption notes)	Country	Application	User
-	Federal Railroad Administration - Code of federal regulations, Title 49 - PART 179	US	Safety	Manufacturers
CGA S-1.1	Pressure relief device standards – Part 1 – Cylinders for compressed gases	US	Safety	Manufacturers
CGA S-1.2	Pressure relief device standards – Part 2 – Portable containers for compressed gases	US	Safety	Manufacturers
CGA S-1.3	Pressure relief device standards – Part 3 – Stationary storage containers for compressed gases	US	Safety	Manufacturers
CSA/ANSI HPRD 1	Thermally activated pressure relief devices for compressed hydrogen vehicle (HGV) fuel containers	CAN US	Safety	Manufacturers
ISO 4126-1	Safety devices for protection against excessive pressure - Part 1: Safety valves	Intl	Safety	Manufacturers

Table 9: Standards for pressure relief devices

3.1.10 Standards for electrical equipment

Some general electrical equipment standards are listed in Table 10. Usually, the equipment certification standard has the electrical requirements specified within, and it may reference other electrical equipment standards. For example, CSA C22.2 No. 301 specifies the required distances for personnel to perform work, protection for shock hazards, and other similar requirements. This CSA standard is referenced in most fuel cell standards for Canada for general electrical fire and shock safety. The other CSA standards in Table 10 are also usually referenced in fuel cell standards. Usually, the equipment standard will reference appropriate valve standards (e.g., CSA C22.2 No. 139). Depending on the location of the electrical equipment, other standards may be applicable such as those relevant to equipment for use in classified areas.

Code / standard	Title (and adoption notes)	Country	Application	User
IEC 60034-1	Rotating electrical machines - Part 1: Rating and performance	Intl	Performance	Manufacturers
CSA C22.1	Canadian electrical code, Part I (25th edition), Safety standard for electrical installations	CAN	Safety	Designers Manufacturers AHJ
CSA C22.2 No. 0.4	Bonding of electrical equipment	CAN	Safety	Designers Manufacturers
CSA C22.2 No. 139	Electrically operated valves	CAN	Safety	Manufacturers
CSA C22.2 No. 286	Industrial control panels and assemblies	CAN	Safety	Designers Manufacturers
CSA C22.2 No. 301	Industrial electrical machinery	CAN	Safety	Designers Manufacturers
IEC 60204-1	Safety of machinery - Electrical equipment of machines - Part 1: General requirements	Intl	Safety	Designers Manufacturers

Table 10: Standards for electrical equipment

3.1.11 Standards for control equipment

When controls perform safety functions, or if their failure could result in a safety hazard, they need to comply with very strict requirements to ensure they can be relied upon. Table 11 lists some of these requirements for Canada and internationally.

Code / standard	Title (and adoption notes)	Country	Application	User
CAN/CSA C22.2 No. 61010-1-12	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements (Tri-national standard, with UL 61010-1 and ANSI/ISA-61010-1)	CAN	Safety	Manufacturers
CAN/CSA E60730-1	Automatic electrical controls - Part 1: General requirements (Adopted IEC 60730-1:2013, fifth edition, 2013-11, with Canadian deviations)	CAN	Safety	Manufacturers
CAN/CSA E60730-2-6	Automatic electrical controls - Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements (Adopted IEC 60730-2-6:2015, third edition, 2015-04, with Canadian deviations)	CAN	Safety	Manufacturers
CAN/CSA E60730-2-9	Automatic electrical controls - Part 2-9: Particular requirements for temperature sensing controls (Adopted IEC 60730-2-9:2018, edition 4:2015 consolidated with amendment 1:2018, with Canadian deviations)	CAN	Safety	Manufacturers
CSA C22.2 No. 14-18	Industrial control equipment	CAN	Safety	Manufacturers
IEC 60730-2-14	Automatic electrical controls - Part 2-14: Particular requirements for electric actuators	Intl	Safety	Manufacturers
IEC 60730-2-15	Automatic electrical controls - Part 2-15: Particular requirements for automatic electrical air flow, water flow and water level sensing controls	Intl	Safety	Manufacturers
ISO 13849-1	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design	Intl	Safety	Manufacturers
ISO 13849-2	Safety of machinery - Safety-related parts of control systems - Part 2: Validation	Intl	Safety	Manufacturers

Table 11: Standards for control equipment

3.1.12 Standards for functional safety (safety programmable controls)

Table 12 lists standards for functional safety, which are necessary to evaluate the reliability of programmable solid-state devices. Both the software and the hardware must be evaluated to ensure these devices can be relied upon for safety functions, or if their failure could result in a safety hazard (requiring the use of more than one standard). For example, both UL 1998 and UL 991 are required for certification in the US. These standards are very comprehensive and it is not easy to complete a certification program. Usually manufacturers reach out to a certification agency (e.g., CSA, UL or others) and the certification agency and the manufacturer agree on the standards that will be used. The certification agency develops a testing program to confirm compliance with the standards, and verifies that the manufacturer has an adequate quality assurance program in place to ensure that the quality control of the manufacturing process is sufficient to ensure all appliances are manufactured as agreed upon. Once it is proven that the appliance complies with all of the requirements in the standards, a report detailing the appliance and all of its components and specifications is produced. The certification agency puts in place a factory visit schedule (e.g., twice per year, by a certification agency representative) to verify that in fact the product is being manufactured in compliance with the certification report.

Fuel cell modules usually need programmable circuit boards to manage the safety of the fuel cell stack, due to the large number of parameters that must be measured and the different actions that must take place. Therefore, the application of these standards is very important. The existing CSA functional safety standards for Canada are colour-coded blue, as more than one standard is required to completely evaluate the software and hardware (CAN/CSA C22.2 No. 61508 part 1, 2 and 3).

Code / standard	Title (and adoption notes)	Country	Application	User
CAN/CSA C22.2 No. 61508-1	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (Adopted IEC 61508-1:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 61508-2	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems (Adopted IEC 61508-2:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 61508-3	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 3: Software requirements (Adopted IEC 61508-3:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CAN/CSA C22.2 No. 61511-1	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, second edition, 2016-02, with Canadian deviations)	CAN	Safety	Designers Manufacturers
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems - Parts 1 to 7	Intl	Safety	Designers Manufacturers
IEC 62061	Safety of machinery - Functional safety of safety-related control systems	Intl	Safety	Designers Manufacturers
UL 1998	Standard for software in programmable components	US	Safety	Designers Manufacturers
UL 991	Standard for tests for safety-related controls employing solid-state devices	US	Safety	Designers Manufacturers

Table 12: Standards for functional safety

3.1.13 Standards for electromagnetic compatibility

Electrical standards require that the safety of equipment is not compromised due to electromagnetic interference. The standards listed in Table 13 are used to ensure the equipment and its components are resistant to electromagnetic interference, and at the same time ensure that the equipment's electromagnetic emissions meet essential parameters. The CSA C61000 series of standards (adopted from the IEC 61000 series of standards) are used to address different elements of electromagnetic compatibility (EMC). Table 13 includes just two examples as they are too numerous to list. They are colour-coded blue as more than one standard will be required to evaluate all aspects of EMC. EMC needs to address the emission and reception of electromagnetic waves such that electromagnetic interference is avoided. The assessment must include consideration of the location of the equipment and its surrounding environment (for example, in aviation, the radio communications should not affect the equipment under investigation for certification).

Code / standard	Title (and adoption notes)	Country	Application	User
CSA C61000-3-11	Electromagnetic compatibility (EMC) — Part 3-11: Limits — Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems — Equipment with rated current ≤ 75 A and subject to conditional connection (Adopted IEC 61000-3-11:2017, second edition, 2017-04, with Canadian deviations)	CAN	Safety	Manufacturers
CSA C61000-4-1	Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of the IEC 61000-4 series (Adopted IEC TR 61000-4-1:2016, first edition, 2016-04, with Canadian deviations)	CAN	Safety	Manufacturers
IEC 61000-3-11	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection	Intl	Safety	Manufacturers
IEC 61000-3-2	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)	Intl	Safety	Manufacturers
IEC 61000-3-3	Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection	Intl	Safety	Manufacturers
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments	Intl	Safety	Manufacturers
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments	Intl	Safety	Manufacturers
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for equipment in residential environments	Intl	Safety	Manufacturers
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments	Intl	Safety	Manufacturers
IEC TS 61000-3-4	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A	Intl	Safety	Manufacturers

Code / standard	Title (and adoption notes)	Country	Application	User
IEC TS 61000-3-5	Electromagnetic compatibility (EMC) - Part 3-5: Limits - Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A	Intl	Safety	Manufacturers

Table 13: Examples of standards for electromagnetic compatibility (many other standards exist)

3.1.14 Standards for material properties and fire ratings

Fuel cell equipment standards and electrical standards require that the materials of key components do not propagate fires. The standards listed in Table 14 are referenced in some fuel cell equipment standards to test for fire propagation of different components. CSA C22.2 No. 0.17 does not cover test procedures for classifying electrical wires and cables. CSA C22.2 No. 2556 is the CSA standard (harmonized with the US and Mexico) for wire and cable test procedures including flame tests. For this reason, CSA C22.2 No. 0.17 is colour-coded blue.

Code / standard	Title (and adoption notes)	Country	Application	User
ASTM E2652-18	Standard test method for assessing combustibility of materials using a tube furnace with a cone-shaped airflow stabilizer, at 750°C	US	Safety	Manufacturers
CSA C22.2 No. 0.17	Evaluation of properties of polymeric materials	CAN	Safety	Manufacturers
CSA C22.2 No. 2556	Wire and cable test methods (Trinational standard with NMX-J-556-ANCE-2021 and UL 2556)	CAN US MEX	Safety	Manufacturers
IEC 60695-11-10	Fire hazard testing - Part 11-10: Test flames - 50 W horizontal and vertical flame test methods	Intl	Safety	Manufacturers
ISO 1182	Reaction to fire tests for products - Non-combustibility test	Intl	Safety	Manufacturers
NFPA 274	Standard test method to evaluate fire performance characteristics of pipe insulation	US	Safety	Manufacturers
UL 746C	Polymeric materials - Use in electrical equipment evaluations	US	Safety	Manufacturers
UL 94	Tests for flammability of plastic materials for parts in devices and appliances	US	Safety	Manufacturers

Table 14: Standards for material properties and fire ratings

3.1.15 Standards for fire alarm systems

Stationary equipment such as power plants and dispensers may have alarm systems. The standards listed in Table 15 can be used to evaluate the fire alarm systems.

Code / standard	Title (and adoption notes)	Country	Application	User
UL 864	Standard for control units and accessories for fire alarm systems	US	Safety	Installers
UL 2017	Standard for general-purpose signaling devices and systems	US	Safety	Installers

Table 15: Standards for fire alarm systems

3.1.16 Standards for enclosures

In North America, enclosures must meet the specified National Electrical Manufacturer Association (NEMA) enclosure rating to ensure adequate protection against solid particles, water ingress, snow and ice. CSA C22.2 No. 94.1 is related to access to electrical equipment to prevent electrical shock hazard. It restricts the size of openings to prevent personnel from touching high voltages. CSA C22.2 No. 94.2 addresses environmental conditions to protect the electrical equipment and avoid fire and shock hazards due to water or particle ingress. CSA C22.2 No. 60529 is an adopted version of IEC 60529, which specifies the ingress protection (IP) rating against solid particles and water as an IP Code. The equipment standard will require a certain NEMA rating, and the standards in Table 16 specify the test requirements for the different NEMA ratings. The IP rating and NEMA tests are different, so they are difficult to harmonize. All of the standards are colour-coded blue because not all the hazards are addressed in one standard; a combination of standards must be used to cover personnel electrical shock hazard, protection from solid particles, water ingress, snow and ice.

Code / standard	Title (and adoption notes)	Country	Application	User
C22.2 No. 60529	Degrees of protection provided by enclosures (IP Code) (Adopted IEC 60529:1989, edition 2:1989 consolidated with amendment 1:1999 and amendment 2:2013, with Canadian deviations)	CAN	Safety	Designers Manufacturers
CSA C22.2 No. 94.1	Enclosures for electrical equipment, non-environmental considerations (Tri-national standard with NMX-J-235/1-ANCE-2015 and UL 50)	CAN US MEX	Safety	Designers Manufacturers
CSA C22.2 No. 94.2	Enclosures for electrical equipment, environmental considerations (Trinational standard with NMX-J-235/2-ANCE-2020 and UL 50E)	CAN US MEX	Safety	Designers Manufacturers

Table 16: Standards for enclosures

3.1.17 Standards for protection against lightning

Hydrogen installations must be protected against lightning. The standard listed in Table 17 is used in Canada for this purpose.

Code / standard	Title (and adoption notes)	Country	Application	User
CSA B72	Installation code for lightning protection systems	CAN	Safety	Installers

Table 17: Standards for protection against lightning

3.1.18 Standards for air compressors

Locomotives and fuel cells need compressed air and thus the standards listed in Table 18 may be relevant. Compressed air at low pressure is required to feed the fuel cell cathode with oxygen from the air. The fuel cell anode on the other side is fed with hydrogen gas. CAN/CSA C22.2 No. 60335-2-34 addresses the motor but not the mechanical components of the compressor. For this reason, it is colour-coded blue.

Code / standard	Title (and adoption notes)	Country	Application	User
CAN/CSA C22.2 No. 60335-2-34	Household and similar electrical appliances - Safety - Part 2-34: Particular requirements for motor-compressors (Binational standard with UL 60335-2-34)	CAN	Safety	Manufacturers
ISO 4414	Pneumatic fluid power - General rules and safety requirements for systems and their components	Intl	Safety	Manufacturers
ISO 5388	Stationary air compressors - Safety rules and code of practice	Intl	Safety	Manufacturers

Table 18: Standards for air compressors

3.1.19 Standards for hydrogen compressors

Filling stations usually have hydrogen compressors. As there are no standards (versus guidelines) for hydrogen compressors, the standards for compressors for other flammable gases are listed in Table 19. ANSI/CSA HGV 4.8 is colour-coded blue because it is a guideline and not a standard. CSA/ANSI NGV 4.8 is colour-coded blue because it addresses natural gas and not hydrogen.

Code / standard	Title (and adoption notes)	Country	Application	User
ANSI/CSA HGV 4.8-2012	Hydrogen gas vehicle fueling station compressor guidelines	CAN US	Guide	Manufacturers
CSA/ANSI NGV 4.8	Natural gas vehicle fuelling station compressor packages	CAN US	Guide	Manufacturers
CAGI 3075	B19.1 Safety standards for compressor systems	US	Safety	Manufacturers
ISO 10439 (All Parts)	Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors	Intl	Safety	Manufacturers
ISO 10440-1	Petroleum, petrochemical and natural gas industries - Rotary-type positive-displacement compressors - Part 1: Process compressors	Intl	Safety	Manufacturers
ISO 10440-2	Petroleum and natural gas industries - Rotary-type positive-displacement compressors - Part 2: Packaged air compressors (oil-free)	Intl	Safety	Manufacturers
ISO 10442	Petroleum, chemical and gas service industries - Packaged, integrally geared centrifugal air compressors	Intl	Safety	Manufacturers
ISO 13631	Petroleum and natural gas industries - Packaged reciprocating gas compressors	Intl	Safety	Manufacturers
ISO 13707	Petroleum and natural gas industries - Reciprocating compressors	Intl	Safety	Manufacturers

Table 19: Standards for hydrogen compressors

3.1.20 Standards for risk assessments

All installations require a risk assessment and risk analysis. A list of standards for risk assessments is presented in Table 20. ISO 12100 identifies risk assessment and risk reduction design principles. The SAE and IEC standards specify requirements for failure mode and effects analysis (FMEA), failure mode, effects and criticality analysis (FMECA), hazard and operability studies (HAZOP) and fault tree analysis (FTA).

Code / standard	Title (and adoption notes)	Country	Application	User
IEC 61882	Hazard and operability studies (HAZOP studies) - Application guide	Intl	Guide	Designers Manufacturers Integrators Installers AHJ
CSA ISO 31000	Risk management – Guidelines (Adopted ISO 31000:2018, second edition, 2018-02)	CAN	Safety	Designers Manufacturers Integrators Installers AHJ
IEC 60812	Failure modes and effects analysis (FMEA and FMECA)	Intl	Safety	Designers Manufacturers Integrators Installers AHJ
IEC 61025	Fault tree analysis (FTA)	Intl	Safety	Designers Manufacturers Integrators Installers AHJ
ISO 12100	Safety of machinery - General principles for design - Risk assessment and risk reduction	Intl	Safety	Designers Manufacturers Integrators Installers AHJ
SAE J1739	Potential failure mode and effects analysis (FMEA) including design FMEA, supplemental FMEA-MSR, and process FMEA	US	Safety	Designers Manufacturers Integrators Installers AHJ

Table 20: Standards for risk assessments

3.2 Ground equipment standards

3.2.1 Standards for ground hydrogen storage system

The standards listed in Table 21 are applicable to ground hydrogen storage systems. These systems may receive the hydrogen from different sources and store it to be dispensed to the hydrogen fuel cell powered locomotive when required.

One very important standard is the Canadian hydrogen installation code (BNQ 1784-000), an updated version of which was released in May 2022. The previous edition of this code applied to installations with equipment that uses a maximum of 21 kg/h of hydrogen on a continuous basis for industrial installations. This code specifies the installation requirements for hydrogen-generating equipment, hydrogen-powered (utilization) equipment, hydrogen dispensing equipment, hydrogen storage containers, hydrogen piping systems and related accessories. The code applies to all gaseous and liquid hydrogen applications. It also addresses system and equipment integration requirements as well as minimum clearance distances to exposures. The CSA/ANSI HGV4 series of standards cover the hydrogen gas dispenser components.

However, the authors of this report are not aware of safety requirements for liquefied hydrogen fueling equipment (except for ISO 13984, Liquid hydrogen - Land vehicle fuelling system interface, included in Table 22). Other standards listed in Table 21 can be used for components, pressure relief devices, insulation, cleanliness, etc. Federal installations must comply with the National Research Council Canada (NRC) building and fire codes. Provincial installations must comply with the applicable provincial building codes and other local building and fire codes.

Some hydrogen storage technologies, such as solid-state hydrogen storage, are lacking North American standards. However, Japan and China have developed some such standards since 2007. This is a gap that needs to be addressed.

Code / standard	Title (and adoption notes)	Country	Application	User
CSA SPE-2.1.3	Best practices for defueling, decommissioning, and disposal of compressed hydrogen gas vehicle fuel containers	CAN	Guide	Users
GB/T 33291	Metal hydride hydrogen storage system for fuel cells backup power	China	Guide	Manufacturers
JIS H 7201	Glossary of terms used in hydrogen absorbing alloys	Japan	Guide	Manufacturers
JIS H 7202	Method for measurement of pressure-composition-temperature (PCT) relations of hydrogen absorbing alloys	Japan	Guide	Manufacturers
JIS H 7203	Method for measurement of hydrogen absorption/desorption reaction rate of hydrogen absorbing alloys	Japan	Guide	Manufacturers
ISO 21014	Cryogenic vessels - Cryogenic insulation performance - Amendment 1	Intl	Performance	Manufacturers
-	National building code of Canada	CAN	Safety	Installers AHJ
-	National fire code of Canada	CAN	Safety	Installers AHJ
-	Provincial building codes	CAN	Safety	Installers AHJ
-	Provincial fire codes	CAN	Safety	Installers AHJ
CAN/BNQ 1784-000	Canadian hydrogen installation code	CAN	Safety	Manufacturers Installers AHJ
CGA H-3	Standard for cryogenic hydrogen storage	US	Safety	Installers AHJ
CGA H-5	Standard for bulk hydrogen supply systems (an American national standard)	US	Safety	Installers AHJ
CGA P-12	Safe handling of cryogenic liquids	US	Safety	Users
CGA P-28	OSHA process safety management and EPA risk management plan guidance document for bulk liquid hydrogen supply systems	US	Safety	Installers AHJ
CGA P-41	Locating bulk liquid storage systems in courts	US	Safety	Installers AHJ
CGA PS-33	CGA position statement on use of LPG or propane tank as compressed hydrogen storage buffers	US	Safety	Installers AHJ

Code / standard	Title (and adoption notes)	Country	Application	User
CGA PS-46	CGA position statement on roofs over hydrogen storage systems	US	Safety	Installers AHJ
CGA PS-48	CGA position statement on clarification of existing hydrogen setback distances and development of new hydrogen setback distances in NFPA 55	US	Safety	Installers AHJ
CSA B51 Part 3	Compressed natural gas and hydrogen refuelling station pressure piping systems and ground storage vessels	CAN	Safety	Installers AHJ
EN 17533: 2020	Transportable gas storage devices - Hydrogen absorbed in reversible metal hydride	EU	Safety	Manufacturers
GB/T 26466	Storage and transportation systems for gaseous hydrogen—Part 1: General requirements	China	Safety	Manufacturers
GB/T 33292	Stationary flat steel ribbon wound vessels for storage of high pressure hydrogen	China	Safety	Manufacturers
GB/T 34542.1	Safety technical requirements for hydrogen storage devices used in hydrogen fuelling station	China	Safety	Manufacturers
GB/T 34583	Method for measurement of hydrogen absorption/ desorption cycle characteristic of hydrogen absorbing alloys	China	Safety	Manufacturers
ISO 16111	Transportable gas storage devices - Hydrogen absorbed in reversible metal hydride	Intl	Safety	Manufacturers
ISO 19882	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	Intl	Safety	Manufacturers Installers AHJ
ISO 21010	Cryogenic vessels - Gas/material compatibility	Intl	Safety	Manufacturers
ISO 21028-1	Cryogenic vessels - Toughness requirements for materials at cryogenic temperature - Part 1: Temperatures below -80 degrees C	Intl	Safety	Manufacturers
ISO 23208	Cryogenic vessels - Cleanliness for cryogenic service	Intl	Safety	Manufacturers Installers AHJ
NFPA 2	Hydrogen technologies code	US	Safety	Manufacturers Installers AHJ
NFPA 70 - Article 692	National electrical code - Fuel cell systems	US	Safety	Installers AHJ
JIS H 7003	Gaseous hydrogen - Cylinders and tubes for stationary storage	Japan	Terminology	Manufacturers

Table 21: Standards for ground hydrogen storage system

3.2.2 Standards for hydrogen dispensers

The standards listed in Table 22 are applicable to hydrogen dispensers. In Canada, CSA/ANSI HGV 4.1 and 4.9 should be regarded as a starting point for hydrogen dispensers. Other CSA standards are considered relevant for components such as break away devices, valves and hoses.

Code / standard	Title (and adoption notes)	Country	Application	User
ANSI/CSA HGV 4.8-2012	Hydrogen gas vehicle fueling station compressor guidelines	CAN US	Guide	Manufacturers
CGA PS-31	CGA position statement on cleanliness for proton exchange membranes hydrogen piping/components	US	Hydrogen quality	Manufacturers
CSA/ANSI HGV 4.3	Test methods for hydrogen fueling parameter evaluation	CAN US	Performance	Manufacturers
OIML R 139-1	Compressed gaseous fuel measuring systems for vehicles – Part 1: Metrological and technical requirements	Intl	Performance	Manufacturers
OIML R 139-2	Compressed gaseous fuel measuring systems for vehicles – Part 2: Metrological controls and performance tests	Intl	Performance	Manufacturers
OIML R 81	Dynamic measuring devices and systems for cryogenic liquids	Intl	Performance	Manufacturers
ANSI/CSA HGV 4.6-2013	Manually operated valves for use in gaseous hydrogen vehicle fueling stations	CAN US	Safety	Manufacturers
ANSI/CSA HGV 4.7-2013	Automatic valves for use in gaseous hydrogen vehicle fueling stations	CAN US	Safety	Manufacturers
CAN/BNQ 1784-000	Canadian hydrogen installation code	CAN	Safety	Manufacturers Installers AHJ
CSA B51, Part 3	Compressed natural gas and hydrogen refuelling station pressure piping systems and ground storage vessels	CAN	Safety	Designers Installers Manufacturers AHJ
CSA HPIT 2	Dispensing systems and components for fueling hydrogen powered industrial trucks	CAN	Safety	Manufacturers
CSA/ANSI HGV 4.1	Hydrogen-dispensing systems	CAN US	Safety	Manufacturers Installers AHJ
CSA/ANSI HGV 4.10	Standard for fittings for use in compressed gaseous hydrogen fueling stations	CAN US	Safety	Manufacturers
CSA/ANSI HGV 4.2	Hoses for dispensing compressed gaseous hydrogen	CAN US	Safety	Manufacturers
CSA/ANSI HGV 4.4	Gaseous hydrogen - Fuelling stations - Valves (Adopted ISO 19880-3:2018, first edition, 2018-06, with North American deviations)	CAN US	Safety	Manufacturers
CSA/ANSI HGV 4.5	Priority and sequencing equipment for hydrogen vehicle fueling	CAN US	Safety	Manufacturers
CSA/ANSI HGV 4.9	Hydrogen fueling stations	CAN US	Safety	Manufacturers Installers AHJ
ISO 13850	Safety of machinery - Emergency stop function - Principles for design	Intl	Safety	Designers Installers Manufacturers AHJ
ISO 13984	Liquid hydrogen - Land vehicle fuelling system interface	Intl	Safety	Manufacturers
ISO 17268	Gaseous hydrogen land vehicle refuelling connection devices	Intl	Safety	Manufacturers

Code / standard	Title (and adoption notes)	Country	Application	User
NFPA 70 - Article 692	National electrical code - Fuel cell systems	US	Safety	Designers Installers Manufacturers AHJ
SAE J2600	Compressed hydrogen surface vehicle fueling connection devices	US	Safety	Manufacturers
SAE J2601	Fueling protocols for light duty gaseous hydrogen surface vehicles	US	Safety	Users
SAE J2799	Hydrogen surface vehicle to station communications hardware and software	US	Safety	Manufacturers

Table 22: Standards for hydrogen dispensers

3.3 Locomotive standards

3.3.1 Current locomotive safety rules and regulations

Table 23 lists generic rules and regulations applicable to rail and locomotive operations in Canada and the US. They will require amendments to cover hydrail locomotives. Since these are rules and regulations versus codes and standards, no colour-coding scheme has been applied.

Code / standard	Title (and adoption notes)	Country	Application	User
-	Canada transportation act (S.C. 1996, c. 10)	CAN	Act	AHJ
-	Canadian transportation accident investigation and safety board act (S.C. 1989, c. 3)	CAN	Act	TSB
-	Railway safety act (R.S.C., 1985, c. 32 (4th Supp.))	CAN	Act	Users AHJ
-	Transportation of dangerous goods act (S.C. 1992, c. 34)	CAN	Act	AHJ
-	Association of American Railroads - Manual of standards and recommended practices, Section M -Locomotives and locomotive interchange equipment	US	Safety	Users AHJ
-	Association of American Railroads - Manual of standards and recommended practices, Section T -Interoperable fuel tenders for locomotives	US	Safety	Users AHJ
-	Canada labour code (R.S.C., 1985, c. L-2)	CAN	Safety	AHJ
-	Canadian rail operating rules (CROR)	CAN	Safety	Users AHJ
-	Federal Railroad Administration - Code of federal regulations, Title 49 – Transportation, Volume: 4, Date: 2011-10-01, Title: Part 229 - Railroad locomotive safety standards	US	Safety	Users AHJ
SOR/2014-275	Grade crossings regulations	CAN	Safety	Users AHJ
SOR/2017-121	Locomotive emissions regulations	CAN	Safety	Users AHJ
SOR/91-103	Notice of railway works regulations	CAN	Safety	Users AHJ
SOR/2015-143	On board trains occupational safety and health regulations	CAN	Safety	Users AHJ
SOR/87-150	Railway employee qualification standards regulations	CAN	Safety	Users AHJ

Code / standard	Title (and adoption notes)	Country	Application	User
-	Railway locomotive inspection and safety rules	CAN	Safety	AHJ
SOR/2014-258	Railway operating certificate regulations	CAN	Safety	Users AHJ
SOR/2014-233	Railway safety administrative monetary penalties regulations	CAN	Safety	Users AHJ
SOR/2015-26	Railway safety management system regulations, 2015	CAN	Safety	Users AHJ

Table 23: Current locomotive safety rules and regulations

3.3.2 Standards for hydrogen storage systems and associated components

Table 24 lists standards that cover hydrogen storage systems and associated components. Since IEC 63341-2 is currently under development, it is recommended that Canadian stakeholders participate in this committee to get up to date on the content of the draft standard, to try to ensure compatibility of the draft standard with Canadian requirements (to simplify the future adoption of this standard into Canada, to help regulate the industry in Canada and to aid the Canadian industry) and to support this committee. At the present time CSA/ANSI HGV2 could be used for rail applications. CSA/ANSI HGV 3.1 covers gas valve train components and CSA/ANSI HPRD 1 addresses pressure relief devices. The ISO standards colour-coded yellow may be useful (complementary) if components are not covered by the CSA standards.

Code / standard	Title (and adoption notes)	Country	Application	User
CSA SPE-2.1.3	Best practices for defueling, decommissioning, and disposal of compressed hydrogen gas vehicle fuel containers	CAN	Guide	Users
CSA/ANSI HGV 2	Compressed hydrogen gas vehicle fuel containers	CAN US	Safety	Manufacturers
CSA/ANSI HGV 3.1	Fuel system components for compressed hydrogen gas powered vehicles	CAN US	Safety	Manufacturers
CSA/ANSI HPRD 1	Thermally activated pressure relief devices for compressed hydrogen vehicle (HGV) fuel containers	CAN US	Safety	Manufacturers
IEC 63341-2	Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 2: Hydrogen storage system	Intl	Safety	Manufacturers Integrators AHJ
ISO 13985	Liquid hydrogen - Land vehicle fuel tanks	Intl	Safety	Manufacturers
ISO 19078	Gas cylinders - Inspection of the cylinder installation, and requalification of high pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles	Intl	Safety	Integrators Users
ISO 19881	Gaseous hydrogen - Land vehicle fuel containers	Intl	Safety	Manufacturers
ISO 19882	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	Intl	Safety	Manufacturers
ISO 19887	Gaseous hydrogen - Fuel system components for hydrogen fuelled vehicles	Intl	Safety	Manufacturers

Table 24: Standards for hydrogen storage systems and associated components

3.3.3 Standards for fuel cell power system

Table 25 lists the standards applicable to fuel cell power systems and associated components. Since IEC 63341-1 is currently under development, it is recommended that Canadian stakeholders participate in this committee to get up to date on the content of the draft standard, to try to ensure compatibility of the draft standard with Canadian requirements (to simplify the future adoption of this standard into Canada, to help regulate the industry in Canada and to aid the Canadian industry) and to support this committee. Also, the Canadian government and SDOs should discuss the possibility of working with the CSA mirror committee to the IEC TC 105 committee (fuel cell technologies) to adopt IEC 63341-1 with Canadian deviations in the future. In the meantime, CSA/ANSI FC 1, ANSI/CSA AMERICA FC 3 or IEC 62282-4-101 can be used to cover some of the hazards and provide a useful safety philosophy. However, these standards do not cover appropriate rail environmental conditions. The IEC and UL standards for forklift applications may be very useful as they at least will have some vibration and shock requirements. Similarly, the safety philosophy of these standards may be used. However, the ambient temperature, rain and snow requirements are not addressed by these standards. The ANSI/CSA AMERICA FC 3 portable fuel cell standard provides guidance for oxygen depletion for non-vented portable systems. If the rail fuel cell system is inside a large enclosure where personnel can enter, this may be useful. The other referenced standards may be complementary and help with hazards such as crashworthiness, hydrogen quality and power conversion equipment.

Code / standard	Title (and adoption notes)	Country	Application	User
SAE J3121	Hydrogen vehicle crash test lab safety guidelines	US	Guide	Integrators
SAE J2719	Hydrogen fuel quality for fuel cell vehicles	US	Hydrogen quality	Manufacturers Users
IEC 62282-4-102	Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods	Intl	Performance	Manufacturers
SAE J2615	Testing performance of fuel cell systems for automotive applications	US	Performance	Manufacturers
SAE J2578	Recommended practice for general fuel cell vehicle safety	US	Recommended practice	Users
ANSI/CSA AMERICA FC 3-2004	Portable fuel cell power systems	US	Safety	Manufacturers Integrators
CSA C22.2 No. 107.1	Power conversion equipment	CAN	Safety	Manufacturers Integrators
CSA/ANSI FC 1 CSA C22.2 No. 62282-3-100	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety (Adopted IEC 62282-3-100:2019, second edition, 2019-02, with Canadian and U.S. deviations)	CAN US	Safety	Manufacturers Integrators
IEC 62282-4-101	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety	Intl	Safety	Manufacturers Integrators
IEC 62282-5-100	Fuel cell technologies - Part 5-100: Portable fuel cell power systems - Safety	Intl	Safety	Manufacturers Integrators
IEC 63341-1	Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 1: Fuel cell system	Intl	Safety	Manufacturers Integrators

Code / standard	Title (and adoption notes)	Country	Application	User
ISO 23273	Fuel cell road vehicles - Safety specifications - Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen	Intl	Safety	Integrators
SAE J1766	Recommended practice for electric, fuel cell and hybrid electric vehicle crash integrity testing	US	Safety	Integrators Users
SAE J2579	Standard for fuel systems in fuel cell and other hydrogen vehicles	US	Safety	Manufacturers
UL 2267	Standard for fuel cell power systems for installation in industrial electric trucks	US	Safety	Manufacturers

Table 25: Standards for fuel cell power system and associated components

3.3.4 Standards for fuel cell module

All fuel cell modules include the fuel cell stack (which comprises many cells) and terminals. However, the boundaries for fuel cell modules are not restricted by standards. Some modules may also include the air compressor or blowers, and some may not. It is easier to evaluate the fuel cell power generator if the module has already been evaluated and proven to meet a minimum set of requirements for safety. For example, the maximum allowable working pressure of the stack and associated parts may already have been determined, the leakage may already have been measured, the terminals may already have been deemed adequate, etc. Table 26 lists the standards applicable to the fuel cell module. Canada has a fuel cell module standard that can be used to ensure the module meets some minimum safety requirements; however, other fuel cell module safety requirements depend on the application (e.g., environmental requirements). Similarly, the safety philosophy, including the fault and automatic emergency response system logic, depends on the end use. CSA/ANSI FC 6 is the American fuel cell module standard. SAE J2617 is useful for determining the fuel cell module performance.

Code / standard	Title (and adoption notes)	Country	Application	User
SAE J2617	Recommended practice for testing performance of PEM fuel cell stack sub-system for automotive applications	US	Performance	Manufacturers
CAN/CSA C22.2 No. 62282-2	Fuel cell technologies - Part 2: Fuel cell modules (Adopted IEC 62282-2:2012, second edition, 2012-03, with Canadian deviations)	CAN	Safety	Manufacturers
CSA/ANSI FC 6	Fuel cell technologies - Part 2: Fuel cell modules (Adopted IEC 62282-2:2012, second edition, 2012-03, with United States deviations)	CAN US	Safety	Manufacturers

Table 26: Standards for fuel cell module

3.3.5 Standards for fuel cell power plant ventilation system

There is no specific standard to assess the adequacy of the ventilation system of a hydrail fuel cell power plant for safety. However, different standards as listed in Table 27 include the necessary requirements for the fuel cell power plant ventilation system. For example, CSA/ANSI FC 1 and ANSI/CSA AMERICA FC 3 have ventilation requirements to effectively dilute the fuel cell stack hydrogen leaks, as well as to ensure the ventilation system is monitored so that if it fails an appropriate remedial action is taken. These standards offer a safety philosophy to address normal and abnormal hydrogen leaks and thus are applicable for the ventilation system. The SAE and IEC standards in Table 27 can also provide guidance for ventilation system requirements.

Code / standard	Title (and adoption notes)	Country	Application	User
SAE J2719	Hydrogen fuel quality for fuel cell vehicles	US	Hydrogen quality	Manufacturers Users
IEC 62282-4-102	Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods	Intl	Performance	Manufacturers
SAE J2615	Testing performance of fuel cell systems for automotive applications	US	Performance	Manufacturers
SAE J2578	Recommended practice for general fuel cell vehicle safety	US	Recommended practice	Manufacturers Integrators
ANSI/CSA AMERICA FC 3-2004	Portable fuel cell power systems	US	Safety	Manufacturers Integrators
CSA/ANSI FC 1 CSA C22.2 No. 62282-3-100	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety (Adopted IEC 62282-3-100:2019, second edition, 2019-02, with Canadian and U.S. deviations)	CAN US	Safety	Manufacturers Integrators
IEC 62282-4-101	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety	Intl	Safety	Manufacturers Integrators
IEC 62282-5-100	Fuel cell technologies - Part 5-100: Portable fuel cell power systems - Safety	Intl	Safety	Manufacturers Integrators
IEC 63341-1	Railway applications – Rolling stock – Fuel cell systems for propulsion -Part 1: Fuel cell power system.	Intl	Safety	Manufacturers Integrators
SAE J2579	Standard for fuel systems in fuel cell and other hydrogen vehicles	US	Safety	Manufacturers Integrators

Table 27: Standards for fuel cell power plant ventilation system

3.3.6 Standards for fuel cell power plant heat exchangers

There are no specific standards to evaluate heat exchangers. However, the same standards as listed for the ventilation system (Table 27) may address some of the necessary heat exchanger requirements.

3.3.7 Standards for fuel cell water treatment

The water treatment system collects the water produced by the fuel cell. This water may be re-used for humidification of the fuel cell cathode air or it may be stored and treated (if needed) to be used for other purposes. The NRC authors did not identify any standards specific to this part of the system.

3.4 Lithium battery standards

Most fuel cell systems for transportation applications are hybrid systems that combine a battery system for energy storage with the hydrogen fuel cell power generator. This allows the battery-fuel cell system to be able to handle peak loads using the energy in the batteries, while also allowing the fuel cell stack size to be reduced. Batteries are available in a variety of chemical types – this section focuses on lithium-based batteries as these are the batteries used in the majority of hybrid fuel cell systems.

The standards listed in Table 28 can be used (in part) to address the risks that lithium batteries pose, and to ensure a minimum safety performance for cells, batteries and battery systems. However, it is important to ensure that lithium batteries do not pose a hazard to the fuel cell system and vice versa. If the referenced battery standards do not address this battery/fuel cell interface, a safety strategy needs to be developed to protect the fuel cell systems from the battery hazards and vice versa. Similarly, a test criterion needs to be developed to ensure that the safety strategy does work. RTCA DO 311 for aviation lithium batteries has a safety strategy that could be adapted for passenger trains as well as for cargo rail applications. UL 1973 (bi-national US/CAN standard) covers batteries for light electric rail applications (covering battery systems used for load balancing, as an energy storage device for regenerative braking, or for emergency power during power outages to take the train to the nearest station). On the other hand, IEC 62928 is the most suitable standard for all rail applications. However, it is not Canadian and it does not reference Canadian component standards or address the Canadian railway environmental conditions. Manufacturers, integrators, regulators and rail companies may focus on IEC 62928 but also use other North American standards to complement it (e.g., UL 1973). Some of the listed standards include requirements to evaluate the lithium cells (e.g., IEC 62660-1, IEC 62660-2). Standards for electric vehicles may also have some relevant requirements. For example, SAE J2464 may offer a reasonable abuse testing criteria which can be used as a baseline for rail as well. The ISO has also developed lithium battery standards for road vehicles.

Code / standard	Title (and adoption notes)	Country	Application	User
IEC 62620	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications	Intl	Performance	Manufacturers
IEC 62660-1	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing	Intl	Performance	Manufacturers Integrators Users
IEC 62660-2	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing	Intl	Performance Safety	Manufacturers
SAE J1766	Recommended practice for electric, fuel cell and hybrid electric vehicle crash integrity testing	US	Recommended practice	Manufacturers Integrators Users AHJ
SAE J1798	Recommended practice for performance rating of electric vehicle battery modules	US	Recommended practice	Manufacturers
SAE J2380	Vibration testing of electric vehicle batteries	US	Recommended practice	Manufacturers Integrators
SAE J2464	Electric and hybrid electric vehicle rechargeable energy storage system (RESS) safety and abuse testing	US	Recommended Practice	Manufacturers Integrators
CAN/CSA E61959	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Mechanical tests for sealed portable secondary cells and batteries (Adopted IEC 61959:2004, first edition, 2004-01, with Canadian deviations)	CAN	Safety	Manufacturers

Code / standard	Title (and adoption notes)	Country	Application	User
IEC 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications	Intl	Safety	Manufacturers
IEC 62928	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	Intl	Safety	Manufacturers Integrators
ISO 6469-1	Electrically propelled road vehicles - Safety specifications - Part 1: Rechargeable energy storage system (RESS)	Intl	Safety	Manufacturers Integrators
ISO 6469-2	Electrically propelled road vehicles - Safety specifications - Part 2: Vehicle operational safety	Intl	Safety	Manufacturers Integrators
ISO 6469-3	Electrically propelled road vehicles - Safety specifications - Part 3: Electrical safety	Intl	Safety	Manufacturers Integrators
SAE J2344	Guidelines for electric vehicle safety	US	Safety	Manufacturers Integrators
SAE J2929	Safety standard for electric and hybrid vehicle propulsion battery systems utilizing lithium-based rechargeable cells	US	Safety	Manufacturers Integrators
UL 1642	Lithium batteries	US	Safety	Manufacturers Integrators
UL 1973	ANSI/CAN/UL Batteries for use in stationary and motive auxiliary power applications	CAN US	Safety	Manufacturers Integrators
UL 583	Electric-battery-powered industrial trucks	US	Safety	Manufacturers Integrators
ULC 2271	Batteries for use in light electric vehicle (LEV) applications	US	Safety	Manufacturers Integrators
ULC 2580	Batteries for use in electric vehicles	US	Safety	Manufacturers Integrators
RTCA DO 311	Minimum operational performance standards for rechargeable lithium batteries and battery systems	US	Safety	Manufacturers Integrators

Table 28: Lithium battery standards

3.5 Natural gas transport standards

Natural gas rail safety standards are North American in character, but also reflect industry norms [6]. Various CNG and LNG standards have been developed for North America and for the international community. Some examples are listed in Table 29. Some of these standards could be used as seed documents or expanded to cover non-existing hydrogen standards for some of the hydrogen equipment and components (e.g., CSA B108.2 and CSA Z276 Annex B could be useful standards to cover liquid hydrogen fuelling stations and components). The hydrogen container standards listed in Section 3.3.2 may also be applicable.

Code / standard	Title (and adoption notes)	Country	Application	User
CSA/ANSI NGV 4.3	Temperature compensation for compressed natural gas vehicle fuelling	CAN US	Performance Safety	Manufacturers
SAE J1616	Recommended practice for compressed natural gas vehicle fuel	US	Recommended practice	Supplier

Code / standard	Title (and adoption notes)	Country	Application	User
CGA C-6.4	Methods for external visual inspection of natural gas vehicle (NGV) and hydrogen gas vehicle (HGV) fuel containers and their installations	US	Safety	Users
CSA B108.1	Compressed natural gas refuelling stations installation code	CAN	Safety	Installers
CSA B108.2	Liquefied natural gas refuelling stations installation code	CAN	Safety	Installers
CSA B109.1	Compressed natural gas vehicle installation code	CAN	Safety	Integrators
CSA B109.2	Liquefied natural gas vehicle installation code	CAN	Safety	Integrators
CSA B401.2	Propane vehicle maintenance facilities code	CAN	Safety	Users
CSA Z276	Liquefied natural gas (LNG) - Production, storage, and handling	CAN	Safety	Designers Installers
CSA/ANSI LNG 3.1 – 3.19	Road vehicles - Liquefied natural gas (LNG) fuel system components (series of standards)	CAN US	Safety	Manufacturers Integrators
CSA/ANSI LNG 4.1-2018	LNG vehicle dispensing systems	CAN US	Safety	Manufacturers
CSA/ANSI NGV 2	Compressed natural gas vehicle fuel containers	CAN US	Safety	Manufacturers
CSA/ANSI NGV 4.1-2018	Natural gas vehicle (NGV) dispensing systems	CAN US	Safety	Manufacturers
CSA/ANSI NGV 6.1	Compressed natural gas (CNG) fuel storage and delivery systems for road vehicles	CAN US	Safety	Manufacturers Integrators
CSA/ANSI PRD 1	Pressure relief devices for natural gas vehicle (NGV) fuel containers	CAN US	Safety	Manufacturers
ISO 12617	Road vehicles - Liquefied natural gas (LNG) refuelling connector - 3,1 MPa connector	Intl	Safety	Integrators
NFPA 57	Liquefied natural gas (LNG) vehicular fuel systems code	US	Safety	Manufacturers Integrators

Table 29: Natural gas transport standards

3.6 Railway bulk transport standards

Part 2 of the Transport Canada transportation of dangerous goods regulations (SOR 2017-137) covers classification of dangerous goods, where hydrogen is classified as a Class 2.1 flammable gas. Part 10 of the regulations covers rail regulations; however, these regulations address the transportation of dangerous goods by rail, and do not consider the use of these dangerous goods as fuel. The regulations are also general in nature. Nevertheless, these regulations cover the required markings, documentation, training, emergency response and other very useful information that should be reviewed and kept in mind for this and future projects.

CAN/CGSB-43.147 – Containers for transport of dangerous goods by rail (dated 2005), was replaced in 2013 by Transport Canada TP 14877, which will be replaced by a new version of CAN/CGSB-43.147. It will set out the requirements for designing, manufacturing, maintaining, qualifying, inspecting, marking, selecting and using tank cars. It will also lay out the requirements for the quality management system and its applicability, and the registration of facilities performing manufacture, inspection, maintenance or qualification of tank cars. A 60-day consultation period ended in August, 2022. The new standard has not yet been incorporated by a regulatory amendment.

The standards listed in Table 30 may not be directly applicable to the transport of hydrogen, but cross linkages may exist and are worthwhile to list for future determination. The hydrogen container standards listed in Section 3.3.2 may also be applicable.

Code / standard	Title (and adoption notes)	Country	Application	User
-	Federal Railroad Administration - Code of federal regulations, Title 49 - Parts 172, 173, 174, 179, and 180	US	Safety	Users AHJ
SOR 2017-137	Consolidated transportation of dangerous goods regulations	CAN	Safety	Users AHJ
TP 14877E	Containers for transport of dangerous goods by rail	CAN	Safety	Users AHJ
CSA B620	Highway tanks and TC portable tanks for the transportation of dangerous goods	CAN	Safety	Designers Manufacturers AHJ
CSA B622	Selection and use of highway tanks and TC portable tanks for the transportation of dangerous goods, Class 2	CAN	Safety	Designers Manufacturers AHJ
CSA B625	Portable tanks for the transport of dangerous goods	CAN	Safety	Designers Manufacturers AHJ
AAR M-1002	AAR Manual of Standards and Recommended Practices – Section C-III - Specifications for Tank Cars (M-1002)	US	Safety	Designers Manufacturers AHJ

Table 30: Railway bulk transport standards

4 Canadian risks

Canada poses unique challenges to the design of machinery due to the extreme weather conditions: temperatures ranging from -45°C to +50°C, high rain and snow levels, and the potential for icing conditions. Extreme cold environments can impair electrical equipment in two main ways: safety and functionality. Safety is the primary concern for equipment used in proximity to potentially explosive gases, such as hydrogen. Low temperatures can both negatively impact the strength of materials, as well as increase the pressure produced when gases are ignited.

Some standards (e.g., the IEC 60079 series of standards) define an ambient temperature range that may be narrower than that experienced in a Canadian environment, but may provide for additional test requirements for products intended to operate outside the standard range. Alternatively, abnormal ambient temperatures may be outside the scope of a standard.

Further investigation may be required to evaluate the suitability of components for Canada. Such components include:

- fuel cell stacks;
- lithium batteries;
- enclosures;
- gas containing and conveying components;
- components certified for hazardous areas; and
- electrical components.

Equipment destined for Canada may require unique heating systems for lithium batteries and fuel cell systems, for both storage and operation, to avoid abusing those systems by subjecting them to temperatures outside of their recommended temperature ranges.

Fuel cells have ambient temperature limitations for storage and operations. For example, the Ballard FCmove™-HD [7] fuel cell power module has a minimum startup temperature of -25°C, a short-term storage temperature range of -40°C to +80°C and an operating temperature of -30°C to +50°C. The start-up temperature could potentially be an issue (if not managed) as the fuel cell system may need a ventilation system pre-purge of the fuel cell stack area to get rid of any hydrogen residues before some components are energized, and ambient air may be drawn inside the system to achieve that. Introducing very cold air while at sub-zero conditions might produce ice during start up, which may result in damage to the electrocatalyst layer and the polymer electrolyte membrane (PEM) [8].

Lithium batteries also have temperature limitations. For example, the LG Li-ion Battery Safety Guide [9] specifies the charging temperature to be within 0°C to +50°C. The discharge temperature range for these cells is from -20°C to +75°C. Abusing the cells by charging or discharging them at temperatures outside their range may result in safety hazards as the cells age, and may lead to performance or safety issues. For example, low temperature charging may result in lithium plating, which may eventually result in an internal short which ultimately can evolve into a thermal runaway later in the life of the cell.

The outdoor enclosures of equipment for use in Canada must take into account expected snow accumulations. The air intakes and exhaust must be above the expected snow line and be designed to prevent snowfall from accumulating inside of them. This is especially important for fuel cell systems that may rely on ventilation to keep normal stack hydrogen leaks below the lower flammability level of the gas through the use of ventilation. Other considerations include ice buildup, which can also plug the air intakes.

Extreme cold can affect material properties in a number of ways. Both metals and plastics can become embrittled at low temperatures, with metals with a body-centered cubic lattice structure (e.g., alpha-iron, beta titanium and chromium) sometimes showing an abrupt transition to a brittle state. Where a wide range of temperatures is expected, differential expansion and contraction can also be a concern. Therefore, extreme cold temperatures may make some materials unsuitable for hydrogen applications when they would otherwise be suitable when temperatures are more moderate. This should be a consideration when choosing materials for gas conveying and containing components.

Hydrogen material compatibility for seals includes the capacity of the material to withstand the hydrogen exposure without degradation, the ability to contain the hydrogen due to its capability to deform and compress (completely filling gaps) and seal, as well as the ability to contain the hydrogen by not allowing permeation. However, if used outside their temperature range, elastomers may fail to seal as designed because they may become too stiff. This should be a consideration for material selection of seals for gas-containing and conveying components as well as for components certified for hazardous areas, where they rely on seals to keep the hydrogen away from regular electrical components, and a failure of those seals may result in a safety hazard.

For the reasons just described, even elastomer products that may be rated for operation at the required temperature may have installation temperature requirements that are more stringent and require specific accommodation in areas that experience extreme temperatures.

Another potential issue with plastics is higher buildup of static electricity due to the lower humidity often associated with lower temperatures. Therefore, additional precautions may be required to avoid static buildup.

Lubricants can be another area of concern, since they may fail to lubricate components as designed if they are used outside their intended temperature range.

Finally, resistance and capacitance of electric circuits can be affected by temperature variation, so sensitive systems exposed to a wide range of temperatures must take this into account. For example, as a general rule conductors (metals) increase their resistance with an increase in temperature. However, the opposite is true for insulators.

In summary, additional testing at the expected temperature range in Canada may be required for components to ensure safety and reliability. Similarly, the expected snow and icing conditions should be part of the criteria for enclosures, air intakes and air exhausts. These considerations apply to the rail equipment as well as to the fueling infrastructure.

5 Assessment of codes and standards gaps

Table 31 summarizes whether or not Canadian, US or international standards exist for each hydrail system, component or application discussed in this report. It also provides an assessment of the codes and standards landscape – i.e., whether or not established standards exist to appropriately address each area, or if there are significant gaps. The table is subdivided into overarching standards (as discussed in Section 3.1), ground equipment standards (as discussed in Section 3.2), locomotive standards (as discussed in Section 3.3), and other standards (as discussed in Sections 3.4 to 3.6). Again, a colour-coding scheme has been applied, where dark green indicates that the area is well covered with existing standards, light green indicates that the area is well covered but improvements are recommended, and yellow indicates that some work is required to provide the necessary coverage.

Hydrail system/ component/ application	Codes and standards coverage			Comments
	CAN	US	Intl	
Overarching standards				
General hydrogen stand[ards	No	Yes	Yes	Although no Canadian standards exist, there are plenty of US and international standards for general hydrogen safety. As these standards are general in nature the specific Canadian context is not critical.
Hydrogen quality	No	Yes	Yes	Fuel cell vehicle hydrogen quality can cover hydrail fuel cells.
Components containing or conveying pressurized hydrogen	Yes	Yes	Yes	
Area classification and equipment for use in classified areas	Yes	Yes	Yes	It is recommended that prescriptive area classifications be provided similar to other alternative fuel codes (e.g., CNG and LNG), with IEC 60079-10-1 used as an alternative method where the prescriptive methods are not practical.
Hydrogen venting systems	No	Yes	No	
Static electricity	No	Yes	No	No Canadian standard addresses static electricity.
Hydrogen material compatibility	Yes	Yes	Yes	One improvement is required to make it easier for manufacturers and AHJs – a list of all materials that have been proven to be compatible for hydrogen use would be beneficial to minimize duplication of work.
Hydrogen sensors	No	No	Yes	No North American standard specifically addresses hydrogen sensors.
Pressure relief devices	No	No	No	Canadian standard for hydrogen vehicle pressure relief devices exists. Need to ensure it is sufficient for the larger storage tanks expected in rail. Also need to assess the international standards.
Electrical equipment	Yes	Yes	Yes	
Control equipment	Yes	Yes	Yes	
Functional safety (safety programmable controls)	Yes	Yes	Yes	Need to ensure adequacy of existing standards for rail application.
Electromagnetic compatibility	Yes	Yes	Yes	Need to ensure adequacy of existing standards for rail application.
Material properties and fire ratings	Yes	Yes	Yes	

Hydrail system/ component/ application	Codes and standards coverage			Comments
	CAN	US	Intl	
Fire alarm systems	No	Yes	Yes	No North American standard exists specific to rail.
Enclosures	Yes	Yes	Yes	Need to add specific Canadian rail application requirements.
Protection against lightning	Yes	Yes	Yes	
Air compressors	No	No	Yes	Need to address the mechanical components of air compressors specific for fuel cell systems.
Hydrogen compressors	No	No	No	Only a guideline exists for Canada. Standards specific to hydrogen compressors that address the electrical components, hazardous locations and mechanical components are needed.
Risk assessments	Yes	Yes	Yes	
Ground equipment standards				
Ground hydrogen storage system	Yes	Yes	Yes	A gap exists in North America for solid-state hydrogen storage technologies.
Hydrogen dispensers	Yes	Yes	Yes	The existing standards are not specific to rail.
Locomotive standards				
Hydrogen storage systems and associated components	No	No	No	The existing standards are not specific to rail. However, IEC 63341-2 (Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 2: Hydrogen storage system) is being developed.
Fuel cell power system	No	No	No	The existing standards are not specific to rail. However, IEC 63341-1 (Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 1: Fuel cell system) is being developed.
Fuel cell module	Yes	Yes	Yes	
Ventilation system	No	No	No	The existing standards are not specific to rail.
Heat exchangers	No	No	No	The existing standards are not specific to rail.
Water treatment	No	No	No	The existing standards are not specific to rail.
Other standards				
Batteries	No	Yes	Yes	UL 1973 (ANSI/CAN/UL Batteries for use in stationary and motive auxiliary power applications) only covers light rail applications. IEC 62928 (Railway applications - Rolling stock - Onboard lithium-ion traction batteries) is applicable but it has not been adopted in Canada.
Natural gas transport	Yes	Yes	Yes	
Railway bulk transport	Yes	Yes	Yes	

Table 31: Summary of coverage of existing codes and standards

As can be seen, there are numerous gaps that must be addressed to ensure all aspects of hydrail operation are covered by adequate standards. These include areas for which existing standards apply but could use improvement, including area classification, EMC for rail, and enclosures for rail. Standards for solid-state hydrogen storage are also lacking.

Areas where existing standards would need to be evaluated for appropriateness for a rail environment include hydrogen sensors for rail (tested to ensure they will work well in the rail environment when exposed to the dust, vapours and environmental conditions of rail applications), pressure relief devices (this is extremely important as their failure ranked to be the highest risk according to the risk analysis report [2]), fire alarm systems, air compressors (specific to fuel cell systems), hydrogen compressors, hydrogen dispensers, locomotive hydrogen storage systems, locomotive fuel cell power systems and associated equipment (ventilation, heat exchanger, water treatment), and batteries for rail applications.

In cases where no applicable Canadian standards exist, international standards may be adopted. For example, in Canada, NFPA 77 is used to manage static electricity as no equivalent Canadian standard exists. Similarly, the CGA, ISO and SAE have published standards for hydrogen quality that address the requirements for fuel cell systems. This is an important subject for fuel cell systems, as traces of contaminants such as carbon monoxide (CO) can degrade the performance of fuel cells, severely limiting their life span.

In relation to area classification, Chapter 18 of the Canadian Electrical Code specifies what type of equipment can be used in classified areas, and CAN/CSA C22.2 No. 60079 and the IEC 60079 series of standards cover different types of protections for equipment used inside classified areas (e.g., protection by pressurized enclosure "p" or protection by increased safety "e") as well as for some types of equipment (e.g., resistance trace heating). The current standard used to classify areas in Canada, IEC 60079-10-1, may not effectively mitigate risks. The methods described in this standard are complex and too dependent on the assumptions and leak rates used. Therefore, if the person working with this standard is too optimistic or too conservative when estimating the assumptions, the classified area may not be of the right size resulting in extra costs or compromising safety. It is recommended that prescriptive area classifications be provided similar to other alternative fuel codes (e.g., CNG and LNG), with IEC 60079-10-1 used as an alternative method where the prescriptive methods are not practical.

As far as locomotive batteries are concerned, IEC 62928 is the most suitable standard for all rail applications. Also, IEC 63341-1 is being developed to cover the locomotive fuel cell power system. Similarly, IEC 63341-2 is being developed to cover the rail hydrogen storage system. It is recommended that Canadian stakeholders participate in the IEC 63341-1 and IEC 63341-2 committees to get up to date on the content of the draft standards, to try to ensure compatibility of the draft standards with Canadian requirements (to simplify the future adoption of these standards into Canada, to help regulate the industry in Canada and to aid the Canadian industry) and to support these committees. Because these IEC standards are not Canadian, they do not reference Canadian component standards or address the Canadian railway environmental conditions and thus their adoption will need to have Canadian deviations.

6 Conclusions

There are many existing codes and standards that may be applicable to the hydrogen fuel cell and lithium battery systems that will be central to hydrail implementation. Some may provide the required coverage without any modification, while others may require minor or significant modification to provide the necessary coverage. Furthermore, Canadian weather conditions could also affect the safety and functionality of hydrail systems, so these risks will also have to be addressed by codes and standards.

A summary of the coverage of existing codes and standards is presented in Table 31. Areas that require better coverage by codes and standards include area classification, electromagnetic compatibility, enclosures, and solid-state hydrogen storage. Areas where existing standards would need to be evaluated for adequacy for a rail environment include hydrogen sensors, pressure relief devices, fire alarm systems, air compressors (specific to fuel cell systems), hydrogen compressors, hydrogen dispensers, locomotive hydrogen storage systems, locomotive fuel cell power systems and associated equipment (ventilation, heat exchanger, water treatment), and batteries. In cases where no applicable Canadian standards exist, it may be appropriate to adopt international standards.

For locomotive batteries, IEC 62928 is the most suitable standard for all rail applications. Also, IEC 63341-1 is being developed to cover the locomotive fuel cell power system, and IEC 63341-2 is being developed to cover the rail hydrogen storage system. It is recommended that Canadian stakeholders work with the CSA mirror committee to the IEC TC 105 committee (fuel cell technologies) to simplify the adoption of IEC 63341-1 and IEC 63341-2 in Canada. Because these IEC standards are not Canadian, they do not reference Canadian component standards or address the Canadian railway environmental conditions, and thus their adoption will have Canadian deviations.

Acronyms and abbreviations

AAR	Association of American Railroads
AHJ	authority having jurisdiction
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
AQSIQ	General Administration of Quality Supervision, Inspection and Quarantine
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BNQ	Bureau de normalisation du Québec
CAGI	Compressed Air and Gas Institute
CAN	Canada
CEN	European Committee for Standardization
CGA	Compressed Gas Association
CGSB	Canadian General Standards Board
CNG	compressed natural gas
CO	carbon monoxide
CRN	Canadian registration number
CSA	Canadian Standards Association
EMC	electromagnetic compatibility
FMEA	failure modes and effects analysis
FMECA	failure mode, effects and criticality analysis
FRA	Federal Railroad Administration
FTA	fault tree analysis
HAZOP	hazard and operability studies
HGV	hydrogen gas vehicle
IEC	International Electrotechnical Commission
intl	international
IP	ingress protection
ISO	International Organization for Standardization
JIS	Japanese Industrial Standards
JSA	Japanese Standards Association
LNG	liquefied natural gas
MEX	Mexico
NACE	National Association of Corrosion Engineers
NEMA	National Electrical Manufacturer Association
NFPA	National Fire Protection Association
NGV	natural gas vehicle
NRC	National Research Council of Canada
OIML	International Organization of Legal Metrology
PEM	polymer electrolyte membrane
RTCA	Radio Technical Committee for Aeronautics
SAE	Society of Automotive Engineers

SCC	Standards Council of Canada
SDO	standards development organization
UL	Underwriters Laboratories
ULC	Underwriters Laboratories of Canada
US	United States

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Appendix A: Summary of applicable codes and standards

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
-	-	-	Provincial fire codes	CAN	Safety
-	-	-	Provincial building codes	CAN	Safety
AAR	-	2020	Association of American Railroads - Manual of standards and recommended practices, Section M -Locomotives and locomotive interchange equipment	US	Safety
AAR	-	available late 2022	Association of American Railroads - Manual of standards and recommended practices, Section T -Interoperable fuel tenders for locomotives	US	Safety
ANSI/AIAA	ANSI/AIAA G-095A-2017	2017	Guide to safety of hydrogen and hydrogen systems	US	Safety
ANSI/CSA	ANSI/CSA AMERICA FC 3-2004	2004 (reaffirmed 2021)	Portable fuel cell power systems	US	Safety
ANSI/CSA	ANSI/CSA CHMC 1-2014	2014 (reaffirmed 2018)	Test methods for evaluating material compatibility in compressed hydrogen applications - Metals	CAN US	Safety
ANSI/CSA	ANSI/CSA HGV 4.6-2013	2013 (reaffirmed 2018)	Manually operated valves for use in gaseous hydrogen vehicle fueling stations	CAN US	Safety
ANSI/CSA	ANSI/CSA HGV 4.7-2013	2013	Automatic valves for use in gaseous hydrogen vehicle fueling stations	CAN US	Safety
ANSI/CSA	ANSI/CSA HGV 4.8-2012	2012 (reaffirmed 2018)	Hydrogen gas vehicle fueling station compressor guidelines	CAN US	Guide
ANSI/NACE	ANSI/NACE TM0284-2016	Mar 2016	Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-induced cracking	US	Safety
AQSIQ	GB/T 26466	2011	Stationary flat steel ribbon wound vessels for storage of high pressure hydrogen	China	Safety
AQSIQ	GB/T 33291	2016	Measurement method of pressure-composition-temperature for reversible hydrogen absorption and desorption of hydrides	China	Guide
AQSIQ	GB/T 33292	2016	Metal hydride hydrogen storage system for fuel cells backup power	China	Safety
AQSIQ	GB/T 34542.1	2017	Storage and transportation systems for gaseous hydrogen—Part 1: General requirements	China	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
AQSIQ	GB/T 34583	2017	Safety technical requirements for hydrogen storage devices used in hydrogen fuelling station	China	Safety
ASME	ASME B31.12	Dec 2019	Hydrogen piping and pipelines	US	Safety
ASME	ASME BPVC	2021	Boiler and pressure vessel code	US	Safety
ASME	ASME STP-PT-006	Dec 2007	Design guidelines for hydrogen piping and pipelines	US	Guide
ASTM	ASTM B577-19	Apr 2019	Standard test methods for detection of cuprous oxide (hydrogen embrittlement susceptibility) in copper	US	Safety
ASTM	ASTM E2652-18	Dec 2018	Standard test method for assessing combustibility of materials using a tube furnace with a cone-shaped airflow stabilizer, at 750°C	US	Safety
ASTM	ASTM F1459-06	Dec 2017	Standard test method for determination of the susceptibility of metallic materials to hydrogen gas embrittlement (HGE)	US	Safety
ASTM	ASTM F1624-12	Dec 2018	Standard test method for measurement of hydrogen embrittlement threshold in steel by the incremental step loading technique	US	Safety
ASTM	ASTM F519-18	Nov 2018	Standard test method for mechanical hydrogen embrittlement evaluation of plating/coating processes and service environments	US	Safety
ASTM	ASTM G142-98	Dec 2016	Standard test method for determination of susceptibility of metals to embrittlement in hydrogen containing environments at high pressure, high temperature, or both	US	Safety
BNQ	CAN/BNQ 1784-000	May 2022	Canadian hydrogen installation code	CAN	Safety
CAGI	CAGI 3075	Jan 2011	B19.1 Safety standards for compressor systems	US	Safety
Canada	-	-	Canada transportation act (S.C. 1996, c. 10)	CAN	Act
Canada	-	-	Canadian transportation accident investigation and safety board act (S.C. 1989, c. 3)	CAN	Act
Canada	-	-	Railway safety act (R.S.C., 1985, c. 32 (4th Supp.))	CAN	Act
Canada	-	-	Transportation of dangerous goods act (S.C. 1992, c. 34)	CAN	Act
Canada	-	-	Canada labour code (R.S.C., 1985, c. L-2)	CAN	Safety
Canada	SOR/2014-233	-	Railway safety administrative monetary penalties regulations	CAN	Safety
Canada	SOR/2014-258	-	Railway operating certificate regulations	CAN	Safety
Canada	SOR/2014-275	-	Grade crossings regulations	CAN	Safety
Canada	SOR/2015-143	-	On board trains occupational safety and health regulations	CAN	Safety
Canada	SOR/2015-26	-	Railway safety management system regulations, 2015	CAN	Safety
Canada	SOR/2017-121	-	Locomotive emissions regulations	CAN	Safety
Canada	SOR/87-150	-	Railway employee qualification standards regulations	CAN	Safety
Canada	SOR/91-103	-	Notice of railway works regulations	CAN	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CEN	EN 17533: 2020	Sep 2020	Gaseous hydrogen - Cylinders and tubes for stationary storage	EU	Safety
CGA	CGA C-6.4	Oct 2012	Methods for external visual inspection of natural gas vehicle (NGV) and hydrogen gas vehicle (HGV) fuel containers and their installations	US	Safety
CGA	CGA G-5.3	Nov 2017	Commodity specification for hydrogen	US	Hydrogen quality
CGA	CGA G-5.5	Apr 2021	Standard for hydrogen vent systems	US	Safety
CGA	CGA H-3	May 2019	Standard for cryogenic hydrogen storage	US	Safety
CGA	CGA H-4	Apr 2020	Terminology associated with hydrogen fuel technologies	US	Terminology
CGA	CGA H-5	Sep 2020	Standard for bulk hydrogen supply systems (an American national standard)	US	Safety
CGA	CGA P-12	Mar 2017	Safe handling of cryogenic liquids	US	Safety
CGA	CGA P-28	Jul 2022	OSHA process safety management and EPA risk management plan guidance document for bulk liquid hydrogen supply systems	US	Safety
CGA	CGA P-41	Jun 2018	Locating bulk liquid storage systems in courts	US	Safety
CGA	CGA P-6	Oct 2012	Standard density data, atmospheric gases and hydrogen	US	Guide
CGA	CGA PS-31	Nov 2007	CGA position statement on cleanliness for proton exchange membranes hydrogen piping/components	US	Hydrogen quality
CGA	CGA PS-33	Aug 2008 (reaffirmed May 2020)	CGA position statement on use of LPG or propane tank as compressed hydrogen storage buffers	US	Safety
CGA	CGA PS-46	Apr 2017	CGA position statement on roofs over hydrogen storage systems	US	Safety
CGA	CGA PS-48	Mar 2016	CGA position statement on clarification of existing hydrogen setback distances and development of new hydrogen setback distances in NFPA 55	US	Safety
CGA	CGA S-1.1	Feb 2022	Pressure relief device standards – Part 1 – Cylinders for compressed gases	US	Safety
CGA	CGA S-1.2	Jun 2019	Pressure relief device standards – Part 2 – Portable containers for compressed gases	US	Safety
CGA	CGA S-1.3	Apr 2020	Pressure relief device standards – Part 3 – Stationary storage containers for compressed gases	US	Safety
CSA	CSA B620	2020	Highway tanks and TC portable tanks for the transportation of dangerous goods	CAN	Safety
CSA	CSA B622	2020	Selection and use of highway tanks and TC portable tanks for the transportation of dangerous goods, Class 2	CAN	Safety
CSA	CSA B625	2020	Portable tanks for the transport of dangerous goods	CAN	Safety
CSA	C22.2 No. 60529	2016 (reaffirmed 2021)	Degrees of protection provided by enclosures (IP Code) (Adopted IEC 60529:1989, edition 2:1989 consolidated with amendment 1:1999 and amendment 2:2013, with Canadian deviations)	CAN	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA	CAN/CSA 60079-2	2016 (reaffirmed 2021)	Explosive atmospheres - Part 2: Equipment protection by pressurized enclosure "p" (Adopted IEC 60079-2:2014, sixth edition, 2014-07, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-1	2016 (reaffirmed 2021)	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d" (Adopted IEC 60079-1:2014, seventh edition, 2014-06, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-11	2014 (reaffirmed 2018)	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i" (Adopted IEC 60079-11:2011, sixth edition, 2011-06, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-15	2018	Explosive atmospheres - Part 15: Equipment protection by type of protection "n" (Adopted IEC 60079-15:2017, fifth edition, 2017-12, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-25	2022	Explosive atmospheres - Part 25: Intrinsically safe electrical systems (Adopted IEC 60079-25:2020, third edition, 2020-06, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-29-1	2017 (reaffirmed 2022)	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases (Adopted IEC 60079-29-1:2016, second edition, 2016-07, with Canadian deviations)	CAN	Performance
CSA	CAN/CSA C22.2 No. 60079-29-4	2016 (reaffirmed 2021)	Explosive atmospheres - Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases (Adopted IEC 60079-29-4:2009, first edition, 2009-11, with Canadian deviations)	CAN	Performance
CSA	CAN/CSA C22.2 No. 60079-5	2016 (reaffirmed 2021)	Explosive atmospheres - Part 5: Equipment protection by powder filling "q" (Adopted IEC 60079-5:2015, fourth edition, 2015-02, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-6	2017 (reaffirmed 2022)	Explosive atmospheres - Part 6: Equipment protection by liquid immersion "o" (Adopted IEC 60079-6:2015, fourth edition, 2015-02, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 60079-7	2016 (reaffirmed 2021)	Explosive atmospheres - Part 7: Equipment protection by increased safety "e" (Adopted IEC 60079-7:2015, fifth edition, 2015-06, with Canadian deviations)	CAN	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA	CAN/CSA C22.2 No. 60335-2-34	2017	Household and similar electrical appliances - Safety - Part 2-34: Particular requirements for motor-compressors (Binational standard with UL 60335-2-34)	CAN	Safety
CSA	CAN/CSA C22.2 No. 61010-1-12	2012 (reaffirmed 2022)	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements (Tri-national standard, with UL 61010-1 and ANSI/ISA-61010-1)	CAN	Safety
CSA	CAN/CSA C22.2 No. 61508-1	2017 (reaffirmed 2022)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (Adopted IEC 61508-1:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 61508-2	2017 (reaffirmed 2022)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems (Adopted IEC 61508-2:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 61508-3	2017 (reaffirmed 2022)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 3: Software requirements (Adopted IEC 61508-3:2010, second edition, 2010-04, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA C22.2 No. 62282-2	2018	Fuel cell technologies - Part 2: Fuel cell modules (Adopted IEC 62282-2:2012, second edition, 2012-03, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA E60730-1	2015 (reaffirmed 2020)	Automatic electrical controls - Part 1: General requirements (Adopted IEC 60730-1:2013, fifth edition, 2013-11, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA E60730-2-6	2017	Automatic electrical controls - Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements (Adopted IEC 60730-2-6:2015, third edition, 2015-04, with Canadian deviations)	CAN	Safety
CSA	CAN/CSA E60730-2-9	2018	Automatic electrical controls - Part 2-9: Particular requirements for temperature sensing controls (Adopted IEC 60730-2-9:2018, edition 4:2015 consolidated with amendment 1:2018, with Canadian deviations)	CAN	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA	CAN/CSA E61959	2014 (reaffirmed 2019)	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Mechanical tests for sealed portable secondary cells and batteries (Adopted IEC 61959:2004, first edition, 2004-01, with Canadian deviations)	CAN	Safety
CSA	CSA 60079-40	2020	Explosive atmospheres - Part 40: Requirements for process sealing between flammable process fluids and electrical systems (Adopted IEC 60079-40:2015, first edition, 2015-02, with Canadian deviations)	CAN	Safety
CSA	CSA B108.1	2021	Compressed natural gas refuelling stations installation code	CAN	Safety
CSA	CSA B108.2	2021	Liquefied natural gas refuelling stations installation code	CAN	Safety
CSA	CSA B109.1	2021	Compressed natural gas vehicle installation code	CAN	Safety
CSA	CSA B109.2	2021	Liquefied natural gas vehicle installation code	CAN	Safety
CSA	CSA B401.2	2021	Propane vehicle maintenance facilities code	CAN	Safety
CSA	CSA B51	2019	Boiler, pressure vessel, and pressure piping code	CAN	Safety
CSA	CSA B51 Part 3	2019	Compressed natural gas and hydrogen refuelling station pressure piping systems and ground storage vessels		Safety
CSA	CSA B72	2020	Installation code for lightning protection systems	CAN	Safety
CSA	CSA C22.1	2021	Canadian electrical code, Part I (25th edition), Safety standard for electrical installations	CAN	Safety
CSA	CSA C22.1 - Section 18	2021	Canadian electrical code, Part I (25th edition), Safety standard for electrical installations	CAN	Safety
CSA	CSA C22.2 No. 0.17	2022	Evaluation of properties of polymeric materials	CAN	Safety
CSA	CSA C22.2 No. 0.4	2017 (reaffirmed 2022)	Bonding of electrical equipment	CAN	Safety
CSA	CSA C22.2 No. 107.1	2016 (reaffirmed 2021)	Power conversion equipment	CAN	Safety
CSA	CSA C22.2 No. 139	2019	Electrically operated valves	CAN	Safety
CSA	CSA C22.2 No. 14-18	2018	Industrial control equipment	CAN	Safety
CSA	CSA C22.2 No. 2556	2021	Wire and cable test methods (Trinational standard with NMX-J-556-ANCE-2021 and UL 2556)	CAN US MEX	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA	CSA C22.2 No. 286	2017 (reaffirmed 2022)	Industrial control panels and assemblies	CAN	Safety
CSA	CSA C22.2 No. 301	2016 (reaffirmed 2021)	Industrial electrical machinery	CAN	Safety
CSA	CSA C22.2 No. 60079-0	2019	Explosive atmospheres - Part 0: Equipment - General requirements (Adopted IEC 60079-0:2017, seventh edition, 2017-12, with Canadian deviations)	CAN	Safety
CSA	CSA C22.2 No. 60079-46	2019	Explosive atmospheres - Part 46: Equipment assemblies (Adopted IEC TS 60079-46:2017, first edition, 2017-08, with Canadian deviations)	CAN	Safety
CSA	CSA C22.2 No. 94.1	2015 (reaffirmed 2020)	Enclosures for electrical equipment, non-environmental considerations (Tri-national standard with NMX-J-235/1-ANCE-2015 and UL 50)	CAN US MEX	Safety
CSA	CSA C22.2 No. 94.2	2020	Enclosures for electrical equipment, environmental considerations (Trinational standard with NMX-J-235/2-ANCE-2020 and UL 50E)	CAN US MEX	Safety
CSA	CSA C60079-13	2019	Explosive atmospheres - Part 13: Equipment protection by pressurized room "p" and artificially ventilated room "v" (Adopted IEC 60079-13:2017, second edition, 2017-05, with Canadian deviations)	CAN	Safety
CSA	CSA C61000-3-11	2021	Electromagnetic compatibility (EMC) — Part 3-11: Limits — Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems — Equipment with rated current ≤ 75 A and subject to conditional connection (Adopted IEC 61000-3-11:2017, second edition, 2017-04, with Canadian deviations)	CAN	Safety
CSA	CSA C61000-4-1	2019	Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of the IEC 61000-4 series (Adopted IEC TR 61000-4-1:2016, first edition, 2016-04, with Canadian deviations)	CAN	Safety
CSA	CSA HPIT 2	2017 (reaffirmed 2021)	Dispensing systems and components for fueling hydrogen powered industrial trucks	CAN	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA	CSA ISO 31000	2018	Risk management – Guidelines (Adopted ISO 31000:2018, second edition, 2018-02)	CAN	Safety
CSA	CSA SPE-2.1.3	2020	Best practices for defueling, decommissioning, and disposal of compressed hydrogen gas vehicle fuel containers	CAN	Guide
CSA	CSA Z276	2022	Liquefied natural gas (LNG) - Production, storage, and handling	CAN	Safety
CSA/ANSI	CSA/ANSI CHMC 2	2019	Test methods for evaluating material compatibility in compressed hydrogen applications - Polymers	CAN US	Safety
CSA/ANSI CSA	CSA/ANSI FC 1 CSA C22.2 No. 62282-3-100	2021	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety (Adopted IEC 62282-3-100:2019, second edition, 2019-02, with Canadian and U.S. deviations)	CAN US	Safety
CSA/ANSI	CSA/ANSI FC 6	2019	Fuel cell technologies - Part 2: Fuel cell modules (Adopted IEC 62282-2:2012, second edition, 2012-03, with United States deviations)	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 2	2021	Compressed hydrogen gas vehicle fuel containers	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 3.1	2022	Fuel system components for compressed hydrogen gas powered vehicles	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.1	2020	Hydrogen-dispensing systems	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.10	2021	Standard for fittings for use in compressed gaseous hydrogen fueling stations	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.2	2022	Hoses for dispensing compressed gaseous hydrogen	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.3	2022	Test methods for hydrogen fueling parameter evaluation	CAN US	Performance
CSA/ANSI	CSA/ANSI HGV 4.4	2021	Gaseous hydrogen - Fuelling stations - Valves (Adopted ISO 19880-3:2018, first edition, 2018-06, with North American deviations)	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.5	2013	Priority and sequencing equipment for hydrogen vehicle fueling	CAN US	Safety
CSA/ANSI	CSA/ANSI HGV 4.9	2020	Hydrogen fueling stations	CAN US	Safety
CSA/ANSI	CSA/ANSI HPRD 1	2021	Thermally activated pressure relief devices for compressed hydrogen vehicle (HGV) fuel containers	CAN US	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
CSA/ANSI	CSA/ANSI LNG 3.1 – 3.19	2022	Road vehicles - Liquefied natural gas (LNG) fuel system components (series of standards)	CAN US	Safety
CSA/ANSI	CSA/ANSI LNG 4.1-2018	2018	LNG vehicle dispensing systems	CAN US	Safety
CSA/ANSI	CSA/ANSI NGV 2	2019	Compressed natural gas vehicle fuel containers	CAN US	Safety
CSA/ANSI	CSA/ANSI NGV 4.1-2018	2018	Natural gas vehicle (NGV) dispensing systems	CAN US	Safety
CSA/ANSI	CSA/ANSI NGV 4.3	2022	Temperature compensation for compressed natural gas vehicle fuelling	CAN US	Performance Safety
CSA/ANSI	CSA/ANSI NGV 4.8	2021	Natural gas vehicle fuelling station compressor packages	CAN US	Guide
CSA/ANSI	CSA/ANSI NGV 6.1	2021	Compressed natural gas (CNG) fuel storage and delivery systems for road vehicles	CAN US	Safety
CSA/ANSI	CSA/ANSI PRD 1	2020	Pressure relief devices for natural gas vehicle (NGV) fuel containers	CAN US	Safety
FRA	-	-	Federal Railroad Administration - Code of federal regulations, Title 49 - PART 179	US	Safety
FRA	-	-	Federal Railroad Administration - Code of federal regulations, Title 49 – Transportation, Volume: 4, Date: 2011-10-01, Title: Part 229 - Railroad locomotive safety standards	US	Safety
IEC	IEC 60034-1	Feb 2022	Rotating electrical machines - Part 1: Rating and performance	Intl	Safety
IEC	IEC 60079-10-1	Dec 2020	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres	Intl	Safety
IEC	IEC 60079-14	Nov 2013	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	Intl	Safety
IEC	IEC 60079-18	Aug 2017	Explosive atmospheres - Part 18: Equipment protection by encapsulation "m"	Intl	Safety
IEC	IEC 60079-26	Feb 2021	Explosive atmospheres - Part 26: Equipment with separation elements or combined levels of protection	Intl	Safety
IEC	IEC 60204-1	Oct 2016	Safety of machinery - Electrical equipment of machines - Part 1: General requirements	Intl	Safety
IEC	IEC 60695-11-10	May 2013	Fire hazard testing - Part 11-10: Test flames - 50 W horizontal and vertical flame test methods	Intl	Safety
IEC	IEC 60730-2-14	Oct 2021	Automatic electrical controls - Part 2-14: Particular requirements for electric actuators	Intl	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
IEC	IEC 60730-2-15	Aug 2017	Automatic electrical controls - Part 2-15: Particular requirements for automatic electrical air flow, water flow and water level sensing controls	Intl	Safety
IEC	IEC 60812	Aug 2018	Failure modes and effects analysis (FMEA and FMECA)	Intl	Safety
IEC	IEC 61000-3-11	Apr 2017	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection	Intl	Safety
IEC	IEC 61000-3-2	Jul 2020	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)	Intl	Safety
IEC	IEC 61000-3-3	Mar 2021	Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection	Intl	Safety
IEC	IEC 61000-6-1	Aug 2016	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments	Intl	Safety
IEC	IEC 61000-6-2	Aug 2016	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments	Intl	Safety
IEC	IEC 61000-6-3	Jul 2020	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for equipment in residential environments	Intl	Safety
IEC	IEC 61000-6-4	Feb 2018	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments	Intl	Safety
IEC	IEC 61025	Dec 2006	Fault tree analysis (FTA)	Intl	Safety
IEC	IEC 61508	Apr 2010	Functional safety of electrical/electronic/programmable electronic safety-related systems - Parts 1 to 7	Intl	Safety
IEC	IEC 61882	Mar 2016	Hazard and operability studies (HAZOP studies) - Application guide	Intl	Safety
IEC	IEC 62061	Mar 2021	Safety of machinery - Functional safety of safety-related control systems	Intl	Safety
IEC	IEC 62282-4-101	Aug 2022	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety	Intl	Safety
IEC	IEC 62282-4-102	Sep 2022	Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods	Intl	Performance
IEC	IEC 62282-5-100	Apr 2018	Fuel cell technologies - Part 5-100: Portable fuel cell power systems - Safety	Intl	Safety
IEC	IEC 62619	May 2022	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications	Intl	Safety

Organization	Code / Standard	Date	Title (and adoption notes)	Country	Application
IEC	IEC 62620	Nov 2014	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications	Intl	Safety
IEC	IEC 62660-1	Dec 2018	Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing	Intl	Safety
IEC	IEC 62660-2	Dec 2018	Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing	US	Performance Safety
IEC	IEC 62928	Dec 2017	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	Intl	Safety
IEC	IEC 63341-1	*under development	Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 1: Fuel cell system	Intl	Safety
IEC	IEC 63341-2	*under development	Railway applications - Rolling stock - Fuel cell systems for propulsion - Part 2: Hydrogen storage system	Intl	Safety
IEC	IEC TS 60079-32-1	Mar 2017	Explosive atmospheres - Part 32-1: Electrostatic hazards - guidance	Intl	Guide
IEC	IEC TS 61000-3-4	Oct 1998	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A	Intl	Safety
IEC	IEC TS 61000-3-5	Jul 2009	Electromagnetic compatibility (EMC) - Part 3-5: Limits - Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A	Intl	Safety
ISO	ISO 10439 (All Parts)	2020	Petroleum, petrochemical and natural gas industries - Axial and centrifugal compressors and expander-compressors	Intl	Safety
ISO	ISO 10440-1	Aug 2007	Petroleum, petrochemical and natural gas industries - Rotary-type positive-displacement compressors - Part 1: Process compressors	Intl	Safety
ISO	ISO 10440-2	Dec 2001 (confirmed 2020)	Petroleum and natural gas industries - Rotary-type positive-displacement compressors - Part 2: Packaged air compressors (oil-free)	Intl	Safety
ISO	ISO 10442	Dec 2002 (confirmed 2020)	Petroleum, chemical and gas service industries - Packaged, integrally geared centrifugal air compressors	Intl	Safety
ISO	ISO 11114-4	Apr 2017	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	Intl	Safety
ISO	ISO 1182	Jun 2020	Reaction to fire tests for products - Non-combustibility test	Intl	Safety

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ISO	ISO 12100	Nov 2010 (confirmed 2022)	Safety of machinery - General principles for design - Risk assessment and risk reduction	Intl	Safety
ISO	ISO 12617	Mar 2015 (confirmed 2020	Road vehicles - Liquefied natural gas (LNG) refuelling connector - 3,1 MPa connector	Intl	Safety
ISO	ISO 13631	Aug 2002 (confirmed 2020)	Petroleum and natural gas industries - Packaged reciprocating gas compressors	Intl	Safety
ISO	ISO 13707	Dec 2000 (confirmed 2020)	Petroleum and natural gas industries - Reciprocating compressors	Intl	Safety
ISO	ISO 13849-1	Dec 2015	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design	Intl	Safety
ISO	ISO 13849-2	Oct 2012 (confirmed 2018)	Safety of machinery - Safety-related parts of control systems - Part 2: Validation	Intl	Safety
ISO	ISO 13850	Nov 2015 (confirmed 2020)	Safety of machinery - Emergency stop function - Principles for design	Intl	Safety
ISO	ISO 13984	Mar 1999 (confirmed 2021)	Liquid hydrogen - Land vehicle fuelling system interface	Intl	Safety
ISO	ISO 13985	Nov 2006 (confirmed 2021)	Liquid hydrogen - Land vehicle fuel tanks	Intl	Safety
ISO	ISO 14687	Nov 2019	Hydrogen fuel quality - Product specification	Intl	Hydrogen quality
ISO	ISO 16111	Aug 2018	Transportable gas storage devices - Hydrogen absorbed in reversible metal hydride	Intl	Safety
ISO	ISO 16528-1	Aug 2007 (confirmed 2022)	Boilers and pressure vessels - Part 1: Performance requirements	Intl	Performance
ISO	ISO 17268	Feb 2020	Gaseous hydrogen land vehicle refuelling connection devices	Intl	Safety

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ISO	ISO 19078	Jan 2013 (confirmed 2018)	Gas cylinders - Inspection of the cylinder installation, and requalification of high pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles	Intl	Safety
ISO	ISO 19881	Oct 2018	Gaseous hydrogen - Land vehicle fuel containers	Intl	Safety
ISO	ISO 19882	Nov 2018	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	Intl	Safety
ISO	ISO 19887	*under development	Gaseous hydrogen - Fuel system components for hydrogen fuelled vehicles	Intl	Safety
ISO	ISO 21010	Dec 2017	Cryogenic vessels - Gas/material compatibility	Intl	Safety
ISO	ISO 21014	Aug 2022	Cryogenic vessels - Cryogenic insulation performance - Amendment 1	Intl	Performance
ISO	ISO 21028-1	Sep 2016	Cryogenic vessels - Toughness requirements for materials at cryogenic temperature - Part 1: Temperatures below -80 degrees C	Intl	Safety
ISO	ISO 23208	Apr 2017 (confirmed 2022)	Cryogenic vessels - Cleanliness for cryogenic service	Intl	Safety
ISO	ISO 23273	Jun 2013 (confirmed 2019)	Fuel cell road vehicles - Safety specifications - Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen	Intl	Safety
ISO	ISO 26142	Jun 2010 (confirmed 2021)	Hydrogen detection apparatus - Stationary applications	Intl	Performance
ISO	ISO 4126-1	Jul 2013 (confirmed 2019)	Safety devices for protection against excessive pressure - Part 1: Safety valves	Intl	Safety
ISO	ISO 4414	Nov 2010 (confirmed 2021)	Pneumatic fluid power - General rules and safety requirements for systems and their components	Intl	Safety
ISO	ISO 5388	Aug 1981 (confirmed 2021)	Stationary air compressors - Safety rules and code of practice	Intl	Safety
ISO	ISO 6469-1	Apr 2019	Electrically propelled road vehicles - Safety specifications - Part 1: Rechargeable energy storage system (RESS)	Intl	Safety
ISO	ISO 6469-2	May 2022	Electrically propelled road vehicles - Safety specifications - Part 2: Vehicle operational safety	Intl	Safety
ISO	ISO 6469-3	Oct 2021	Electrically propelled road vehicles - Safety specifications - Part 3: Electrical safety	Intl	Safety

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ISO	ISO/TR 15916	2015	Basic considerations for the safety of hydrogen systems	Intl	Guide
JSA	JIS H 7003	Jun 2007 (confirmed Oct 2021)	Glossary of terms used in hydrogen absorbing alloys	Japan	Terminology
JSA	JIS H 7201	Jun 2007 (confirmed Oct 2021)	Method for measurement of pressure-composition-temperature (PCT) relations of hydrogen absorbing alloys	Japan	Guide
JSA	JIS H 7202	Jun 2007 (confirmed Oct 2022)	Method for measurement of hydrogen absorption/desorption reaction rate of hydrogen absorbing alloys	Japan	Guide
JSA	JIS H 7203	Jun 2007 (confirmed Oct 2021)	Method for measurement of hydrogen absorption/desorption cycle characteristic of hydrogen absorbing alloys	Japan	Guide
NFPA	NFPA 2	2020	Hydrogen technologies code	US	Safety
NFPA	NFPA 274	2018	Standard test method to evaluate fire performance characteristics of pipe insulation	US	Safety
NFPA	NFPA 57	2002	Liquefied natural gas (LNG) vehicular fuel systems code	US	Safety
NFPA	NFPA 70 - Article 692	2023	National electrical code - Fuel cell systems	US	Safety
NFPA	NFPA 77	2019	Recommended practice on static electricity	US	Safety
NRC	-	2020	National building code of Canada	CAN	Safety
NRC	-	2020	National fire code of Canada	CAN	Safety
OIML	OIML R 139-1	2014	Compressed gaseous fuel measuring systems for vehicles – Part 1: Metrological and technical requirements	Intl	Performance
OIML	OIML R 139-2	2014	Compressed gaseous fuel measuring systems for vehicles – Part 2: Metrological controls and performance tests	Intl	Performance
OIML	OIML R 81	1998	Dynamic measuring devices and systems for cryogenic liquids	Intl	Performance
RTCA	RTCA DO 311	Dec 2017	Minimum operational performance standards for rechargeable lithium batteries and battery systems	US	Safety
SAE	SAE J1616	Mar 2017	Recommended practice for compressed natural gas vehicle fuel	US	Recommended practice
SAE	SAE J1739	Jan 2021	Potential failure mode and effects analysis (FMEA) including design FMEA, supplemental FMEA-MSR, and process FMEA	US	Safety
SAE	SAE J1766	Jan 2014	Recommended practice for electric, fuel cell and hybrid electric vehicle crash integrity testing	US	Safety

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SAE	SAE J1798	Nov 2019	Recommended practice for performance rating of electric vehicle battery modules	US	Recommended practice
SAE	SAE J2344	Oct 2020	Guidelines for electric vehicle safety	US	Safety
SAE	SAE J2380	Dec 2021	Vibration testing of electric vehicle batteries	US	Recommended practice
SAE	SAE J2464	Aug 2021	Electric and hybrid electric vehicle rechargeable energy storage system (RESS) safety and abuse testing	US	Recommended practice
SAE	SAE J2578	Aug 2014	Recommended practice for general fuel cell vehicle safety	US	Recommended practice
SAE	SAE J2579	Jun 2018	Standard for fuel systems in fuel cell and other hydrogen vehicles	US	Safety
SAE	SAE J2600	Oct 2015	Compressed hydrogen surface vehicle fueling connection devices	US	Safety
SAE	SAE J2601	May 2020	Fueling protocols for light duty gaseous hydrogen surface vehicles	US	Safety
SAE	SAE J2615	Oct 2011	Testing performance of fuel cell systems for automotive applications	US	Performance
SAE	SAE J2617	Aug 2011	Recommended practice for testing performance of PEM fuel cell stack sub-system for automotive applications	US	Performance
SAE	SAE J2719	Mar 2020	Hydrogen fuel quality for fuel cell vehicles	US	Hydrogen quality
SAE	SAE J2799	Dec 2019	Hydrogen surface vehicle to station communications hardware and software	US	Safety
SAE	SAE J2929	Feb 2013	Safety standard for electric and hybrid vehicle propulsion battery systems utilizing lithium-based rechargeable cells	US	Safety
SAE	SAE J3121	Feb 2022	Hydrogen vehicle crash test lab safety guidelines	US	Guide
TC	-	May 2022	Railway locomotive inspection and safety rules	CAN	Safety
TC	-	May 2022	Canadian rail operating rules (CROR)	CAN	Safety
TC	SOR 2017-137		Consolidated transportation of dangerous goods regulations	CAN	Safety
TC	TP 14877E	Jan 2018	Containers for transport of dangerous goods by rail	CAN	Safety
UL	UL 1642	Sep 2020	Lithium batteries	US	Safety
UL	UL 1973	Feb 2022	ANSI/CAN/UL Batteries for use in stationary and motive auxiliary power applications	CAN US	Safety
UL	UL 1998	Dec 2013	Standard for software in programmable components	US	Safety
UL	UL 2017	Dec 2008	Standard for general-purpose signaling devices and systems	US	Safety
UL	UL 2075	Mar 2013	Gas and vapor detectors and sensors	US	Performance
UL	UL 2267	Mar 2020	Standard for fuel cell power systems for installation in industrial electric trucks	US	Safety
UL	UL 583	Aug 2012	Electric-battery-powered industrial trucks	US	Safety
UL	UL 746C	Feb 2018	Polymeric materials - Use in electrical equipment evaluations	US	Safety
UL	UL 864	Dec 2014	Standard for control units and accessories for fire alarm systems	US	Safety

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UL	UL 94	Mar 2013	Tests for flammability of plastic materials for parts in devices and appliances	US	Safety
UL	UL 991	Oct 2004	Standard for tests for safety-related controls employing solid-state devices	US	Safety
ULC	ULC 2271	Sep 2018	Batteries for use in light electric vehicle (LEV) applications	US	Safety
ULC	ULC 2580	Mar 2020	Batteries for use in electric vehicles	US	Safety