NRCan Hydrogen Codes and Standards Gap Analysis Project

(NRCan H2 CSGA)

Prepared for: NRCan

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LIST OF ACRONYMS

CTL	Certification Testing Laboratory
DUT	Device Under Test
EN	European Standards
IR	Infrared
K	Degree Kelvin
NFPA	National Fire Protection Association
Non-OEM Components	Components (e.g., batteries) manufactured by independent third party manufacturers intended to be used within OEM equipment.
OCV	Open Circuit Voltage
OEM	Original Equipment Manufacturer
PID	Proportional–Integral–Derivative Controller
SAE	Society of Automotive Engineers
SMD	Surface Mount Devices
SOC	State of Charge
UN	United Nations

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EXECUTIVE SUMMARY

This document was generated as an output for an NRC project that supports the deployment of Canada's Hydrogen Strategy for Canada, which provides sector-wide theme recommendations applicable to eight pillars. This report specifically falls under the fourth pillar related to codes and standards, and it proposes updating existing codes and standards and creating new codes and standards to keep up with industry innovation and remove barriers to the deployment of hydrogen in Canada's economic sectors.

This project aims at addressing gaps in codes, standards and ultimately regulations along the hydrogen value chain in support of the deployment of the Hydrogen Strategy for Canada. A thorough codes, standards and regulations (CSR) study of the entire hydrogen value chain is required to ensure all hydrogen issues are addressed appropriately and to ensure acceptance by the Authorities Having Jurisdiction (AHJ), a critical step for the deployment of hydrogen hubs as the first phase of the strategy deployment. In addition, a mapping of the existing codes and standards relevant to the hydrogen value chain is needed to identify the prioritized gaps to address.

A goal of this project is to develop an effective method to classify, organize, and display the very vast amount of CSR-related information gathered throughout the project; this will result in easier dissemination of the information to the wide range of hydrogen stakeholders. The long-term government objective is to de-risk hydrogen technologies to allow the AHJs, manufacturers, installers, integrators and all hydrogen stakeholders to have a clear understanding of the relevant Codes, Standards, and Regulations that hydrogen installations need to comply with to appropriately address hazards and ensure the safe deployment of the different technologies.

Since the process to create standards requires balanced committees that include industrial stakeholders with the required experience, standards cannot be created without participation from industry. For this reason, a main task in this project is to understand the industrial representation in the Canadian hydrogen value chain.

To obtain feedback from Canadian hydrogen companies, a questionnaire was developed and issued to 16 companies. A gap analysis of the hydrogen CSRs was performed with stakeholder input, which resulted in the following recommendations:

Codes/standards:

- Provide prescriptive requirements for area classification in the CAN/BNQ code.
- Develop appliance standards and reference them in the CAN/BNQ code.
- Develop a hydrogen facilities design and installation standard for generation/utilization and liquefaction facilities that are outside the scope of the CAN/BNQ standards.
- Develop new standards for field approval of fuel-burning appliances and equipment and include hydrogen generation and utilization equipment.

- Increase the 21 kg/h hydrogen generation/utilization limit and define industrial installation in the CAN/BNQ hydrogen installation.
- Expand the CAN/BNQ to include liquid fueling facilities and adopt the CAN/BNQ code in the building and fire codes.

Regulations (All of Canada):

- Adopt standards for hydrogen equipment, hydrogen installations, hydrogen appliances, as they become available.
- Develop regulations for hydrogen generation and liquefaction facilities.
- Adopt the BNQ standard for hydrogen installations.
- Develop a common approach for permitting throughout Canada for truck conversions, repair garage upgrades, fueling stations, and hydrogen generating and utilization installations.
- Establish training/certification requirements for hydrogen installations and dual fuel truck conversions.

Following this phase of the project, a roadmap will be established in subsequent years to address the identified gaps and define the required adjustments to regulations through engagement with relevant federal labs as well as with the AHJs.

1. INTRODUCTION

CODES, STANDARDS AND REGULATIONS

Standards can be defined as a set of technical definitions and guidelines – or simply a “how-to” set of instructions for designers and manufacturers. Many types of standards exist today and, according to the Standards Council of Canada, include categories such as:

- **Performance standards** test products by simulating their performance under actual service conditions.
- **Prescriptive standards** identify product characteristics, such as material thickness, type, and dimension.
- **Design standards** identify specific design or technical characteristics of a product.
- **Management system standards** define and establish an organization’s quality policy and objective.
- **Service standards** specify the requirements that are to be fulfilled by a service and establish its fitness for purpose. Service standards may be prepared in fields such as laundering, hotel-keeping, transportation, car-servicing, telecommunications, trading, and insurance and banking.

Standards

Standards outline all the necessary requirements for a product, service, or operation. An engineer will use standards to design a product while a production facility will use different standards to manufacture the product. Standards serve as a common language for defining quality and establishing safety criteria. CSA, UL, ASTM, ISO are some examples of standards. Standards consist of a set of technical requirements written by balanced committee experts and are intended to be used to meet safety objectives. Standards help industrial development and can be used to harmonize practices across borders to ensure the success of a sector utilizing hydrogen technology for different global applications such as mobility and power-to-gas [1] enabling specialized products or services to be manufactured, implemented and sold around the world.

Codes

Codes result when standards are adopted by authorities having jurisdiction (AHJ) (federal/provincial/municipal government) and become legally enforceable thereafter – a standard then must be followed (a standard document may then become a code, or an existing code may reference a standard). CSA codes are legally enforceable in many Canadian provinces as well as internationally, usually with deviations. If a code has not been adopted as law by a regulatory body, then it will serve as a generally accepted guideline for design, fabrication, construction, installation, etc. – a voluntary standard that may be followed to meet customer or industry demands. Codes provide a set of rules that specify the minimum acceptable level of safety and quality. They tend to be broad in scope but may also reference other standards or specifications for further details or additional requirements that are not specified in the code.

Regulations

Regulations are compulsory legal restrictions to meet safety objectives, which can adversely affect growth and productivity [1]. They are statutory instruments governments employ to establish rules and guidelines in order to protect the health, safety and environment of their citizens or to ensure fair trade. Regulations can incorporate codes and standards or be created independently. Unlike codes and standards, regulations do not require stakeholder consensus to be put into effect.

DEVELOPING NATIONAL STANDARDS FOR CANADA

Canadian standards are developed by applying international standard development best practices and prioritizing Canada's interests. Standards may be developed nationally or may be international standard adoptions with Canadian deviations as required. Standards are developed by accredited Standards Development Organizations (SDOs) such as CSA, BNQ and UL. The SDOs must ensure appropriate funding, committee assembly and timing. The initial steps to develop standards include [2]:

- Identifying the need for the standard
- Reviewing the existing standards landscape
- Engaging affected stakeholders
- Notifying the public at the project start
- Developing the standard (by technical experts)

To be recognized as a national standard of Canada, the standard must be developed in accordance with the Requirements & Guidance – Accreditation of Standards Development Organizations [2].

This project aims to facilitate the hydrogen standards creation process by identifying the need for the standard, reviewing the existing standards landscape, and engaging the affected stakeholders such as government, AHJs, and industry.

Standards Council of Canada's (SCC) accreditation of SDOs include [3]:

- Standards development by consensus by a balanced committee of stakeholders
- Public scrutiny
- Consistency with (or incorporating) existing international and pertinent foreign standards

The stakeholder categories for international standards (balanced committee) include:

- Industry and commerce
- Government and authorities having jurisdiction
- Consumer and public interest

- Academic and research bodies
- Standards development organizations [3]

It is important to note that the process to create standards requires balanced committees that include industrial stakeholders with the required experience. In other words, standards cannot be created without participation from industry. For this reason, it is very important to understand the industrial representation of the Canadian hydrogen value chain.

The work under this project supports Canada's Hydrogen Strategy for Canada, which provides sector-wide theme recommendations applicable to eight pillars. The theme of the fourth pillar is codes and standards, and it proposes updating existing codes and standards and creating new codes and standards to keep up with industry innovation and remove barriers [4].

2 BACKGROUND

2.1. Project Objective

This project aims at identifying and addressing gaps in codes, standards and ultimately regulations along the hydrogen value chain in support of the deployment of the Hydrogen Strategy for Canada. A thorough codes, standards and regulations study of the entire hydrogen value chain is required to ensure all hydrogen issues are addressed appropriately and to ensure acceptance by the Authorities Having Jurisdiction (AHJ), a critical step for the deployment of hydrogen hubs as the first phase of the strategy deployment.

Specifically, the deliverable for the first year of this project is a mapping of the existing codes and standards relevant to the hydrogen value chain along with an identification of gaps to address. In parallel, CSA (Canadian Standards Association) will be engaged to ensure alignment of the complementary efforts including prioritization. This will help focus on segments of the value chain in which early deployment of hydrogen technologies is needed. Active participation in the SCC codes and standards working group[1] will be required to receive feedback on the work performed. This work is required to ensure all hydrogen issues are addressed appropriately.

Following the prioritization exercise (and beyond the scope of the current project), a roadmap will be established in subsequent years to address the identified gaps and define the required adjustments to regulations through engagement with relevant federal labs as well as with the Authorities Having Jurisdiction (AJH).

The long-term government objective is to de-risk hydrogen technologies to allow the AHJs, manufacturers, installers, integrators and all hydrogen stakeholders to have a clear understanding of the relevant Codes, Standards, and Regulations (CSR) that hydrogen installations need to comply with to appropriately address hazards and ensure the safe deployment of the different technologies. This project aims to initiate the work to eventually meet the long-term objective which includes the following:

- understanding the Canadian industry participation in the hydrogen value chain;
- informing all stakeholders of the gaps in CSRs that cover different hydrogen technologies and components and to make recommendations to address those gaps; and
- understanding CSR gaps in Canada and gaining insight to prioritize the development of hydrogen CSRs for the Canadian industry along the value chain.

[1] The SCC codes and standards working group is being led by SCC and NRCan staff. The goal of this working group is to gather inclusive and diverse groups of stakeholders across various sectors to articulate the sector needs, coordinate standardization activity and identify path forward across the Canadian ecosystem via a published roadmap. This working group consists of more than 200 participants who are tasked with identifying in the roadmap existing codes, standards, and regulatory solutions, gaps and priorities.

One of the goals of this project is to develop an effective method to classify, organize, and display the very vast amount of CSR-related information gathered throughout the project; this will result in easier dissemination of the information to the wide range of hydrogen stakeholders.

2.2. Tasks

The project tasks include the following:

1. Defining the Canadian hydrogen value chain. This includes identifying, classifying and organizing the different parts of the hydrogen value chain.

2. Identifying the most active Canadian value chain elements (in terms of the number of companies active in Canada) and priorities.

3. Selecting areas that will be covered in this study.

4. Mapping the existing codes, standards and regulations against the hydrogen value chain.

5. Selecting the hydrogen value chain elements that will be analyzed in more detail based on the results of 2 and 3.

6. Identifying and describing gaps in the chosen hydrogen value chain for industry to take action.

7. Proposing priorities.

8. Proposing recommendations for next steps to meet the long-term project objective as described above.

9. Engaging with NRCan personnel, the NRCan H2 standards working group, SDOs (e.g., CSA, BNQ), CanmetENERGY, CanmetMINING, gas suppliers (e.g., Linde, Air Liquide), and hydrogen experts to ensure alignment of their respective efforts including prioritization.

10. Disseminating results:

    a. Writing a comprehensive report

    b. Presenting project overview and key results

    c. Sharing the gathered information with the Canadian hydrogen value chain stakeholders

3. HYDROGEN VALUE CHAIN DESCRIPTION

One of the goals of this project is to develop an effective method to classify, organize, and display the vast amount of CSR-related information gathered throughout the project to facilitate dissemination of the information to the hydrogen stakeholders.

Classification of the Canadian hydrogen value chain requires first defining what it actually is; this means deciding on its boundaries, the appropriate level of granularity, how it should be organized, and how the information should be displayed. To define the Canadian hydrogen value chain, the NRC examined the different ways other bodies including NRCan, CSA, and the SCC had described it in publications or on their websites. It was essential that the Canadian hydrogen value chain is defined in a way that aligns with the goals and objectives of the project.

It was decided that the Canadian hydrogen value chain should include all viable parts of the hydrogen value chain from production to end use because these parts have the potential to prosper in Canada. Including all these parts of the chain makes the scope very large; therefore, elements related to the energy source required to produce the hydrogen were not included. The NRC is participating in a related NRCan project titled "Life cycle assessment of hydrogen production pathways in Canada[2]"; in that project, the source of energy used to produce the hydrogen is included in the analysis.

The Canadian hydrogen value chain was divided into the following four segments which correspond with the hydrogen lifecycle:

1. Production and purification
2. Storage, conversion, and liquefaction
3. Distribution transportation
4. Dispensing and end use

Figure 1 below illustrates the four segments, which are a high-level representation of the Canadian hydrogen value chain.

[2] Project Code NRC-21-301.

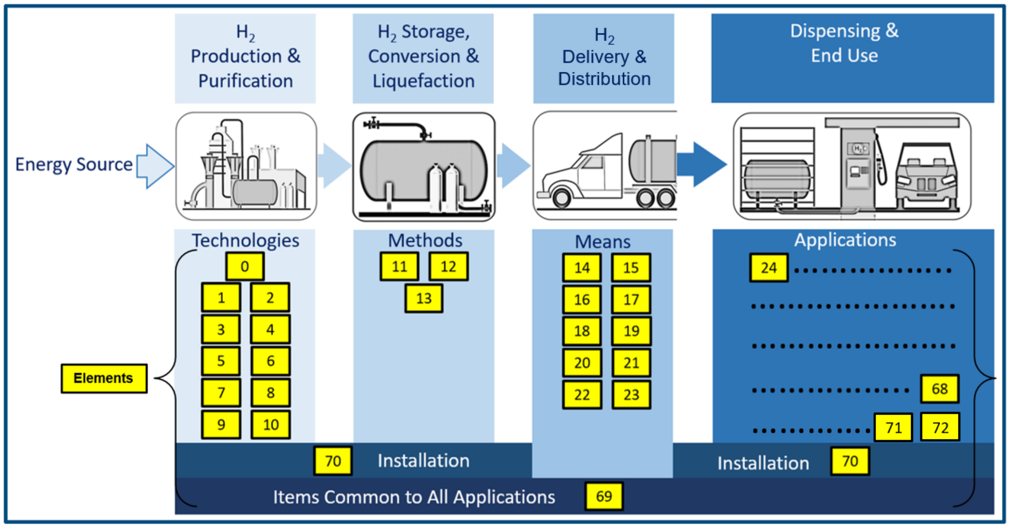


Figure 1: Visual representation of the four hydrogen value chain segments.

Within each of the four segments, elements relating to different technologies, methods, means, and applications were assigned with sufficient commonalities to be classified in the same segment. Each element was numbered and is represented by the yellow squares in Figure 1. As can be seen in the figure, the production technologies are classified into 11 elements, the storage segment is divided into 3 elements, the hydrogen transportation segment is divided into 10 elements, and the dispensing and end use segment is divided into 45 elements. In addition, there are cross-cutting elements that are relevant to all hydrogen technologies such as material compatibility, pressure vessels, and others; these are all included in element 69. There are also elements applicable to all stationary or portable installations such as installation codes, electrical codes, plumbing codes, etc.; these are included in element 70.

Figure 2 below illustrates details of the elements included in the first two segments (hydrogen production and purification; and storage, conversion and liquefaction). As can be seen in the figure, the 10 elements for hydrogen production pictorially represented include the following:

1. Electrolysis (centralized or decentralized)
2. Electrolysis (offshore)
3. Natural gas reforming
4. Biomass gasification
5. Biomass-derived liquid reforming

6. Refined industrial waste

7. Solar thermochemical hydrogen

8. Photo-electrochemical hydrogen production

9. Microbial biomass conversion and photo-biological

10. Accelerated carbon transition (ACT)

Electrolysis was divided into two elements because the authorities having jurisdiction are expected to be different for land and sea installations.

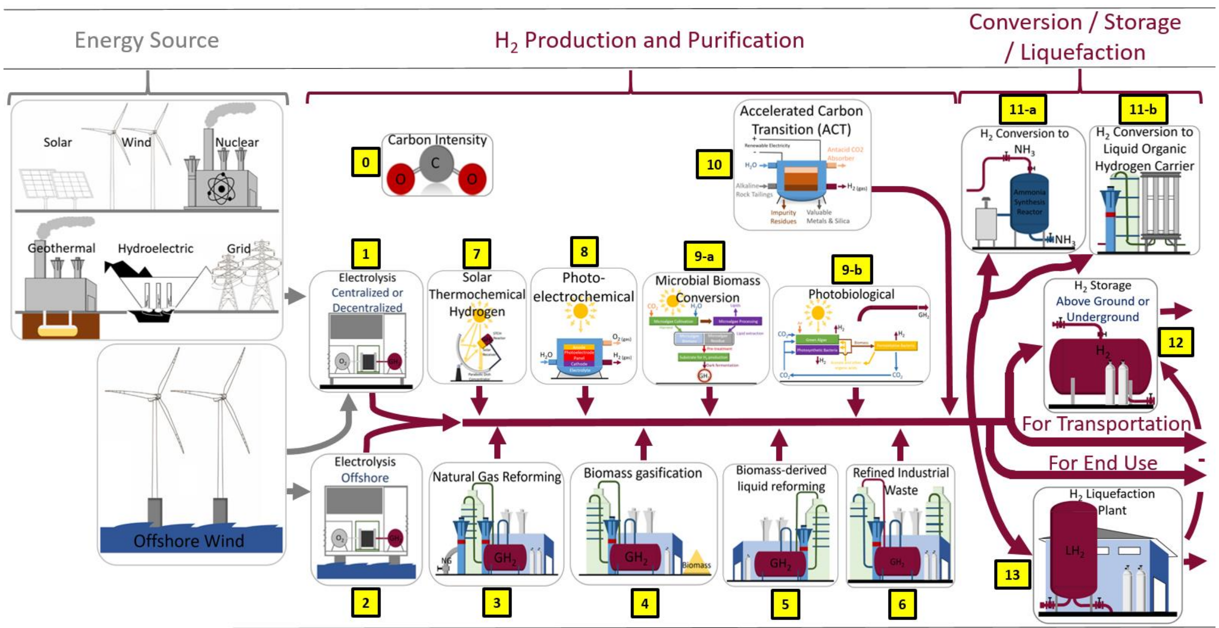


Figure 2: Elements of the hydrogen production and purification; and storage, conversion, and liquefaction segments.

An important aspect of this value chain categorization is the carbon intensity associated with each element, which is represented by the element 0 (Carbon intensity). Element 11 involves the conversion of hydrogen into ammonia (11-a) or liquid organic hydrogen carriers (11-b) for transportation (distribution) purposes. Element 12 includes above ground and below ground storage as well as liquid hydrogen storage. Element 13 includes hydrogen liquefaction systems. After the hydrogen is liquefied it may be stored, meaning it would be represented by element 12. If the hydrogen production process is located at the user's site, then it may be used directly and remains within element 12.

The burgundy lines in Figure 2 represent the flow of hydrogen flow from left to right. As can be seen, the purple lines continue to the right either for hydrogen to be transported for distribution (this segment is further described in Figure 3) or for end use (in the case where the hydrogen production is located at the end-use site).

There are 72 elements in total, each of which are pictorially represented and described in more detail, including the technologies they comprise, in Annex G (Canadian Hydrogen Value Chain Element Details). Some elements have sub-categories, for example, element 3 for natural gas reforming includes:

- Natural gas reforming
- Hydrogen extraction -in-situ well gasification
- Methane pyrolysis

Element 4 for biomass gasification includes:

- Wood
- Organic waste
- Land fill

Element 5 for Biomass-derived liquid reforming includes:

- Biomass-derived liquid reforming
- Extracting hydrogen from bio-ethanol alcohol production
- Methanol fuel cell power plants

Element 12 for hydrogen storage (above ground or underground) includes:

- GH2 storage
- LH2 storage
- Solid state storage
- Underground well and salt cavern storage
- Compression stations and compressors

Figure 3 below illustrates the hydrogen transportation and distribution segment in greater detail. As can be seen from this figure, all 10 elements for hydrogen transportation and distribution are pictorially represented and include the following:

14. Transportation of converted hydrogen by truck
    a. Ammonia
    b. Liquid organic hydrogen carrier
15. Transportation of converted hydrogen by ship
    a. Ammonia
    b. Liquid organic hydrogen carrier
16. Converted hydrogen transportation by rail[3]
    a. Ammonia
    b. Liquid organic hydrogen carrier
17. Gaseous hydrogen transportation by rail
18. Gaseous hydrogen transportation by truck
19. Gaseous hydrogen distribution by pipeline
20. Gaseous hydrogen pressure reduction station
21. Liquid hydrogen transportation by ship
22. Liquid hydrogen transportation by truck
23. Liquid hydrogen transportation by train

[3] Hydrogen is not expected to be distributed and delivered by air.

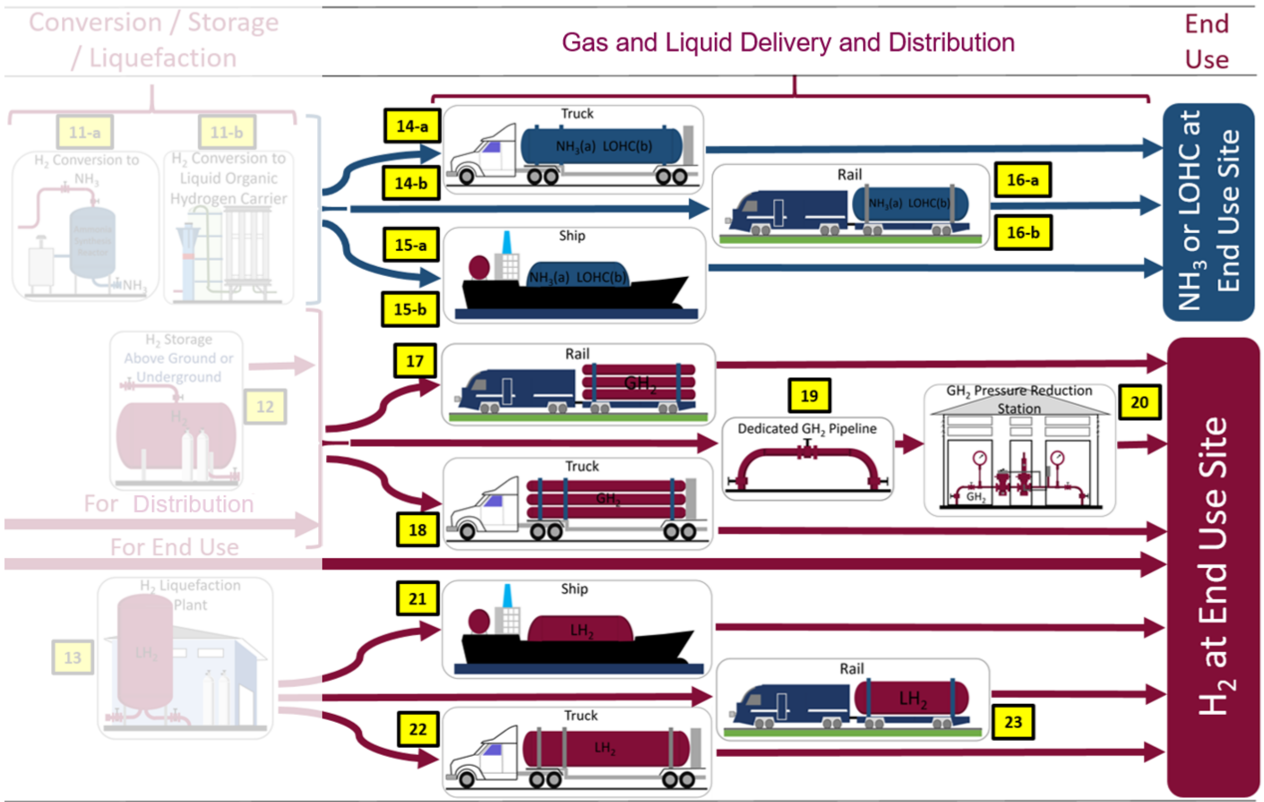


Figure 3: Hydrogen transportation and distribution segment details.

The next step after the hydrogen is transported or distributed to the end site is dispensing and end use, as partially shown in Figure 4 below.

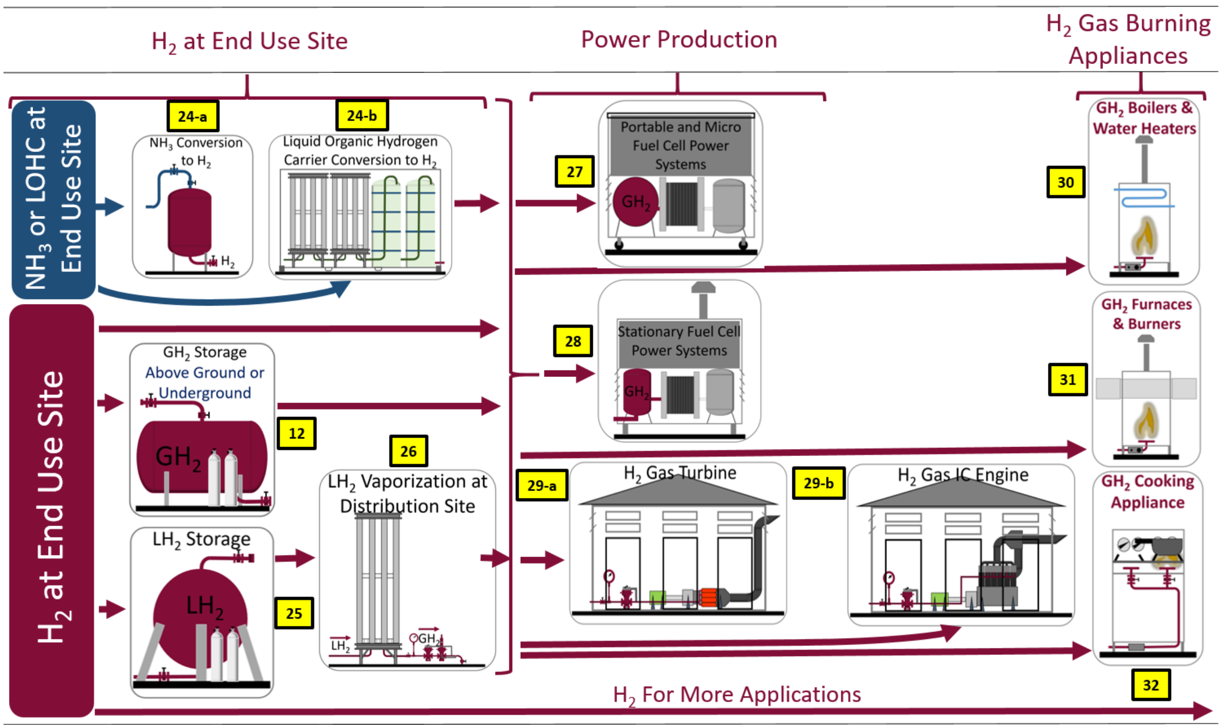


Figure 4: End-use segment - power production and heating appliances.

The end-use segment includes on site storage elements as follows:

12. On site gaseous hydrogen storage
24. Conversion back to hydrogen from
    a. Ammonia
    b. Liquid organic hydrogen carrier
25. On site liquid hydrogen storage
26. Hydrogen vaporization at distribution site

The end-use segment also includes the power production sub-segment as follows:

27. Portable fuel cell power system
28. Stationary fuel cell power system
29. Combustion

a. Gas turbines

b. IC engines

The end-use segment also includes the hydrogen gas burning appliance sub-segment as follows:

30. Boilers and water heaters

31. Furnaces and burners

32. Cooking appliances.

The water heater element (30) includes:

- Hot water tank heaters
- Instantaneous tankless water heaters
- Pool heaters
- Boilers
- Industrial water heaters

Figure 5 below illustrates the dispensing and end use segment for land transportation in more detail. This segment also includes hydrogen for mobility and materials handling. Hydrogen dispensing was divided into 3 elements for each mode as follows:

43. Light-duty dispensers

    a. Permanently installed dispensers

    b. Portable dispensers

44. Medium-duty dispensers

    a. Permanently installed dispensers

    b. Portable dispensers

    c. LH2 dispensers

    d. GH2 dispensers

45. Heavy-duty dispensers

a. Permanently installed dispensers

b. Portable dispensers

c. LH2 dispensers

d. GH2 dispensers

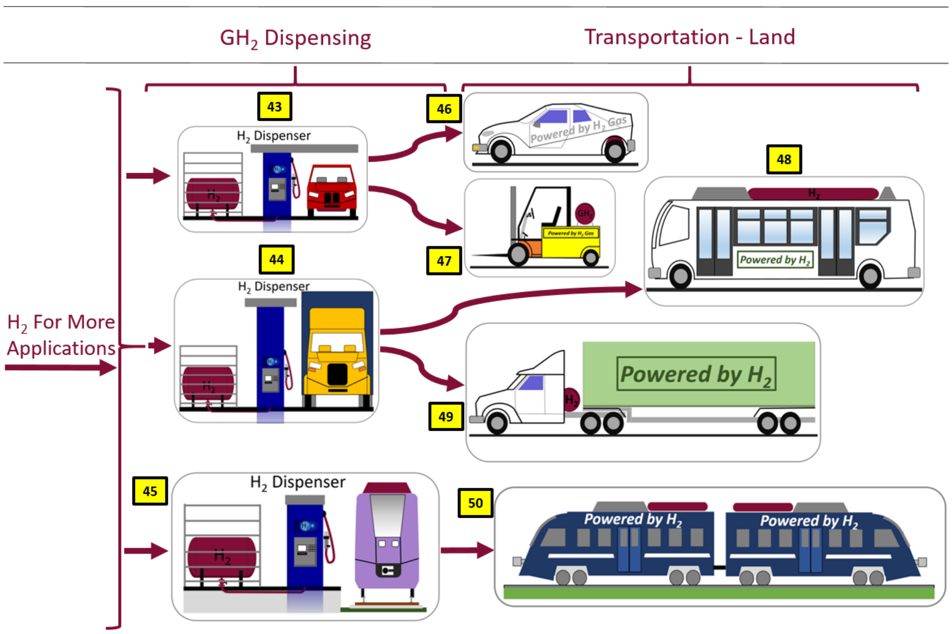


Figure 5: Dispensing and end-use segment - land transportation.

Element 46 for vehicles includes:

- Cars
- SUV
- Utility vehicles
- Off-road vehicles
- Ice resurfacers

Element 47 for material handling includes all applications (retail, ports, and airports). Element 48 includes buses that use gaseous or liquid hydrogen fuel. Element 49 includes trucks that use gaseous or liquid hydrogen fuel. Element 50 includes:

- LH2trains
- GH2trains
- Passenger trains
- Freight trains
- Switcher locomotives

Figure 6 below illustrates the dispensing and end-use segment for air and water transportation in more detail. Hydrogen dispensing was divided into 3 elements for each mode as follows:

51. Marine dispensers
    a. Permanently installed dispensers
    b. Portable dispensers
    c. LH2 dispensers
    d. GH2 dispensers
52. Dispensers for airborne applications
    a. Permanently installed dispensers
    b. Portable dispensers
    c. LH2 dispensers
    d. GH2 dispensers
53. Dispensers for unmanned aerial vehicles
    a. Permanently installed dispensers
    b. Portable dispensers
    c. LH2 dispensers
    d. GH2 dispensers

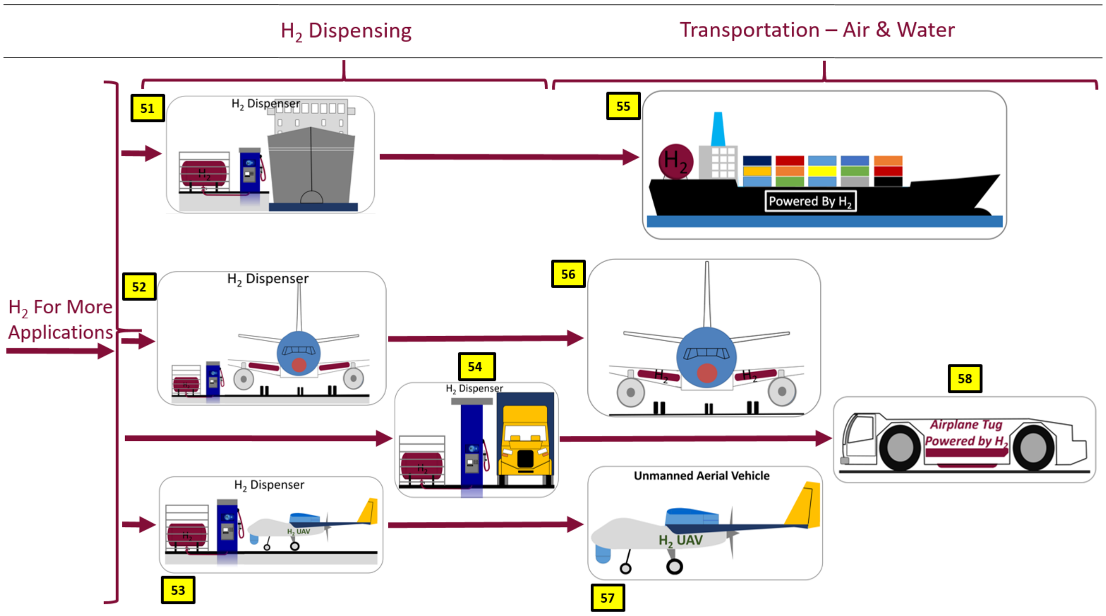


Figure 6: Dispensing and end use segment - air and water transportation.

Element 55 for marine applications includes:

- LH2 marine
- GH2 marine
- Ships
- Tug boats
- Boats
- Submarines
- Unmanned marine vehicles

Element 56 for airborne applications includes:

- LH2airplanes
- GH2airplanes
- Rigid blimps

- Dirigibles
- Helicopters

Element 57 for UAVs includes drones, airplanes, and helicopters that use gaseous or liquid hydrogen fuel. Element 58 for airport vehicles and ground equipment includes:

- LH2 airport vehicles and ground equipment
- GH2 airport vehicles and ground equipment
- Airplane tugs
- Airplane ground power units (GPUs)
- Airport trucks
- Airport luggage handling trucks

Figure 7 below illustrates the dispensing and end-use segment for mining hydrogen dispensing, stationary power generation, and mining operations (on the surface and below ground).

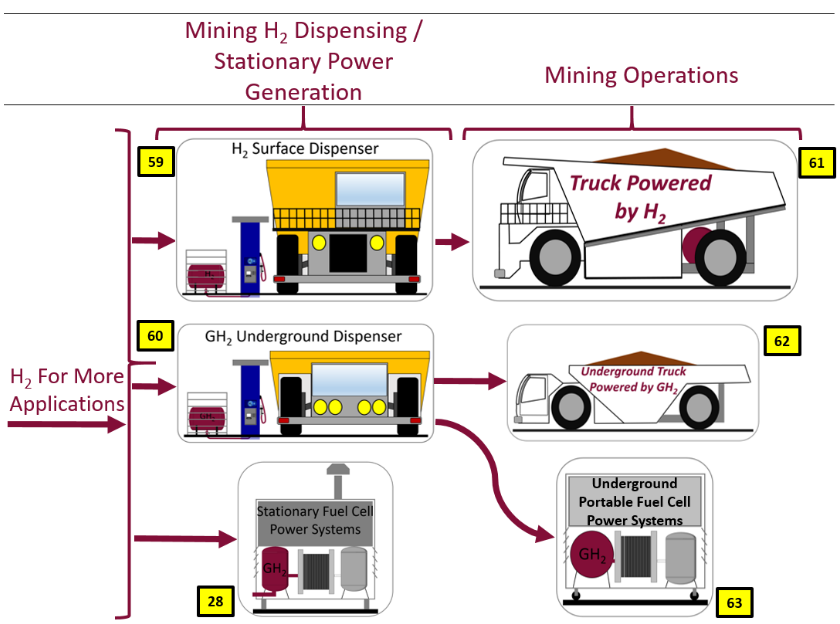


Figure 7: Dispensing and end use segment - mining dispensing, power generation and operations.

Elements 59 and 60 include liquid and gaseous hydrogen dispensers. Element 62 includes underground trucks and locomotives.

Figure 8 below illustrates the dispensing and end use segment for industrial use in more detail.

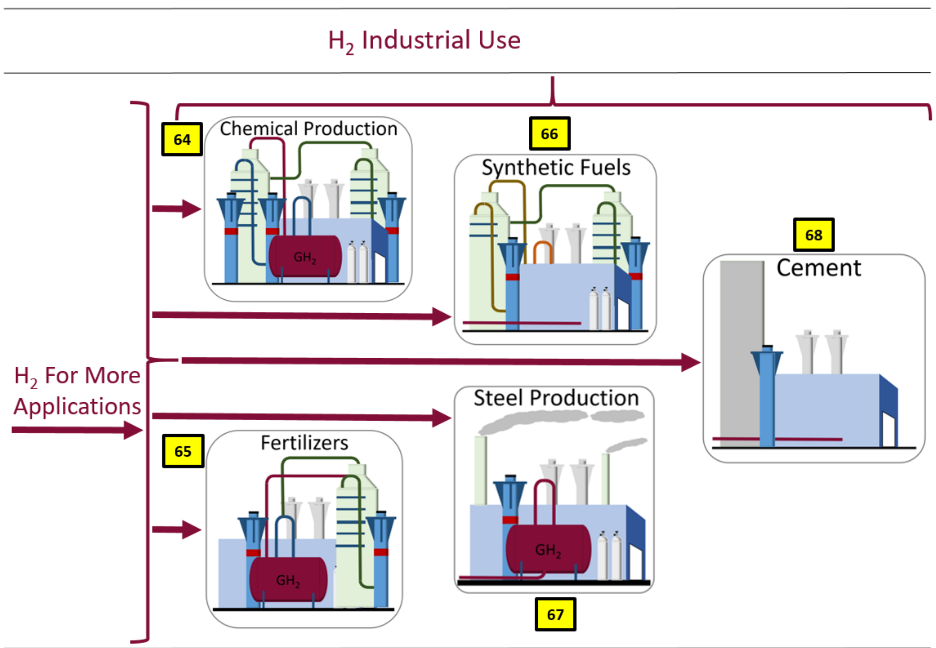


Figure 8: Dispensing and end use segment – industrial use.

Figure 9 below illustrates the dispensing and end use segment for hydrogen injection into the natural gas line in more detail.

As discussed earlier, the purple lines shown in Figures 2–8 represent hydrogen and continue to the right for other end uses. The concept is to include all of the segments and elements on a single drawing, with the purple lines helping to determine how to put everything together (similar to assembling a puzzle). The ultimate goal is to create a user-friendly website that displays the complete drawing of the Canadian hydrogen value chain with the ability to enlarge the drawing so that users can focus on their areas of interest. The website would allow users to click on the diagram to access detailed information about each elements related to available CSRs, gaps, and Canadian industrial representation.

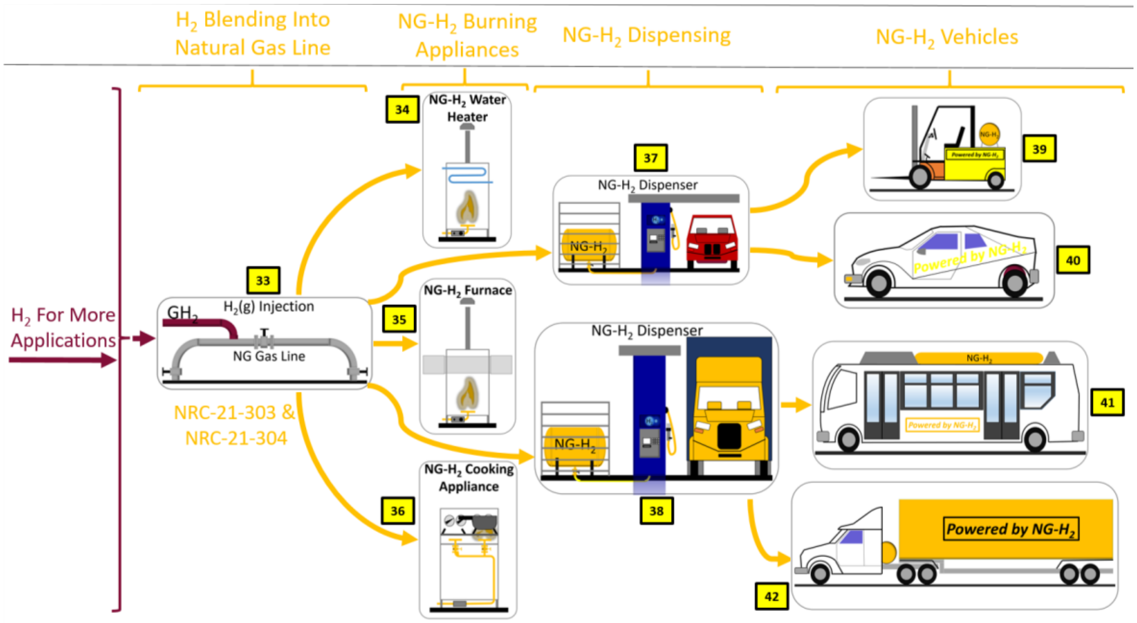


Figure 9: Dispensing and end use segment – hydrogen injection into the natural gas line.

In Figure 9, the yellow lines denote the flow of natural gas/hydrogen blend. Gas burning appliances are represented by 3 elements: water heaters, furnaces, and cooking appliances (34, 35 and 36). The water heater element (34) includes:

- Hot water tank heaters
- Instantaneous tankless water heaters
- Pool heaters
- Boilers
- Industrial water heaters

Element 35 includes furnaces and gas fire fireplace heaters.

Light and medium duty dispensing was included in this segment as well as transportation by land and forklifts (elements 39-42).

Figure 10 below illustrates the renewable energy power-to-gas system. This system has elements from the hydrogen production and purification segments, hydrogen storage conversion and liquefaction segment as well as from the dispensing and end use segment. This system will be outlined in the overall chart and will be linked to the hydrogen blending into the natural gas line.

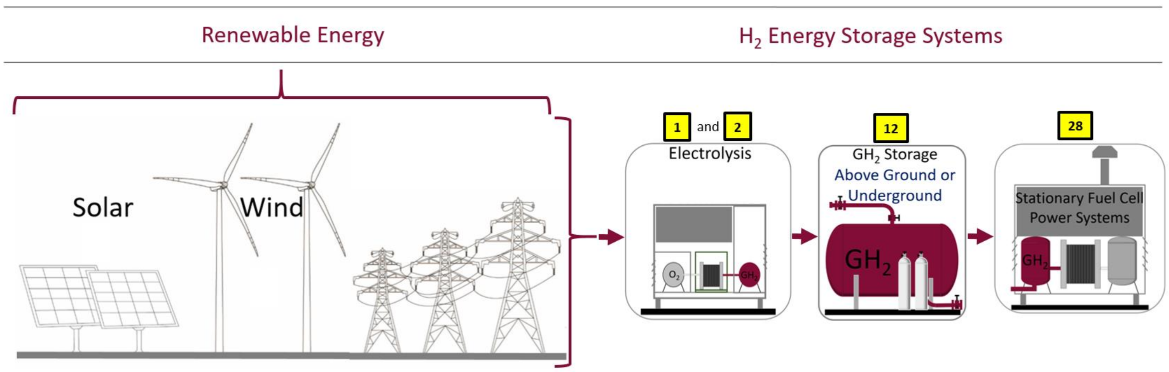
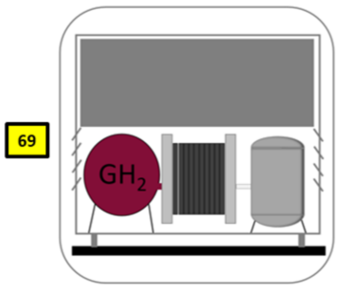


Figure 10: Renewable energy power-to-gas system.

Figure 11 represents element 69. This element consists of items that are common to all applications and that are listed in the figure.

Items Common to All Applications



This element includes:

- Components
  - Enclosures
  - Fuel cell stack
  - Air compressors
  - Compressors
  - Gas valve train
  - Pressure regulating equipment
  - Pressure relief devices
  - Hydrogen sensors
  - Flame sensors
  - Electrical equipment
  - Control equipment
  - Fire alarm systems
  - Lightning protection
  - Component testing
    - ✓ Fuel cells
    - ✓ Material properties and fire ratings
- Hydrogen quality
- Pressure vessels
- Material compatibility
- Area classification
- Hydrogen venting
- Static electricity
- Risk assessment
- Functional safety
- EMC
- Disposal
- Recycling
- Refurbishment
- Personnel qualification and training
- Emergency response
- Etc.

Figure 11: Element 69 – items common to all applications.

Figure 12 represents element 70, which consists of items common to all installations as listed in the figure.

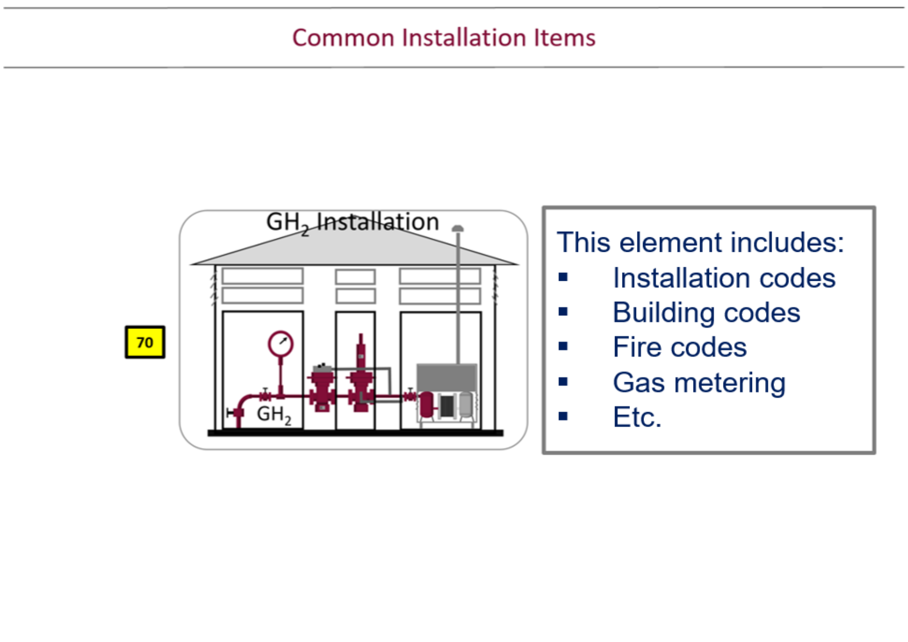


Figure 12: Element 70 – installation items.

Element 71 shown in figure 13 represents the oil and gas industry where hydrogen can be produced or used to lower emissions.

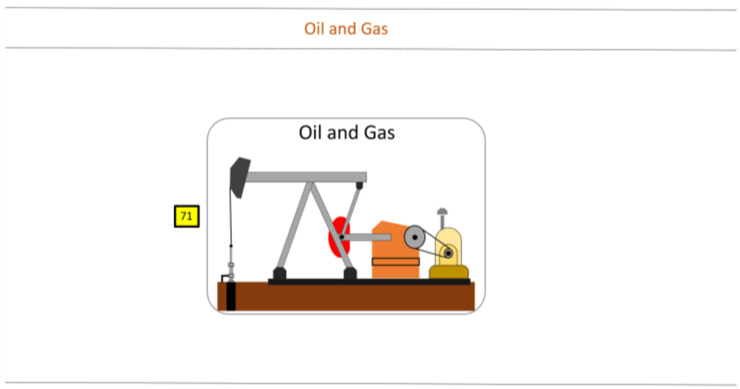


Figure 13: Element 71 – oil and gas industry.

Element 72 shown in Figure 14 represents hydrogen injection systems to lower truck GHG emissions from internal combustion engines.

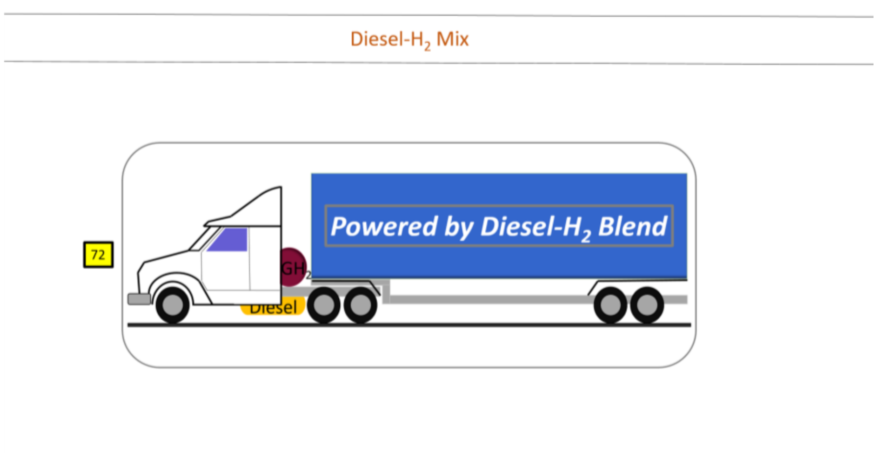


Figure 14: Element 72 – hydrogen injection systems in diesel engines.

4. INDUSTRIAL REPRESENTATION OF THE CANADIAN HYDROGEN VALUE CHAIN

It is important to understand the Canadian industrial landscape within the hydrogen value chain. More specifically, to maximize the impact of this activity, it is essential to understand which elements in the Canadian hydrogen value chain have industrial activities. Removing codes and standards barriers for elements that are very active will have more impact than removing barriers for elements with no industrial activity at all. Similarly, as discussed before, industry presence is important to create balanced committees and to avoid creating standards in elements with little or no industrial activity. However, government priorities may require work in areas where industry is not yet active due to the high impact of these elements or to be prepared to regulate these elements when the time comes.

To this end, the NRC performed a landscape review to identify current information on active Canadian companies in the hydrogen sector as well as active international companies in the Canadian hydrogen sector. Similarly, the NRC reviewed the Canadian Hydrogen and Fuel Cell Association (CHFCA) member directory to collect information about the Canadian industry.

The gathered information was further analysed by reviewing company websites and press releases to determine which elements best represented their activities. Table 1 illustrates the results of this research. Table 1 also includes columns for the four segments and 72 elements described above, as well as the names of Canadian companies, international companies active in Canada, and companies the NRC is aware that use hydrogen technologies in Canada.

Table 1: List of active companies in Canada within each element.

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
0	Carbon Intensity	Carbon Intensity	Y	1. Bright Solutions Inc. 2. Canadian Nuclear Laboratories (CNL)	1. TUV Rheinland	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
1	H2 Production and purification	Electrolysis (Centralized or decentralized)	Y	1. RH2C 2. HTEC 3. Next Hydrogen 4. Powertech 5. Hydrogenics 6. Hydrogen Optimized – Cummins 7. Linde 8. Air Liquide 9. FuelPositive 10. Charbone 11. Canadian Nuclear Laboratories 12. Atura Power 13. Hydro-Québec **LIST CONTINUES IN ROW BELOW**	1. Airproducts 2. H2gen 3. Terrestrial Energy 4. Nel Hydrogen - NH3 5. ITM power	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
1	H2 production and purification	Electrolysis (centralized or decentralized)	Y	14. Schaeffler Group 15. Solaris Management Consultants 16. Innergex Renewable Energy 17. ITM Power 18. Permascand 19. Rangeland Engineering 20. Sea to Sky Energy Solutions 21. Altabec Energy 22. Hydrolux 23. Renewable Hydrogen Corporation 24. University of Toronto 25. Hy2Gen 26. Planetary Hydrogen 27. Change Energy 28. Tugliq Energie Co. 29. Canadian Nuclear Laboratories (CNL) 30. Hydrogen Optimized Ontario 31. ITM Power 32. G&S Budd Consulting Ltd	1. GHD	
2	H2 production and purification	Electrolysis (offshore)	Y	1. Hydrogenics - Cummins 2.Planetary Hydrogen		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
3	H2 production and purification	Natural gas reforming	Y	1. AZETEC 2. Xebec 3. Air Liquide 4. Linde 5. ATCO 6. ILF Consultants 7. NORAM Engineering and Constructors 8. Rangeland Engineering 9. Cariboo Low Carbon Fuels 10. Homefield Consulting Services 11. SpectrumH2 12. Aurora Hydrogen H2 13. Nu:ionic (Canada) 14. GHD	1. Nu:ionic 2. NuScale 3. Airproducts 4. Messer	
3	H2 production and purification	H2 extraction - in-situ well gasification	Y	1. Proton Technologies Canada,		
3	H2 production and purification	Methane pyrolysis	Y	1. Ekona 2. UBC 3. Innova Hydrogen		
4	H2 production and purification	Biomass gasification	Y	1. Omni Conversions 2. Hy2Gen 3. Duma Eng 4. Quadrogen 5. Enbridge 6. Evolugen 7. Viridity Hydrogen 8. GHD 9. NORAM Engineering and Constructors		
5	H2 production and purification	Biomass-derived liquid reforming	Y	1. Air Liquide,		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
5	H2 production and purification	EtOH Reformation	Y	1. SBI BioEnergy Inc.		
5	H2 production and purification	MeOH	Y		1. Palcan (China) 2. Element 1 (USA)	
6	H2 production and purification	Refined Industrial Waste	Y	1. HTEC 2. Linde 3. Air Liquide 4. Sacre-Davey 5. Duma Eng 6. BIO-H2-GEN Inc. 7. NORAM Engineering and Constructors	1. Airproducts	
7	H2 production and purification	Solar Thermochemical	A	1. Ontario Tech University		
8	H2 production and purification	Photo-electrochemical	G	1. Quantiam Technologies		
9	H2 production and purification	Microbial Biomass Conversion	N			
9-b	H2 production and purification	Photobiological	Y	1. Solarvest BioEnergy Inc.		
10	H2 production and purification	Accelerated Carbon transition (ACT)	Y	1. Planetary Hydrogen		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
11-a	Storage / Conversion / Liquefaction	H2 to NH3 Conversion	Y	1. Linde 2. H2Gen-Courant 3. HydroFuel 4. NH3Canada 5. FuelPositive 6. Green Cat Renewables 7. Renewable Hydrogen Corporation 8. Ontario Tech University 9. Eneus Energy 10. Nikkiso	1. H2Gen 2. Solas Energy Consulting 3. GHD 4. Nel Hydrogen	
11-b	Storage / Conversion / Liquefaction	H2 to Liquid Organic Hydrogen Carrier (LOHC) Conversion	N			
12	Storage / Conversion / Liquefaction	GH_2 Storage (above or belowground)	Y	1. HTEC 2. Powertech 3. Linde 4. Hexagon Purus Systems Canada 5. Luxfer 6. Vessel-Energy 7. ILF Consultants 8. Rangeland Engineering 9. Waterloo Institute for Nanotechnology (University of Waterloo) 10. Change Energy	2. GHD	
12	Storage / Conversion / Liquefaction	LH_2 Storage	Y	1. Cryo Solutions Inc. 2. Chart Ind. 3. Nikkiso		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
12	Storage / Conversion / Liquefaction	Solid State storage	Y	1. Hydrogen in Motion 2. GKN Hydrogen 3. Dimatec 4. Canadian Nuclear Laboratories (CNL)		
13	Storage / Conversion / Liquefaction	H_2 liquefaction plant	Y	1. Air Liquide 2. Linde 3. Air Products 4. Quantum Technologies 5. Nikkiso		
14-a	Gas and Liquid Transportation	NH3 Trucking	Y	1. Yara Canada 2. Northern Nitrogen 3. Dyterra 4. Charbone	1. Solas Energy Consulting	
14-b	Gas and Liquid Transportation	Liquid Organic Hydrogen Carrier (LOHC) Trucking				
15	Gas and Liquid Transportation	NH3 Marine Shipping	N			
16-a	Gas and Liquid Transportation	NH3 Rail Shipping	Y	1. CN 2. CP	1. Solas Energy Consulting	
16-b	Gas and Liquid Transportation	Liquid Organic Hydrogen Carrier (LOHC) Rail Shipping				
17	Gas and Liquid Transportation	gH2 Rail Shipping	Y	1. Hexagon Purus Systems Canada,	1. Solas Energy Consulting	1. CP 2. CN
18	Gas and Liquid Transportation	gH2 Trucking	Y	1. Hexagon Purus Systems Canada 2. Air Liquide 3. HTEC 4. Westport 5. Hydra	1. Airproducts 2. Messer 3. Solas Energy Consulting	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
				6. Rangeland Engineering		
19	Gas and Liquid Transportation	Dedicated gH2 Pipeline	Y	1. Linde 2. Airproducts 3. ATCO 4. ILF Consultants	1. Solas Energy Consulting	
20	Gas and Liquid Transportation	gH2 Pressure reduction station	Y	1. Linde 2. ILF Consultants	1. Airproducts 2. Solas Energy Consulting	
21	Gas and Liquid Transportation	lH2 Ship	N		1. Kawasaki	
22	Gas and Liquid Transportation	lH2 Truck	Y	1. Linde 2. Airproducts 3. Westcanbulk	1. Airproducts 2. Solas Energy Consulting	
23	Gas and Liquid Transportation	lH2 Rail	Y	1. Linde 2. CP 3. CN	1. Solas Energy Consulting	
24	H2 at end use site	NH3 Conversion to gH2	Y		1. Petronua 2. Itochu	
25	H2 at end use site	lH2 Storage	Y	1. Air Liquide 2. Linde 3. Matrixservice 4. Cryo Solutions Inc, 5. Nikkiso	1. Airproducts	
26	H2 at end use site	lH2 vaporization	Y	1. Air Liquide 2. Nikkiso	1. Airproducts	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
27	Power Production	Portable Fuel Cell Power Systems	Y	1. Ballard 2. HTEC 3. Westech Industrial Inc 4. Unilia 5. Powertech 6. Intertek 7. CSA 8. ULc 9. SFC Energy 10. TesTneT		
28	Power Production	Stationary Fuel Cell Power Stations	Y	1. Ballard 2. Westech Industrial Inc 3. Loop Energy 4. Hydrogenics - Cummings 5. Intertek 6. CSA 7. Ulc 8. SFC Energy 9. TesTneT 10. Hybrid Energy Inc.		
28	Power Production	Stationary - Indoor UPS systems	Y	1. Westech Industrial Inc	1. Intelligent Energy	
29	Power Production	GH_2 Gas Turbines	Y	1. Change Energy	1. GE 2. Siemens 3. Mitsubishi Heavy Ind. 4. Ansaldo 5. Capstone turbines	
30	H2 Gas burning appliances	GH_2 Water heater	N			
31	H2 Gas burning appliances	GH_2 furnace	N		1. BDR Thermea group	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
32	H2 Gas burning appliances	GH_2 Cooking appliance	N		1. Alto-Shaam	
33	H2 blending into Nat gas Pipelines	H_2 blending into Nat gas Pipelines	Y	1. Enbridge Gas Inc. 2. Canadian Utilities (ATCO) 3. Fortis BC 4. Energir 5. Gazifer 6. Evolugen 7. Renewable Hydrogen Corporation	1. ITM Power	
34	NG-H2 Burning appliances	NG-H_2 Water Heater	Y			1. Enbridge Gas Inc. 2. Canadian Utilities (ATCO)
35	NG-H2 Burning appliances	NG-H_2 Furnace	Y			1. Enbridge Gas Inc. 2. Canadian Utilities (ATCO)
36	NG-H2 Burning appliances	NG-H_2 Cooking Appliance	Y			1. Enbridge Gas Inc. 2. Canadian Utilities (ATCO)
37	NG-H2 Dispensing	NG-H_2 Dispenser (Car)	N			
38	NG-H2 Dispensing	NG-H_2 Dispenser (Truck)	N			
39	NG-H2 Vehicles	NG-H2 Vehicles (Materials Handling)	N			
40	NG-H2 Vehicles	NG-H_2 Vehicles (Car)	N			

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
41	NG-H2 Vehicles	NG-H_2 Vehicles (Bus)	N	1. TransLink (project discontinued)		
42	NG-H2 Vehicles	NG-H_2 Vehicles (Truck)	N			
43	H2 Gas Dispensing	GH_2 Dispenser (Car)	Y	1. HTEC 2. Shell Canada 3. Harnoisenergies 4. Powertech 5. Comtechenergy 6. Hydrogenics – Cummings 7. Altabec Energy	1. Air Liquide 2. Linde 3. Air Products 4. ITM Power 5. Nel Hydrogen	1. Car companies
43	H2 Gas Dispensing	Portable dispensers	Y	1. Comtechenergy 2. Powertech 3. HTEC 4. PWRI 5. + Several more companies		
44	H2 Gas Dispensing	GH_2 Dispenser (Truck)	Y	1. HTEC 2. Shell Canada 3. Harnoisenergies 4. Powertech 5. Comtechenergy 6. Hydrogenics – Cummings 7. Hydraenergy 8. Altabec Energy	1. Air Liquide 2. Linde 3. Air Products 4. Nel Hydrogen	
45	H2 Gas Dispensing	GH_2 Dispenser (Train)	Y	1. Hydrogenics – Cummings 2. Linde	1. Hydrail	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
46	Transportation - Land	GH_2 Vehicles (Car)	Y	1. HTEC 2. Loop Energy 3. Linde 4. Toyota 5. Hyundai 6. Schaeffler Group 7. AVL Fuel Cell 8. CORE dPoint Technologies Ltd. 9. TesTneT 10. Hybrid Energy Inc. 11. Truckenbrodt Clean Energy Consulting 12. Nikkiso	1. GHD 2. ITM Power	1. Moto
47	Transportation - Land	GH_2 Vehicles (Materials Handling)	Y	1. Power Plug Canada 2. Ballard 3. Powertech 4. Loop Energy 5. Hydrogenics – Cummings 6. Intertek 7. CSA 8. ULc 9. CORE dPoint Technologies Ltd. 10. TesTneT 11. Hybrid Energy Inc. 12. Wajax Equipment		1. Walmart 2. Canadian Tire

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
48	Transportation - Land	GH_2 Vehicles (Bus)	Y	1. ElDorado 2. New Flyer 3. Ballard 4. Unilia 5. Loop Energy 6. Hydrogenics - Cummings, 7. Dana TM4 8. AVL Fuel Cell 9. CORE dPoint Technologies Ltd. 10. TesTneT 11. Altabec Energy 12. Red River College Polytechnic 13. Zen Clean Energy Solutions 14. Canadian Urban Transit Association (CUTA)	1. Hyzon Motors	
49	Transportation - Land	GH_2 Vehicles (Truck)	Y	1. AZETEC Pilot Project 2. Ballard 3. Loop Energy 4. Hydrogenics - Cummings, 5. Hexagon Purus Systems Canada 6. Hydraenergy 7. Cellcentric-Daimler & Volvo 8. AVL Fuel Cell 9. CORE dPoint Technologies Ltd. 10. TesTneT 11. Altabec Energy	1. Hyzon Motors	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
50	Transportation - Land	GH_2 Vehicles (Train)	Y	1. Ballard 2. Hydrogenics – Cummings 3. CP 4. Loop Energy 5. Altabec Energy 6. Canadian Urban Transit Association (CUTA) 7. Metrolinx	1. Hydrail-Ballard	
51	H2 Dispensing	LH_2 Dispenser (Marine)	Y	1. Hydrogenics - Cummings 2. Nikkiso		
51	H2 Dispensing	GH_2 Dispenser (Marine)	N			
52	H2 Dispensing	LH_2 Vehicles (Aircraft)	N			
53	H2 Dispensing	GH2 Vehicles (Aircraft)	Y	1. CAAM consortium	1. Airbus 2. Air liquide	
54	H2 Dispensing	GH_2 Dispenser (Aeroplane Tugs and Truck)	Y	1. HTEC		
55	Transportation – Air and Water	LH_2 Marine	Y	1. Capilano Marine Design 2. Altabec Energy	1. Sembcorp-LMG Marin AS	
55	Transportation – Air and Water	GH_2 Marine	Y	1. Capilano Marine Design 2. Cellula Robotics 3. AVL Fuel Cell 4. Redrock Power Systems		
56	Transportation – Air and Water	LH_2 Airplane	N		1. Airbus 2. Audi 3. Aston Martin	

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
					4. Boeing 5. Daimler	
57	Transportation – Air and Water	GH_2 Airplane	N	1. Hybrid Energy Inc. 2. Sky Canoe 3. Truckenbrodt Clean Energy Consulting	1. Airbus 2. Audi 3. Aston Martin 4. Boeing 5. Daimler 6. ZeroAvia-MHIRJ	
57	Transportation – Air and Water	UAV - Micro FCs	Y		1. Intelligent Energy	
58	Transportation – Air and Water	GH_2 airport trucks and tugs	N	1. Hybrid Energy Inc.	1. Airliquide France	
59	Mining H2 Dispensing / Stationary Power Generation	GH_2 Surface dispenser	G			
60	Mining H2 Dispensing / Stationary Power Generation	GH_2 Underground dispenser	G			
61	Mining Operations	GH_2 Mining Equipment	G	1. Loop Energy 2. Ballard 3. Mitsubishi 4. + Others.	1. Anglo American plc	
62	Mining Operations	GH_2 Underground Mining Equipment	G	1. Hybrid Energy Inc.		
63	Mining Operations	Portable Fuel Cell Power Systems	Y	1. Comtechenergy 2. Powertech 3. + several others		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
64	H2 Industrial use	Chemical Production	Y	1. Methanex,		
65	H2 Industrial use	Fertilizers	Y	1. Nutrien	1. CF 2. Yara 3. Scheritt	
66	H2 Industrial use	Synthetic Fuels	G	1. Shell Canada 2. Suncor 3. Syncrude 4. + several others		
67	H2 Industrial use	Steel Production	Y	1. Rio Tinto 2. ArcelorMittal Dofasco	1. Hybrit	
68	H2 Industrial use	Cement	Y	1. Lafarge 2. CRH Canada		
69	Items Common to All Applications	Component development - fuel cell stacks	Y	1. AVL Fuel Cell 2. Ballard 3. Loop Energy 4. Hydrogenics – Cummings 5. SFC Energy 6. Illuming Power 7. Terrella Energy Systems 8. Dana 9. Tandem Technologies 10. Terrella Energy systems Ltd. 11. Dimatic 12. G&S Budd Consulting Ltd. 13. Sylas Consulting		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
69	Items Common to All Applications	Component manufacturer - valve gas train components, fuel cell control units, ventilation systems, etc.	Y	1. Vitesco Technologies 2. CORE dPoint Technologies Ltd. 3. Shaanxi Sirui Advanced Materials Co. Limited 4. Emcara 5. Sim Composites 6. Shaanxi Sirui Advanced Materials Co. (Canada) Limited		
69	Items Common to All Applications	Component certification and testing - Fuel cell stacks, valve gas train components, ventilation systems, etc.	Y	1. Intertek 2. CSA 3. ULc 4. TesTneT	1. TUV Rheinland	
69	Items Common to All Applications	Sensors - Hydrogen Safety	Y	1. Neodym 2. Canadasensors 3. Hatch 4. Emcara 5. IRDI		
69	Items Common to All Applications	Component testing equipment and services - fuel cell stacks	Y	1. Greenlight Innovation 2. Tandem Technologies Ltd.		

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Canadian Industrial Involvement Y = Yes N = None found A = Academia G = Government	Companies (Canadian)	Companies (International)	Companies (Canadian Users)
69	Items Common to All Applications	Research activities	Y	1. Lambton 2. Simon Fraser University 3. Université du Québec à Trois-Rivières (UQTR) – Hydrogen Research Institute 4. University of Toronto 5. Waterloo Institute for Nanotechnology (University of Waterloo) 6. Ontario Tech University 7. Red River College Polytechnic		
69	Items Common to All Applications	Disposal, Recycling, refurbishment	Y	1. Ballard (only their own FCs) 2. Teck	1. specialtymetals	
70	Common Installation Items	Installation codes, building codes and fire codes	Y	All companies from above that make H_2 installations 1. Thor Hydrogen		
71	Oil and Gas					
72	Diesel - H2 blend	Diesel - H_2 blend (Truck)	Y	1. Innovative Hydrogen Solutions	1. HyTech	

Analysing the companies identified and listed in Table 1, the number of companies per element in descending order is shown in Table 2. As can be seen, element 1 for electrolysers is the most active element in the Canadian industry (with 37 active companies). This indicates a high level of activity, which is further validated by current standards harmonization work under the CSA Mirror Committee to the IEC TC 105 (On Fuel Cell Technologies), which is currently adopting the ISO 22734 standard (for Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications) under CSA C22.2 No. 22734.

Table 2: Number of active companies per element in Canada (in descending order).

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
1	H2 Production and purification	Electrolysis (Centralized or decentralized)	37
70	Common Installation Items	Installation codes, building codes and fire codes	25
3	H2 Production and purification	Natural gas reforming	18
46	Transportation - Land	GH2 Vehicles (Car)	15
48	Transportation - Land	GH2 Vehicles (Bus)	15
11-a	Storage / Conversion / Liquefaction	H2 to NH3 Conversion	14
47	Transportation - Land	GH2 Vehicles (Materials Handling)	14
43	H2 Gas Dispensing	GH2 Dispenser (Car)	13
69	Items Common to All Applications	Component development - fuel cell stacks	13
44	H2 Gas Dispensing	GH2 Dispenser (Truck)	12
49	Transportation - Land	GH2 Vehicles (Truck)	12
12	Storage / Conversion / Liquefaction	GH2 Storage (above or belowground)	11

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
4	H2 Production and purification	Biomass gasification	10
27	Power Production	Portable Fuel Cell Power Systems	10
28	Power Production	Stationary Fuel Cell Power Stations	10
18	Gas and Liquid Transportation	gH2 Trucking	9
57	Transportation – Air and Water	GH2 Airplane	9
6	H2 Production and purification	Refined Industrial Waste	8
50	Transportation - Land	GH2 Vehicles (Train)	8
69	Items Common to All Applications	Research activities	7
22	Gas and Liquid Transportation	lH2 Truck	6
29	Power Production	GH2 Gas Turbines	6
69	Items Common to All Applications	Component manufacturer - valve gas train components, fuel cell control units, ventilation systems, etc.	6
13	Storage / Conversion / Liquefaction	H2 liquefaction plant	5
14-a	Gas and Liquid Transportation	NH3 Trucking	5

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
19	Gas and Liquid Transportation	Dedicated gH2 Pipeline	5
43	H2 Gas Dispensing	Portable dispensers	5
56	Transportation – Air and Water	LH2 Airplane	5
61	Mining Operations	GH2 Mining Equipment	5
69	Items Common to All Applications	Component certification and testing - Fuel cell stacks, valve gas train components, ventilation systems, etc.	5
69	Items Common to All Applications	Sensors - Hydrogen Safety	5
12	Storage / Conversion / Liquefaction	Solid State storage	4
17	Gas and Liquid Transportation	gH2 Rail Shipping	4
20	Gas and Liquid Transportation	gH2 Pressure reduction station	4
23	Gas and Liquid Transportation	lH2 Rail	4
55	Transportation – Air and Water	GH2 Marine	4
65	H2 Industrial use	Fertilizers	4
66	H2 Industrial use	Synthetic Fuels	4

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
0	Carbon Intensity	Carbon Intensity	3
3	H2 Production and purification	Methane pyrolysis	3
12	Storage / Conversion / Liquefaction	LH2 Storage	3
16-a	Gas and Liquid Transportation	NH3 Rail Shipping	3
45	H2 Gas Dispensing	GH2 Dispenser (Train)	3
53	H2 Dispensing	GH2 Vehicles (Aircraft)	3
55	Transportation – Air and Water	LH2 Marine	3
63	Mining Operations	Portable Fuel Cell Power Systems	3
67	H2 Industrial use	Steel Production	3
69	Items Common to All Applications	Disposal, Recycling, refurbishment	3
2	H2 Production and purification	Electrolysis (offshore)	2
24	H2 at end use site	NH3 Conversion to gH2	2
28	Power Production	Stationary - Indoor UPS systems	2
34	NG-H2 Burning appliances	NG-H2 Water Heater	2

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
35	NG-H2 Burning appliances	NG-H2 Furnace	2
36	NG-H2 Burning appliances	NG-H2 Cooking Appliance	2
51	H2 Dispensing	LH2 Dispenser (Marine)	2
58	Transportation – Air and Water	GH2 airport trucks and tugs	2
68	H2 Industrial use	Cement	2
72	Diesel - H2 blend	Diesel - H2 blend (Truck)	2
3	H2 Production and purification	H2 extraction - in-situ well gasification	1
5	H2 Production and purification	Biomass-derived liquid reforming	1
5	H2 Production and purification	EtOH Reformation	1
7	H2 Production and purification	Solar Thermochemical	1
8	H2 Production and purification	Photo-electrochemical	1
10	H2 Production and purification	Photobiological	1
25	H2 at end use site	lH2 Storage	1
26	H2 at end use site	lH2 vaporization	1

Element No.	Hydrogen Value Chain Segment	Hydrogen Value Chain Element	Total Number of Active Companies
31	H2 Gas burning appliances	GH2 furnace	1
32	H2 Gas burning appliances	GH2 Cooking appliance	1
33	H2 blending into Nat gas Pipelines	H2 blending into Nat gas Pipelines	1
57	Transportation – Air and Water	UAV - Micro FCs	1
62	Mining Operations	GH2 Underground Mining Equipment	1
64	H2 Industrial use	Chemical Production	1
1	H2 Production and purification	Electrolysis (Centralized or decentralized)	0

Figure 15 below illustrates the number of active companies in the production and purification and storage, and conversion and liquefaction segments. In the figure, the numbers in the blue circles represent the number of active companies in that particular element. The final product of this work includes a pictorial representation of the Canadian hydrogen value chain with the blue circles indicating the number of active companies and another circle representing the number of codes and standards in that element. When implemented, web users will be able to move the cursor inside the circles to display the company names or the codes and standards.

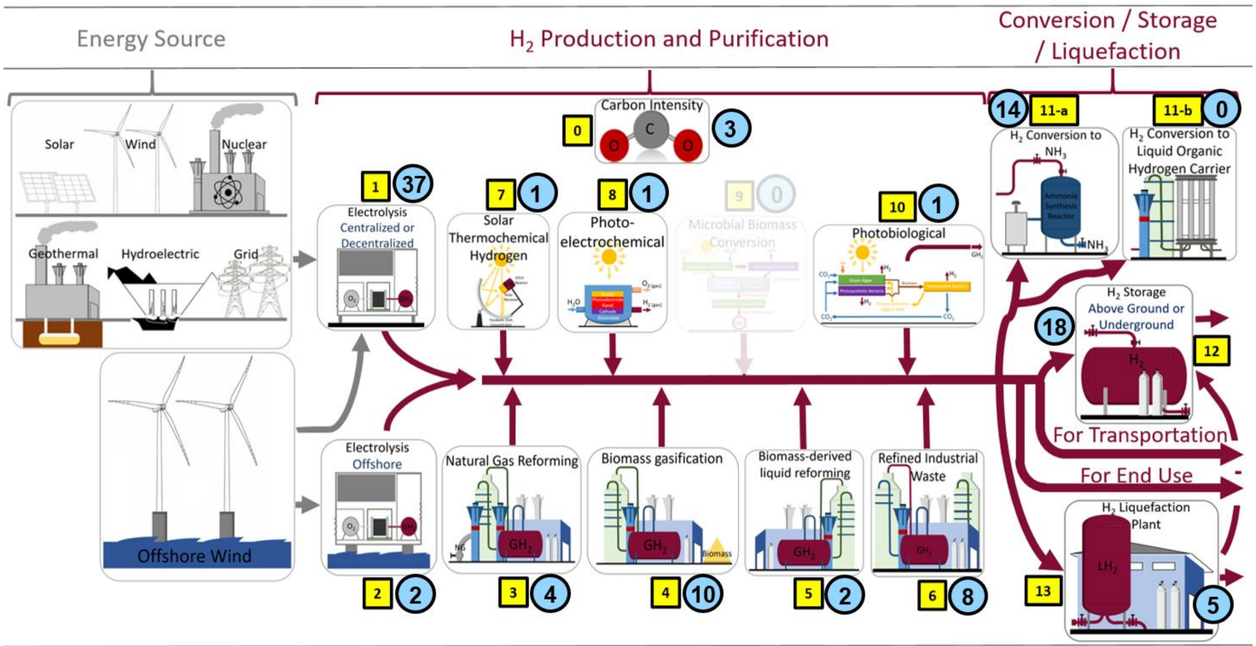


Figure 15: Illustration of the number of active companies (shown in blue circles) in the first two value chain segments.

5. LITERATURE REVIEW

The NRC performed a literature review to gather information on the Canadian hydrogen value chain, CSRs for the different elements of the hydrogen value chain, and gaps within the existing hydrogen codes and standards.

A search of NRC information resources and online publicly available information resulted in the following:

- 18 reports from Canadian entities
- Six reports from other jurisdictions
- Two websites for established hydrogen standards

Most reports confirmed that there is a gap in standards and regulations coverage for hydrogen uptake in Canada but little information is available regarding specific details of the gaps. The literature review revealed C&S information about some of the elements, listed below:

- Element 0 - Carbon Intensity
- Element 19 - Hydrogen Pipeline Standards
- Element 33-42 - Hydrogen Blending Into The Natural Gas Lines
- Elements 43-45 - Dispensing Facilities
- Element 50 - Rail

- Element 72 - Hydrogen Co-Combustion Technology

Also, the literature review revealed other important information and facts on the following topics:

- ISO/TC 197
- Low carbon fuel standard (LCFS)
- National clean fuel standard
- US government hydrogen codes and standards activities

This chapter is a brief summary of the literature review.

ELEMENT 0 - CARBON INTENSITY

The widely used color scheme to represent the different hydrogen pathways has vague definitions and delimitations which can result in ambiguity [5].

Therefore, it is essential for Canada to develop or harmonize well established Carbon Intensity (CI) standards with clear thresholds that can be used for certification of ‘clean’ hydrogen [4]. Currently, Canada is creating internationally aligned procedures to define the CI of hydrogen production pathways (through initiatives such as the Canada/US Regulatory Cooperation Council).

ELEMENT 19 - HYDROGEN PIPELINE STANDARDS

The Board on Pressure Technology Codes and Standards from the American Society of Mechanical Engineers (ASME) is developing consensus based codes or standards for the construction of hydrogen pipelines. These hydrogen pipeline codes and standards, when published, will have similarities with those for natural gas pipelines. However, as hydrogen has different gas properties than natural gas, differences are expected such as [6]:

- Energy density of the gas
- Flammability limits
- Ignition energy
- Emissions while burning
- Explosive force
- Resulting damage from explosion and fire
- Open air detonation

In the US, hydrogen gas pipeline facilities must be designed, built, and tested in accordance with the DOT Title 49 regulations, Part 192 (49 CFR Part 192), “Transportation of Natural Gas and Other Gas by Pipeline: Minimum Federal Safety Standards” as well as with local regulations (and any other applicable federal regulations). Part 192 stipulates minimum design requirements, corrosion protection, materials, etc. [6].

ELEMENT 33-42 - HYDROGEN BLENDING INTO THE NATURAL GAS LINES

Power to gas (P2G) allows the conversion of renewable electrical grid energy into hydrogen at times of excess power supply and low power demand. However, regulation and techno-economic issues related to the implementation and commercialization of current technologies have made it challenging to adopt P2G in Canada. For example, whereas electrolyzers have been widely used worldwide, the distribution of the produced hydrogen needs a large infrastructure, a viable market, and supportive regulations. These obstacles can be mitigated by injecting the produced hydrogen into existing natural gas pipelines. Other alternatives include the production of liquid fuels or renewable natural gas from hydrogen. The LCFS regulation may include the required incentives (to produce renewable hydrogen) to increase the use of P2G technology and thus the injection of hydrogen into the natural gas grid [7]. This is especially important for Canada as it has one of the largest networks of natural gas pipelines due to its natural gas production in the west and eastern regions and distribution lines to different markets in North America.

Although hydrogen could be injected into the natural gas grid, the maximum amount of hydrogen that can safely be injected is not well defined. Initially it was thought that 5% (by volume) was the safe upper limit but higher ratios have been demonstrated (e.g., 12%) based on the end uses and pipeline engineering [7]. Material compatibility is an issue with hydrogen and cast iron fittings from older natural gas pipelines and some steel pipes may become embrittled and prone to leak if exposed to hydrogen mixed gases. Advanced plastic materials may contain the hydrogen blend better and may be able to tolerate higher hydrogen concentrations without material degradation. However, it must be ensured that the higher hydrogen ratios do not negatively affect end users [7]. According to NRC [7], hydrogen concentrations of 20% pose a challenge to end-use appliances and the concerns of end-users (e.g., emissions and safety) must be adequately addressed. Therefore, more research is needed to determine safe hydrogen blending upper limits to develop harmonized HCNG (Hydrogen Compressed Natural Gas) standards and regulations [7].

Many demonstrations of hydrogen blending into natural gas systems have been performed worldwide. The volume of hydrogen that can be injected into the natural gas infrastructure is constrained by local national codes and standards. For example, in the UK, up to 0.1% hydrogen by volume can be injected whereas in Holland up to 12% hydrogen by volume can be injected [4]. Other countries are working on standards that will establish similar limits.

Hydrogen blending is in the early stages in many Canadian jurisdictions although provincial policies have been enacted to stimulate R&D and pilot projects in this area. Currently, there are nine utility stakeholders [4] developing or performing blending demonstrations. However, Canada (and North America, in general) needs to develop hydrogen injection standards that include the maximum hydrogen concentration that can be injected as well as set allowable contamination limits (hydrogen quality standards) for the injected hydrogen [4]. The gap in the codes and standards in this area is one of the obstacles that needs to be addressed in Canada to support new opportunities in this field and facilitate wider adoption. Trade and exports across different jurisdictions can be stimulated through codes and standards harmonization efforts (provincial and international) and Inter-provincial coordination (as pipelines cross borders) ensuring the use of global best practices helping hydrogen blending across different provinces and territories [4]. Policy makers and energy regulators can play an important role motivating industry to develop and adopt global hydrogen injection and quality standards.

According to Zen Clean Energy Solutions[4] [8], the Canadian Gas Association expects the publication of a report confirming that 5% hydrogen blending (by volume) into natural gas systems is acceptable in the short term. Zen Clean Energy Solutions [8] also recommends the creation of provincial codes and standards concerning hydrogen blending into the natural gas grid as well as the establishment of a directive for technical bodies to govern hydrogen injection into the NG grid. They also suggest that the province of BC should take a leadership role to create a regulatory frame work that coordinates between all the relevant authorities and agencies (CSA, Technical Safety BC, the National Energy Board, BC Oil and Gas Commission and the BC Utilities Commission) to make the necessary changes to introduce hydrogen into the natural gas grid.

Some standard activities relevant to hydrogen blending into the natural gas lines in Canada include [7, 14]:

Table 3: Standard committees from CEN and ISO relevant to hydrogen blending in Canada.

TECHNICAL COMMITTEE	TC TITLE	NATIONALITY
CEN/TC 234	Gas infrastructure	EUR
CEN/TC 408	Biomethane for use in transport and injection in natural gas pipelines	EUR
CEN/TC 238	Test gases, test pressures, appliance categories	EUR
ISO/TC 197	Hydrogen technologies	INT
ISO/TC 193	Natural gas	INT
ISO/TC 22/SC25	Road vehicles using gaseous fuels	INT
ISO/PC 252	Natural gas fueling stations for vehicles	INT
ISO/TC 192	Gas turbines	INT

ELEMENTS 43-45 - DISPENSING FACILITIES

According to Change Energy Services Inc.[5], codes and standards exist for the design and operation of hydrogen gas and liquid dispensing equipment and installations; thus, they consider this technology to be mature. However, gaps exist in Canada related to measurement standards limiting the sale of hydrogen as a fuel. However, this is

[4] Zen Clean Energy Solutions has more than 50 years of combined experience in the clean energy sector. Zen's mission is to commercially advance and deploy clean energy solutions and technologies that promote sustainability, by working with organizations and developing projects (https://zenenergysolutions.com/about/).

[5] Change Energy Services is an engineering consulting firm focused on the low carbon economy and has helped their clients to plan and execute fuel system transitions for more than 30 years (https://www.changeenergy.ca/).

not expected to affect rail as metered dispensing may not be required for rail [9]. Similarly, in the case of locomotives, even though it is technically feasible to use current technologies to fuel and defuel locomotives and fuel tenders with hydrogen dispensing equipment or by fuel tankers located at dedicated facilities, standard procedures are immature [9].

ELEMENT 50 - RAIL

Liquid Hydrogen Storage for Rail:

Standards for the rail transportation of cryogenic liquids as cargo exist and may be used to develop liquid hydrogen tender concepts. However, experience in real-world operation would provide significant engineering required to refine the concepts to a mature level [9].

Servicing or repairing a hydrogen-powered locomotive inside an enclosed shop requires shop modifications for compliance with codes developed by SDOs such as CSA, BNQ and NFPA to account for the possibility of accidental releases of hydrogen [9]. Warehouses in which hydrogen fuel cell-powered forklifts are operated (and fuelled) and some hydrogen bus maintenance bays already meet the requirements of these codes [9].

According to Change Energy Services Inc., standards and procedures exist for servicing and storing liquefied natural gas-powered locomotives indoors which need to be followed for hydrogen-fuelled locomotives as well (e.g., evacuating hydrogen lines and vessels to safe levels), and that consulting the AHJs will be required [9].

Rail Regulators:

In Canada, Transport Canada is the agency that develops and manages safety policies and regulations for the rail transportation system. The Railway Safety Act (RSA) defines the relationship between railway companies and government in areas including public safety, property damage, and the environment [9]. However, railway companies develop engineering standards, which must be approved by the Minister of Transport. If the minister is satisfied with a company's safety management system (in compliance with the Railway Safety Management System Regulations under the Act), Transport Canada will issue a Railway Operating Certificate [9]. The RSA does reference some technical standards for typical equipment such as diesel tanks but it may also references accepted practices from railway companies (e.g., AAR industry standards), which helps companies to introduce new technologies such as hydrogen and fuel cells. Railway companies wanting to incorporate hydrogen systems must submit design details regarding the fuel system and motive power and how it will maintain safety (the submission is based on the risk assessment) through an exception request demonstrating equivalent safety. If applicable codes, standards and guidelines (e.g., the Canadian Hydrogen Installation Code) can be used or adapted, it helps to build confidence in the risk assessment [9].

In Canada, the rail regulatory system relevant to hydrogen system integrations includes the acts, regulations, rules, and codes, as shown in Table 4 below.

Table 4: Regulatory system in Canada.

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
Railway Safety Act (1985, c. 32 (4th Supp.))	Railway Safety Act (1985, c. 32 (4th Supp.))	CAN	Safety Legislation
Railway Operating Certificate Regulations (SOR/2014-258)	Railway Operating Certificate Regulations (SOR/2014-258)	CAN	Safety Regulation
Railway Safety Management System Regulations, 2015 (SOR/2015-26)	Railway Safety Management System Regulations, 2015 (SOR/2015-26)	CAN	Safety Regulation
Notice of Railway Works Regulations (SOR/91-103)	Notice of Railway Works Regulations (SOR/91-103)	CAN	Safety Regulation
Grade Crossings Regulations (SOR/2014-275)	Grade Crossings Regulations (SOR/2014-275)	CAN	Safety Regulation
Locomotive Emissions Regulations (SOR/2017-121)	Locomotive Emissions Regulations (SOR/2017-121)	CAN	Safety Regulation
Railway Safety Administrative Monetary Penalties Regulations (SOR/2014-233)	Railway Safety Administrative Monetary Penalties Regulations (SOR/2014-233)	CAN	Safety Regulation
Railway Employee Qualification Standards Regulations (1987-3 Rail) (SOR/87-150)	Railway Employee Qualification Standards Regulations (1987-3 Rail) (SOR/87-150)	CAN	Safety Regulation
Transport Canada - Railway Locomotive	Transport Canada - Railway Locomotive Inspection and Safety Rules	CAN	Safety Rule https://tc.canada.ca/en/rail-

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
Inspection and Safety Rules			transportation/rules/railway-locomotive-inspection-safety-rules
Canadian Rail Operating Rules (CROR) with Rules for the Protection of Track Units and Track Work	Canadian Rail Operating Rules (CROR) with Rules for the Protection of Track Units and Track Work	CAN	Safety Rule
Canada Transportation Act	Canada Transportation Act	CAN	Act
Canadian Transportation Accident Investigation and Safety Board Act	Canadian Transportation Accident Investigation and Safety Board Act	CAN	Act
Transportation of Dangerous Goods Act	Transportation of Dangerous Goods Act	CAN	Act
Canada Labour Code	Canada Labour Code	CAN	Safety Code
On Board Trains Occupational Safety and Health Regulations (SOR/87-184)	On Board Trains Occupational Safety and Health Regulations (SOR/87-184)	CAN	Safety Regulations

Approval of new railway technologies start with proposals from railway companies based on risk assessments. This includes identification of all the hazards from the use of the new technology and assessment of the resulting risks.

Transport Canada must review safety management system changes resulting from the addition of hydrail[6]. The submission must include local AHJ (e.g., Technical Safety BC, Technical Standards and Safety Authority, the Electrical Safety Authority or the Canadian Association of Fire Chiefs) participation in the associated risk

[6] Hydrail is the term used to describe all types of hydrogen fueled rail vehicles irrespective of size.

assessments and agreement with the proposed system. The AHJs certify hydrogen systems by evaluating compliance to codes which reference standards from SDO such as:

- AGA – American Gas Association
- ANSI – American National Standards Institute
- API – American Petroleum Institute
- ASME – American Society of Mechanical Engineers
- ASTM – American Society for Testing and Materials International
- BNQ – Bureau de normalisation du Québec
- CGA – Compressed Gas Association
- CSA – Canadian Standards Association
- ICC – International Code Council
- IEC – International Electrotechnical Commission
- IEEE – Institute of Electrical and Electronics Engineers
- ISO – International Organization for Standardization
- NFPA – National Fire Protection Association
- SAE – Society of Automotive Engineers
- UL – Underwriters Laboratories

Standards, which are not particular to hydrail systems are frequently referenced (due to a lack of hydrail standards). Similarly, international standards are referenced for systems if Canadian standards do not exist. Standards under the responsibility of the ISO/TC 197 secretariat are often referenced for design and safety. Also, some of the overarching standards listed in this report are frequently referenced for rail applications.

Hydrogen facilities located inside railway properties are regulated by the Transport Canada Rail Safety Group [10]. In contrast, the fuel infrastructure outside of railway property falls under the jurisdiction of the provincial authorities [10]. The Railway Safety Act regulations (Chapter 1151) pertaining to the Design, Location, Construction, Operation, and Maintenance of Stationary Liquefied Petroleum Bulk Storage Facilities may serve as a precedent for hydrogen onsite storage and handling [11]. Another consideration is that provincial environmental assessments may be required for adjacent facilities to the railway due to electromagnetic interference [10]. Jacobs Engineering Group [10] recommends the creation of regulations for the handling and storage of hydrogen (gas and liquid) as well as first responder's emergency response training for hydrail accidents. The authors also recommend building a prototype to track all safety aspects of hydrogen within the Canadian railway context to gain hands-on experience drafting, implementing regulations, and making first response plans [10]. This study uncovered a gap in the Canadian rail safety regulations regarding the use of hydrogen fuel (e.g., railway vehicle and on-site hydrogen containers and accessories). However, regulations have been created in other countries (e.g., Germany), which could be modified to build Canadian regulations. Interaction with the German regulatory and testing agencies as well as OEMs would be required to understand the intent of the German regulations and how they are applied [10].

The Alstom Coradia iLint commuter train installation in Germany, which uses a fuel cell system from Cummins, formerly Hydrogenics, conformed to the following hydrogen pressure appliance regulations and directives [11]:

Table 5: Hydrogen pressure appliance regulations and directives used for Coradia iLint commuter train

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
Regulations EC 79/2009	Type-approval of hydrogen-powered motor vehicles	European Commission	Safety
COMMISSION REGULATION (EU) No 406/2010	Commission Regulation (EU) No 406/2010 of 26 April 2010 implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles	European Commission	Safety
PED 2014/68/EU	Pressure Equipment Directive (PED) 2014/68/EU	European Commission	Safety
Bundessanstait fur Materialforschung (BAM) und –prufing	Concept for Assessment of Safe Life Time of Composite Pressure Receptacles	GER	Safety

These regulations address the storage, pressure regulation, piping and other components for up to 20 years of use and 5,000 filling cycles [11].

According to TELLIGENCE Group [11], risk assessment experts prefer performance-based hydrogen standards as they feel that prescriptive standards have not kept up to date with new information related to hydrogen risks. Similarly, inspectors require well recognised hydrail system codes and standards to reference during installation and equipment inspections. Without these, the AHJ will have difficulties approving projects.

ELEMENT 72 - HYDROGEN CO-COMBUSTION TECHNOLOGY

Zen Clean Energy Solutions [8] suggests the province of BC analyses studies about the BC-made Hydrogen co-combustion technology as it has the potential to develop the heavy duty vehicle hydrogen sector and retrofit into existing vehicles. If the studies support the claimed GHG reductions, the fuel cell specification of the Motor Tax and Low Carbon Fuel Standard should be inclusive of this technology.

ISO/TC 197

The International Standardization Organization (ISO) has a technical committee, ISO/TC 197, in charge of standards development related to components, appliances, and systems for the production, measurement, quality, storage, transportation, and use of hydrogen. The following tables (14 and 15) list standards and projects under the responsibility of the ISO/TC 197 secretariat (https://www.iso.org/committee/54560/x/catalogue/) (updated as of March 15, 2022). These standards are relevant for the design, operation, and maintenance of fueling stations. Table 6 below lists the published standards under the ISO/TC 197.

Table 6: Published standards under ISO TC 197

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO 13984:1999	Liquid hydrogen — Land vehicle fuelling system interface	INT	Safety - Published
ISO 13985:2006	Liquid hydrogen — Land vehicle fuel tanks	INT	Safety - Published
ISO 14687:2019	Hydrogen fuel quality — Product specification	INT	Specification - Published
ISO/TR 15916:2015	Basic considerations for the safety of hydrogen systems	INT	Safety - Published
ISO 16110-1:2007	Hydrogen generators using fuel processing technologies — Part 1: Safety	INT	Safety - Published
ISO 16110-2:2010	Hydrogen generators using fuel processing technologies — Part 2: Test methods for performance	INT	Performance - Published
ISO 16111:2018	Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride	INT	Safety - Published
ISO 17268:2020	Gaseous hydrogen land vehicle refuelling connection devices	INT	Safety - Published
ISO 19880-1:2020	Gaseous hydrogen — Fuelling stations — Part 1: General requirements	INT	Safety - Published
ISO 19880-3:2018	Gaseous hydrogen — Fuelling stations — Part 3: Valves	INT	Safety - Published

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO 19880-5:2019	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies	INT	Safety - Published
ISO 19880-8:2019	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control	INT	Quality Control - Published
ISO 19880-8:2019/AMD 1:2021	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control — Amendment 1: Alignment with Grade D of ISO 14687	INT	Quality Control - Published
ISO 19881:2018	Gaseous hydrogen — Land vehicle fuel containers	INT	Safety - Published
ISO 19882:2018	Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	INT	Safety - Published
ISO/TS 19883:2017	Safety of pressure swing adsorption systems for hydrogen separation and purification	INT	Safety - Published
ISO 22734:2019	Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications	INT	Safety - Published
ISO 26142:2010	Hydrogen detection apparatus — Stationary applications	INT	Safety - Published

Table 7 below lists the standards under development by the ISO/TC 197.

Table 7: Standards under development from ISO TC 197.

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO/AWI 14687	Hydrogen fuel quality — Product specification	INT	Specification - Under development
ISO/AWI TR 15916	Basic considerations for the safety of hydrogen systems	INT	Safety - Under development
ISO/AWI 17268	Gaseous hydrogen land vehicle refuelling connection devices	INT	Safety - Under development
ISO/AWI 19880-5	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies	INT	Safety - Under development
ISO/CD 19880-6	Gaseous hydrogen — Fueling stations — Part 6: Fittings	INT	Safety - Under development
ISO/AWI 19880-7	Gaseous hydrogen — Fuelling stations — Part 7: O-rings	INT	Safety - Under development
ISO/AWI 19880-8	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control	INT	Quality Control - Under development
ISO/AWI 19880-9	Gaseous hydrogen — Fuelling stations — Part 9: Sampling for fuel quality analysis	INT	Quality Control - Under development
ISO/AWI 19881	Gaseous hydrogen — Land vehicle fuel containers	INT	Safety - Under development
ISO/AWI 19882	Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	INT	Safety - Under development
ISO/WD 19884	Gaseous hydrogen — Cylinders and tubes for stationary storage	INT	Safety - Under development

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO/AWI 19885-1	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 1: Design and development process for fuelling protocols	INT	Safety - Under development
ISO/AWI 19885-2	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 2: Definition of communications between the vehicle and dispenser control systems	INT	Safety - Under development
ISO/AWI 19885-3	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 3: High flow hydrogen fuelling protocols for heavy duty road vehicles	INT	Safety - Under development
ISO/AWI 19887	Gaseous Hydrogen — Fuel system components for hydrogen fuelled vehicles	INT	Safety - Under development
ISO/AWI 22734-1	Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications — Part 1: General requirements, test protocols and safety requirements	INT	Safety - Under development
ISO/AWI TR 22734-2	Hydrogen generators using water electrolysis — Part 2: Testing guidance for performing electricity grid service	INT	Safety - Under development

Other relevant standards have been compiled and organized and are included in other sections of this report.

LOW CARBON FUEL STANDARD (LCFS)

In 2010, the province of British Columbia incorporated a Low Carbon Fuel Standard (LCFS) as part of its Renewable and Low Carbon Fuel Requirements Regulation (RLCFRR) [7]. Similarly, the province of Ontario is recommending a LCFS and the Government of Canada has proposed a LCFS, which also covers fuels not related to transportation (e.g., fuels for houses, buildings and industry). This national LCFS will be a performance based regulation established under the Canadian Environmental Protection Act of 1999, which will encourage the use of a wide range of lower carbon fuels and alternative technologies (liquid, gaseous and solid fuels) [6 page 20] [23].

NATIONAL CLEAN FUEL STANDARD

In 2016 the Government of Canada expressed its plan to create a national Clean Fuel Standard which would cover fuels for industry, homes, and buildings as well. The target of this policy is to decrease GHG emissions by up to 30 million tonnes annually by 2030. This standard will be based on life cycle analysis and is expected to drive industry innovation to create lower carbon fuels [7]. Alternative energy sources and fuels such as hydrogen, natural gas, electricity, biogas and others will be included. Environment and Climate Change Canada (ECCC) may apply this regulation to fuel producers, distributors, and importers [7].

U.S. HYDROGEN CODES AND STANDARDS ACTIVITIES

One of the objectives of the U.S. Department of Energy (DOE) is to harmonize national and international hydrogen CSRs to ensure hydrogen product consumer safety in the US and worldwide. The National Renewable Energy Laboratory (NREL) assists the DOE in this work by providing technical and administrative support [12]. Table 8 details the US hydrogen CSR activities.

Table 8: US hydrogen codes, standards and regulation activities [12].

ACTIVITY	OBJECTIVE	ORGANIZATIONS
U.S. Domestic Codes and Standards Development Activities		
Stakeholder Meetings and Technical Forums	Supports technical and coordination meetings to ensure communications among key stakeholders	NREL, PNNL, LANL, SNL, NHA
Technical Expertise	Supports hydrogen safety research and provides expert technical representation at key industry forums and codes and standards development meetings, such as the ICC and NFPA model code revision process	SNL, NREL, LANL
Consensus Codes and Standards Development	Supports coordinated development of codes and standards through a national consensus process	NREL, SNL, SAE, CSA, NHA, NFPA, ICC, ANSI

Information Dissemination	Supports information forums for local chapters of building and fire code officials, and the development of case studies on the permitting of hydrogen refueling stations	PNNL, NHA
Research, Testing and Certification	Supports focused research and testing needed to verify the technical basis for hydrogen codes and standards and equipment	SNL, NREL
Training Modules and Informational Videos	Supports the development of mixed media training modules and informational videos for local code officials, fire marshals and other fire and safety professionals	PNNL
National Template for Standards, Codes, and Regulations	Identifies key areas of standards, codes, and regulations for hydrogen vehicles and hydrogen fueling/service/parking facilities and designates lead and supporting organizations	NREL
Codes and Standards Matrix Database	Provides inventory and tracking of relevant domestic codes and standard: identifies gaps, minimizes overlap, and ensures that a complete set of necessary standards is written	NREL, ANSI

6. CODES STANDARDS AND REGULATIONS INVENTORY

Creating a CSR inventory was an important task for this project. All the gathered document information was compiled in an Excel file with 72 tabs, with each tab corresponding to an element number. Each Excel tab has columns for:

- Element number
- Hydrogen value chain segment
- Part of the hydrogen value chain
- Standard number
- Standard title
- Nationality
- Applicability
- Standard coverage
- Standard scope
- Comments

The information will be linked to the proposed website with the use of filters (e.g., the web user will be able to filter Canadian standards only). Also, more columns will be added to be able to apply more filters.

This chapter includes the gathered documents for the following elements:

- 69 - Items common to all applications
- 1 – Electrolysis
- 12 – Hydrogen storage (above ground or underground)
- 47 - Forklifts
- 70 - Common installation items

All these codes and standard tables for the elements above are examples of the complete list. As the complete list is very comprehensive, the codes and standards for other elements are not included in this report. The list is not yet complete and some of the standards are in categorized in element 69 as well as in the other elements. More effort is required to reduce the number of duplicate standards; since this work is very laborious, this will take some time to complete.

6.1 Standards for Element 69 – Items common to all applications

This element contains common standards which are applicable to all hydrogen and fuel cell installations and equipment that address hydrogen hazards such as hydrogen embrittlement, flammability, low ignition energy, high pressures, etc. These standards also cover hydrogen terminology purity, and material flammability testing (to assess the required flammability ratings from different hydrogen product standards). These standards were classified as follows:

1. Standards for Electrical Equipment
2. Standards for Area Classification and for Equipment for Use in Classified Areas
3. Standards for Static Electricity
4. General Hydrogen Standards
5. Hydrogen Quality Standards
6. Standards for Pressurized Hydrogen Containing or Conveying Components
7. Standards for Hydrogen Venting
8. Standards for hydrogen Material Compatibility
9. Standards for Hydrogen Sensors
10. Standards for Pressure Relief Devices
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 Air Compressors

18. Standards for Compressors
19. Standards for Risk Assessments
20. Standards for training and certification requirements
21. Standards for Protection against Lightning
22. Standards for component testing (fuel cells)

6.1.1 Standards for electrical equipment

The following table lists standards for general electrical equipment and installations to cover fire and shock hazard as well as accessibility.

Table 9: Standards for electrical equipment

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA C22.1	Canadian Electrical Code.	CAN	Safety
CSA C22.2 NO. 301:16 (R2021)	Industrial electrical machinery	CAN	Safety
CAN/CSA C22.2 No. 0.4-0.4	Bonding of Electrical Equipment	CAN	Safety
CSA C22.2 NO. 286-17	Industrial control panels and assemblies	CAN	Safety
C22.2 No. 139	Electrically operated valves	CAN	Safety
IEC 60204-1:2005	Safety of machinery — Electrical equipment of machines — Part 1: General requirements	INT	Safety
IEC 60034-1	Rotating electrical machines — Part 1: Rating and performance	INT	Safety

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

The following table contains standards that can be used to classify hazardous areas or to test different strategies for equipment for use in classified areas.

Table 10: Standards for area classification and for equipment for use in classified areas

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA C22.1 - Section 18	Canadian Electrical Code.	CAN	Safety
IEC 60079-10-1	Electrical Area Classification	INT	ground H2 systems / infrastructure
CSA C22.2 NO. 60079-0:19	Explosive atmospheres - Part 0: Equipment - General requirements (Adopted IEC 60079-0:2017, seventh edition, 2017-12, with Canadian deviations)	CAN	Safety
CSA C22.2 NO. 60079-1:16 (R2021)	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 C22.2 NO. 60079-2:16 (R2021)	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 C22.2 NO. 60079-5:16 (R2021)	Explosive atmospheres - Part 5: Equipment protection by powder filling "q" (Adopted IEC 60079-5:2015, fourth edition, 2015-02, with Canadian deviations)	CAN	Safety
CAN/CSA-C22.2 NO. 60079-6:17	Explosive atmospheres - Part 6: Equipment protection by liquid immersion "o" (Adopted IEC 60079-6:2015, fourth edition,	CAN	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	2015-02, with Canadian deviations)		
CAN/CSA-C22.2 NO. 60079-7:16 (R2021)	Explosive atmospheres - Part 7: Equipment protection by increased safety "e" (Adopted IEC 60079-7:2015, fifth edition, 2015-06, with Canadian deviations)	CAN	Safety
CAN/CSA-C22.2 NO. 60079-11:14 (R2018)	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 C60079-13:19	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
CAN/CSA-C22.2 NO. 60079-15:18	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
CAN/CSA-C22.2 NO. 60079-25:14 (R2018)	Explosive atmospheres - Part 25: Intrinsically safe electrical systems (Adopted IEC 60079-25:2010, second edition, 2010-02, with Canadian deviations)	CAN	Safety
CSA C22.2 NO. 60079-29-4:16 (R2021)	Explosive atmospheres — Part 29-4: Gas detectors — Performance requirements of open path detectors for	CAN	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	flammable gases (Adopted IEC 60079-29-4:2009, first edition, 2009-11, with Canadian deviations)		
CSA C22.2 NO. 60079-40:20	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 C22.2 NO. 60079-46:19	Explosive atmospheres — Part 46: Equipment assemblies (Adopted IEC TS 60079-46:2017, first edition, 2017-08, with Canadian deviations)	CAN	Safety
CAN/CSA C22.2 No. 60079-29-1	Explosive atmospheres – Part 29-1: Gas detectors. Performance requirements of detectors for flammable gases.	CAN	Performance
CAN/CSA-C22.2 NO. 60079-30-1:17	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
IEC 60079-2:2014	Explosive atmospheres - Part 2: Equipment protection by pressurized enclosure "p"	INT	Safety
IEC 60079-7:2015	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
IEC 60079-11:2011	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"	INT	Safety
IEC 60079-14:2013	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	INT	Safety
IEC 60079-18:2014+AMD1:2017 CSV	Explosive atmospheres - Part 18: Equipment protection by encapsulation "m"	INT	Safety
IEC 60079-26:2021	Explosive atmospheres - Part 26: Equipment with Separation Elements or combined Levels of Protection	INT	Safety
IEC 60079-29	Explosive atmospheres – Part 29-2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen	INT	Safety
IEC/IEEE 60079-30-1	Explosive atmospheres — Part 30-1: Electrical resistance trace heating — General and testing requirements	INT	Safety
IEC TS 60079-32-1:2013	Explosive atmospheres - Part 32-1: Electrostatic hazards, guidance	INT	Guidance
FM 3600	Approval Standard for Electrical Equipment for Use in Hazardous Locations	INT	Safety
FM 3615	Approval Standard for Explosion proof Electrical Equipment - General Requirements	INT	Safety
NFPA 497	Recommended Practice for the Classification of Flammable Liquids, Gases or Vapours and	US	H2 systems / infrastructure

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas		

6.1.3 Standards for static electricity

As hydrogen has a low ignition energy it is important to address ignition hazards due to static electricity. The following table lists standards that mitigate the possibility of static buildup.

Table 11: Standards for static electricity

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA C22.2 No. 0.4-0.4	Bonding of Electrical Equipment	CAN	Safety
NFPA 77	Recommended Practice on Static Electricity	US	Safety. This is used in Canada as the CSA standard does not address static electricity

6.1.4 General hydrogen standards

The standards in the following table cover a variety of general hydrogen subjects.

Table 12: General hydrogen standards

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CGA Publication H4	Terminology Associated with Hydrogen Fuel Technologies	US	Terminology
AIAA G-095	Guide to Safety of Hydrogen and Hydrogen Systems	US	Safety

CGA Publication PS31	Cleanliness for PEM Hydrogen Piping / Components	US	Specification
CGA Publication G5	Hydrogen	US	Information
ISO/TR 15916: 2015	Basic Considerations for safety of hydrogen systems	INT	Guidance
CGA Publication P6	Standard Density Data, Atmospheric Gases and Hydrogen	US	Information
National Fire Protection Association (NFPA): NFPA-2-11	Hydrogen Technologies Code	US	Safety

6.1.5 Hydrogen quality standards

The following table lists available hydrogen quality standards.

Table 13: Hydrogen quality standards

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CGA Publication G5.3	Hydrogen Product Standard	US	Specification
ISO 14687-1, 2008	Hydrogen fuel — Product specification Technical Corrigendum 1 & 2.	INT	Specification
ISO 14687-1, 1999	Hydrogen fuel -- Product specification -- Part 1: All applications except proton exchange membrane (PEM) fuel cell for road vehicles	INT	Specification
ISO 14687-2, 2012	Hydrogen fuel -- Product specification -- Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles	INT	Specification

ISO 14687-3, 2014	Hydrogen fuel -- Product specification -- Part 3: Proton exchange membrane (PEM) fuel cell applications for stationary appliances	INT	Specification
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles	INT	Safety

6.1.6 Standards for pressurized hydrogen containing or conveying components

The following table lists standards for pressurized gas conveying or storage components.

Table 14: Standards for pressurized hydrogen containing or conveying components

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA B51-97	Boiler, Pressure Vessel, and Pressure Piping Code	CAN	Safety
ISO 16528-1	Boilers and pressure vessels — Part 1: Performance requirements	INT	Performance
ASME B31.12	Hydrogen Piping and Pipelines (part of ASME B31 Series Piping and Pipelines)	US	Safety
ASME BPVC	Boiler and Pressure Vessel Code	US	Safety
ASME STP-PT-006	Design Guidelines for Hydrogen Piping and Pipelines	US	Safety

6.1.7 Standards for hydrogen venting

The following table lists a standard that should be used for hydrogen venting systems.

Table 15: Standards for hydrogen venting

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CGA Publication G5.5	Hydrogen Vent Systems	US	Safety

6.1.8 Standards for hydrogen material compatibility

The following table lists standards that can be used to test materials for hydrogen compatibility. The Canadian standards to test metals and non-metals for hydrogen material compatibility are the CSA/ANSI CHMC 1 and the CSA/ANSI CHMC 2.

Table 16: Standards for hydrogen material compatibility

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CSA/ANSI CHMC 1-2014	Test methods for evaluating material compatibility in compressed hydrogen applications – Metals	CAN/US	Safety
CSA/ANSI CHMC 2-2019	Test methods for evaluating material compatibility in compressed hydrogen applications – Polymers	CAN/US	Safety
ASTM G142	Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature.	US	Safety
ASTM F519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments	US	Safety
ASTM B577	Standard Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper	US	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ASTM B839	Standard Test Method for Residual Embrittlement in Metallic Coated, Externally Threaded Articles, Fasteners, and Rod-Inclined Wedge Method	US	Safety
ASTM F1459	Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement	US	Safety
ASTM F1624	Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique	US	Safety
ISO 11114	Gas cylinders – Compatibility of cylinder and valve materials with gas contents	INT	Safety
ISO 21010	Cryogenic Vessels – Gas / Materials Compatibility	INT	LH2 storage and distribution systems
ISO 11114-4:2017	Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	INT	Safety
ANSI/NACE TM0284-2016	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking	US	Safety
ISO 21028-1	Cryogenic Vessels – Toughness requirements for materials at cryogenic temperature – Part 1: Temperatures below -80°C.	INT	LH2 storage and distribution systems
ISO 11114-1:2012	Gas cylinders — Compatibility of cylinder and valve materials with	INT	Material compatibility, GH2 storage systems

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	gas contents — Part 1: Metallic materials		
ASTM Committee F07 Aerospace & Aircraft / F07.04	Hydrogen Embrittlement Standard Test Methods	US	hydrogen material selection / acceptance

6.1.9 Standards for hydrogen sensors

Hydrogen sensors are typically used in installations and equipment. The following table lists the current standards used to evaluate the performance of hydrogen sensors.

Table 17: Standards for hydrogen sensors

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
UL 2075	Gas and Vapor Detectors and Sensors	US	Performance
CSA C22.2 No. 152-M1984 (R2016)	Combustible Gas Detection Instruments	CAN	Performance
ISO 26142	Hydrogen detection apparatus — Stationary applications	INT	Performance
FM 6310/6320	Approval Standard for Combustible Gas Detectors	INT	Performance

6.1.10 Standards for pressure relief devices

The following standards can be used for pressure relief devices if the equipment standard does not reference a suitable standard.

Table 18: Standards for pressure relief devices

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CSA/ANSI HPRD1	Basic Requirements for Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers	CAN/US	Safety
ISO 4126-1:2013	Safety devices for protection against excessive pressure — Part 1: Safety valves	INT	Safety
Federal Railroad Administration - Code of Federal Regulations, Title 49 - PART 179	Federal Railroad Administration - Code of Federal Regulations, Title 49 – Transportation, Date: 2020-10-01, Title: 179.15 Pressure relief devices.	US	Safety Code of Federal Regulations (govinfo.gov)
CGA S-1.1	Guides Cylinder Pressure Relief Device Selection and Sizing	US	Safety
CGA S-1.1	Pressure Relief Device Standards-Part 1-Cylinders for Compressed Gases	US	Safety, includes PRD sizing.
CGA S-1.2	Pressure Relief Device Standards-Part 2-Portable Containers for Compressed Gases	US	Safety, includes PRD sizing.
CGA S-1.3	Pressure Relief Device Standards-Part 3-Stationary Storage Containers for Compressed Gases	US	Safety, includes PRD sizing.

6.1.11 Standards for control equipment

The following table lists standards that could be used to evaluate safety control equipment.

Table 19: Standard for control equipment

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
C22.2 No. 14	Industrial control equipment	CAN	Safety
CSA C22.2 NO 61010-1, 3rd Edition, 2017	Safety requirements for electrical equipment for measurement, control, and laboratory use - part 1: general requirements	CAN	Safety
CAN/CSA-E60730-1	Automatic electrical controls — Part 1: General requirements	CAN	Safety
CAN/CSA-E60730-2-6	Automatic electrical controls — Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements	CAN	Safety
CAN/CSA-E60730-2-9	Automatic electrical controls — Part 2-9: Particular requirements for temperature sensing controls	CAN	Safety
UL 61010-1	Safety Requirements for Electrical Equipment for Measurement Control, and Laboratory Use – Part 1: General Requirements	US	Safety
IEC 60730-1	Automatic electrical controls — Part 1: General requirements	INT	Safety
IEC 60730-2-6	Automatic electrical controls — Part 2-6: Particular requirements for automatic electrical	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	pressure sensing controls including mechanical requirements		
IEC 60730-2-9,	Automatic electrical controls — Part 2-9: Particular requirements for temperature sensing control	INT	Safety
IEC 60730-2-14:2017 RLV	Automatic electrical controls – Part 2-14: Particular requirements for electric actuators	INT	Safety
IEC 60730-2-15:2017	Automatic electrical controls – Part 2-15: Particular requirements for automatic electrical air flow, water flow and water level sensing controls	INT	Safety
ISO 13849-1, Safety of machinery	Safety-related parts of control systems — Part 1: General principles for design	INT	Safety
ISO 13849-2	Safety of machinery — Safety-related parts of control systems — Part 2: Validation	INT	Safety

6.1.12 Standards for functional safety (safety programmable controls)

Functional safety standards are necessary to evaluate the reliability of programmable solid state devices. Both the software and the hardware have to be evaluated to ensure these devices are reliable for safety functions, or if their failure could result in a safety hazard.

Table 20: Standards for functional safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA-C22.2 NO. 61511-1:17	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
CAN/CSA-C22.2 No. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems — Part 1: General requirements	CAN	Safety
CAN/CSA-C22.2 NO. 61508-2:17	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
CAN/CSA-C22.2 No. 61508-3:17	Functional safety of electrical/electronic/programmable electronic safety related systems — Part 3: Software requirements	CAN	Safety
IEC 61508-(All Parts)	Functional safety of electrical/electronic/programmable electronic safety-related systems	INT	Safety
IEC 61511-1	Functional safety — Safety instrumented systems for the process industry sector — Part 1: Framework, definitions, system, hardware and application programming requirements	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
IEC 62061	Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems	INT	Safety
ANSI/UL 1998	Standard For Software in Programmable Components	US	Safety
UL 991 (2004)	Standard for Safety Tests for Safety-Related Controls Employing Solid-State Devices	US	Safety

6.1.13 Standards for electromagnetic compatibility

Electrical standards require that the safety of equipment is not compromised due to electromagnetic interference. The following standards are used to ensure the equipment and its components are resistant to electromagnetic interference and at the same time the equipment's electromagnetic emissions meet some parameters.

Table 21: Standards for electromagnetic compatibility

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CSA C61000-4-1:19	Electromagnetic compatibility (EMC) — Part 4-1: Testing and measurement techniques	CAN	Safety
IEC 61000-3-2	Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤16 A per phase)	INT	Safety
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	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	and not subject to conditional connection		
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	INT	Safety
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	INT	Safety
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	INT	Safety
IEC 61000-6-1	Electromagnetic compatibility (EMC) — Part 6-1: Generic standards — Immunity standard for residential, commercial and light-industrial environments	INT	Safety
IEC 61000-6-2	Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity standard for industrial environments	INT	Safety
IEC 61000-6-3	Electromagnetic compatibility (EMC) — Part 6-3: Generic standards — Emission standard	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
	for residential, commercial and light-industrial environments		
IEC 61000-6-4	Electromagnetic compatibility (EMC) — Part 6-4: Generic standards — Emission standard for industrial environments	INT	Safety
CSA C22.2 NO. 60947-5-5:21	Low-voltage switchgear and control gear	CAN	EMC

6.1.14 Standards for material properties and fire ratings

The following table lists standards that can be used to ensure appropriate material fire ratings.

Table 22: Standards for material properties and fire ratings

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ASTM E2652	Standard Test Method for Assessing Combustibility of Materials Using a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750°C	US	Safety
UL 94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances	US	Safety
UL 746C	Polymeric Materials - Use in Electrical Equipment Evaluations	US	Safety
NFPA 274	Standard Test Method to Evaluate Fire Performance Characteristics of Pipe Insulation	US	Safety

ISO 1182:2010	Reaction to fire tests for products — Non-combustibility test	INT	Safety
IEC 60695-11-10	Fire hazard testing - Part 11-10: Test flames - 50 W horizontal and vertical flame test methods	INT	Safety
CAN/CSA C22.2 No. 0.17	CAN/CSA C22.2 No. 0.17 - Evaluation of Properties of Polymeric Materials	CAN	Safety

6.1.15 Standards for fire alarm systems

The following standards can be used to evaluate fire alarm systems used in equipment such as stationary power plants and hydrogen dispensers.

Table 23: Standards for fire alarm systems

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
UL 864	Control Units and Accessories for Fire Alarm Systems	US	Safety
UL 2017	Control Units and Accessories for Fire Alarm Systems	US	Safety
FM 3010	Approval Standard for Fire Alarm Signaling Systems	INT	Safety

6.1.16 Standards for enclosures

In North America, enclosures must meet the National Electrical Manufacturer Association (NEMA) enclosure rating to ensure adequate protection for solid particles, water ingress, snow, and ice. In Europe, the IP (Ingress Protection) rating is used, which accounts for solid particles and water ingress. The equipment standard will require a certain NEMA rating; the standards in the next table include the test requirements for the different NEMA ratings. As the IP rating and NEMA tests are different, they are difficult to harmonize.

Table 24: Standards for enclosures

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
C22.2 No. 94.1	Enclosures for electrical equipment, non-environmental considerations	CAN/US/MEX	Safety
C22.2 No. 94.2	Enclosures for electrical equipment, environmental considerations	CAN/US/MEX	Safety
IEC 60529	Degrees of protection provided by enclosures (IP Code)	INT	Safety

6.1.17 Standards for air compressors

The following table lists standards for air compressors.

Table 25: Standards for air compressors

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO 4414	Pneumatic fluid power — General rules and safety requirements for systems and their components	INT	Safety
ISO 5388	Stationary air compressors — Safety rules and code of practice	INT	Safety
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/US	Safety

6.1.18 Standards for gas compressors

The following standards can be used for flammable gas compressors (there are no standards for hydrogen compressors).

Table 26: Standards for gas compressors

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ANSI NGV 4.8/CSA 12.8	Natural gas vehicle fueling station reciprocating compressor guidelines	CAN/US	Guideline
ASME B19.3	Safety Standard For Compressors For Process Industries	US	Safety
CAGI 3075 – ANSI/CAGI B19.1	Safety Standards for Compressor Systems	US	Safety
ISO 10439 (All Parts)	Petroleum, petrochemical and natural gas industries — Axial and centrifugal compressors and expander-compressors — Part 1: General requirements	INT	Safety
ISO 10440-1	Petroleum, petrochemical and natural gas industries — Rotary-type positive-displacement compressors — Part 1: Process compressors	INT	Safety
ISO10440-2	Petroleum and natural gas industries — Rotary-type positive-displacement compressors — Part 2: Packaged air compressors (oil-free)	INT	Safety
ISO 10442	Petroleum, chemical and gas service industries — Packaged, integrally geared centrifugal air compressors	INT	Safety
ISO 13631	Petroleum and natural gas industries — Packaged reciprocating gas compressors	INT	Safety

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO 13707	Petroleum and natural gas industries — Reciprocating compressors	INT	Safety

6.1.19 Standards for risk assessments

All installations require a risk assessment and risk analysis. The following ISO, SAE, and IEC standards provide guidance for risk assessment and risk reduction design principles.

Table 27: Standards for risk assessments

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
ISO 12100	Safety of machinery — General principles for design — Risk assessment and risk reduction	INT	Safety
SAE J1739_202101	Potential Failure Mode and Effects Analysis (FMEA) Including Design FMEA, Supplemental FMEA-MSR, and Process FMEA	INT	Safety
IEC 60812:2018	Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)	INT	Safety
IEC 61882:2016	Hazard and operability studies (HAZOP studies)	INT	Safety
IEC 61025:2006	Fault Tree Analysis.	INT	Safety

6.1.20 Standards for training and certification requirements

The NRC is currently not aware of standards in this area specific for hydrogen.

6.1.21 Standards for protection against lightning

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

Table 28: Standard for protection against lightning

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA-B72-M	Installation Code for Lightning Protection Systems	CAN	Safety

6.1.22 Standards for component testing (fuel cells)

Table 29: Standard for component testing (fuel cells)

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/CSA-C22.2 No. 62282-2:2018	Fuel cell technologies – Part 2: Fuel cell modules (IEC 62282-2:2012, MOD)	CAN	Safety
CSA/ANSI FC6	Fuel Cell Modules	US	Safety
IEC TS 62282-7-1:2017	Fuel cell technologies - Part 7-1: Test methods - Single cell performance tests for polymer electrolyte fuel cells (PEFC)	INT	Performance
IEC 62282-7-2, Edition 1 (2021-05-21)	Fuel cell technologies - Part 7-2: Test methods - Single cell and stack performance tests for solid oxide fuel cells (SOFCs)	INT	Performance
ASTM Committee D03 Gaseous Fuels / D03.14	Hydrogen and Fuel Cells – Standard Test Methods	US	H2 and FC systems – test methods

6.2 STANDARDS FOR ELEMENT 1 – ELECTROLYSIS

The following table includes standards for Electrolysis. It does not include all the standards that are applicable to all hydrogen installations, which are included in element 69 (e.g., standards for material compatibility, area classification, electrical machinery, lightening systems, etc.). Therefore, the complete list of standards applicable to electrolysers are those listed here in addition to those listed in element 69.

Table 30: Standards related to electrolysis

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
CAN/BNQ 1784-000	Canadian Hydrogen Installation Code	CAN	Safety
ISO 22734-1:2008	Hydrogen generators using water electrolysis process -- Part 1: Industrial and commercial applications	INT	Safety
ISO 22734-2:2011	Hydrogen generators using water electrolysis process -- Part 2: Residential applications	INT	Safety
ISO 19884	Gaseous hydrogen – Cylinders and tubes for stationary storage	INT	Safety
ISO 14687-1, 2008	Hydrogen fuel — Product specification Technical Corrigendum 1 & 2.	INT	Specification
ISO 14687-1, 1999	Hydrogen fuel -- Product specification -- Part 1: All applications except proton exchange membrane (PEM) fuel cell for road vehicles	INT	Specification
ISO 14687-2, 2012	Hydrogen fuel -- Product specification -- Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles	INT	Specification

ISO 14687-3, 2014	Hydrogen fuel -- Product specification -- Part 3: Proton exchange membrane (PEM) fuel cell applications for stationary appliances	INT	Specification
ISO 16528-1	Boilers and pressure vessels — Part 1: Performance requirements	INT	Performance
ISO 4126-1:2013	Safety devices for protection against excessive pressure — Part 1: Safety valves	INT	Safety
IEC 62282-8-201:2020	Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems. This document is under revision, with the CD IEC 62282-8-201 ED2 expected early in 2022	INT	Performance
IEC 62282-8-101:2020	Fuel cell technologies - Part 8-101: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation.	INT	Performance
IEC 62282-8-102:2019	Fuel cell technologies - Part 8-102: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation	INT	Performance
ASME B31.12	Hydrogen Piping and Pipelines (part of ASME B31 Series Piping and Pipelines)	US	Safety
ASME STP-PT-006	Design Guidelines for Hydrogen Piping and Pipelines	US	Safety
ASME BPVC	Boiler and Pressure Vessel Code	US	Safety

CGA Publication G5	Hydrogen	US	Information
CGA Publication G5.3	Hydrogen Product Standard	US	Specification
CGA Publication G5.5	Hydrogen Vent Systems	US	Safety
CGA Publication H4	Terminology Associated with Hydrogen Fuel Technologies	US	Terminology
CGA Publication H5	Installation Standard for Bulk Hydrogen Supply Systems; total process	US	Safety
CGA Publication P6	Standard Density Data, Atmospheric Gases and Hydrogen	US	Information
CGA Publication PS31	Cleanliness for PEM Hydrogen Piping / Components	US	Specification
CGA Publication PS48	CGA Position Statement on Clarification of Existing Hydrogen Setback Distances and Development of New Hydrogen Setback Distances in NFPA 55	US	Safety
National Fire Protection Association (NFPA): NFPA-2-11	Hydrogen Technologies Code	US	Safety
NFPA 55	Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks	US	Safety
NFPA 70 Article 692	National Electrical Code – Fuel Cell Systems	US	Safety
Outline of Investigation UL Subject 2264B	Gaseous Hydrogen Generation Appliances - Water Reaction	US	Safety
Outline of Investigation UL Subject 2264D	Portable Water Electrolysis Type Hydrogen Generators, Part 1: Safety	US	Safety

UL 61010-1	Safety Requirements for Electrical Equipment for Measurement Control, and Laboratory Use – Part 1: General Requirements	US	Safety
UL 864	Control Units and accessories for Fire Alarm Systems	US	Safety
UL 2017	Control Units and Accessories for Fire Alarm Systems	US	Safety
UL 94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances	US	Safety
UL 746C	Polymeric Materials - Use in Electrical Equipment Evaluations	US	Safety
US Department of Labour, OSHA 29 CFR 1910.103	Hydrogen	US	Safety
EIGA Doc 121/04	Hydrogen Pipeline Systems. Limited to gaseous products with a temperature range between –40C and 175C, total pressure from 1 MPa to 21 MPa.	EUR	Safety
FM 3810	Approval Standard for Electrical Equipment for Measurement, Control and Laboratory Use	INT	Safety
AS 22734:2020	Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications (ISO 22734:2019, MOD)	AUS	Safety
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles	INT	Safety
ISO/AWI TR 15916	Basic considerations for the safety of hydrogen systems	INT	Safety
ISO/CD 19880-6	GH2— Fueling stations — Part 6: Fittings	INT	Safety

ISO/AWI TR 22734-2	Hydrogen generators using water electrolysis — Part 2: Testing guidance for performing electricity grid service	INT	Safety

6.3 STANDARDS FOR ELEMENT 12 – HYDROGEN STORAGE (ABOVE GROUND OR UNDERGROUND)

The following table includes standards for hydrogen storage systems. It does not include all the standards that are applicable to all hydrogen installations, which are included in element 69 (e.g., standards for material compatibility, area classification, electrical machinery, hydrogen sensors, lightening protection systems, etc.). Therefore, the complete list of standards applicable to hydrogen storage systems are those listed here plus those listed in element 69.

Table 31. Standard related to hydrogen storage

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
BNQ 1784-000	Canadian Hydrogen Installation Code	CAN	Ground H2 systems / infrastructure
CAN/CSA B51-97	Boiler, Pressure Vessel, and Pressure Piping Code	CAN	GH2 storage, piping, and equipment.
ISO 19882	Gaseous Hydrogen – Thermally active pressure relief devices for compressed hydrogen vehicle fuel containers	INT	GH2 storage TPRDs
ISO 19884	Gaseous hydrogen – Cylinders and tubes for stationary storage	INT	GH2 storage
ISO 21010	Cryogenic Vessels – Gas / Materials Compatibility	INT	LH2 storage and distribution systems
ISO 21010-3	Cryogenic Vessels – Pressure relief accessories for cryogenic service – Part 3: Sizing and capacity determination	INT	LH2 storage PRDs
ISO 21014	Cryogenic Vessels – Cryogenic insulation performance	INT	LH2 storage and distribution systems

ISO 21028-1	Cryogenic Vessels – Toughness requirements for materials at cryogenic temperature – Part 1: Temperatures below -80°C.	INT	LH2 storage and distribution systems
ISO 23208	Cryogenic vessels – Cleanliness for cryogenic service	INT	H2 Storage
OIML R 81	Dynamic measuring devices and systems for cryogenic liquids	INT	LH2 filling and/or refueling
CAN/CSA-B72-M	Installation Code for Lightning Protection Systems	CAN	Ground based H2 systems lightning protection.
CSA/ANSI HGV2	Standards for Hydrogen Vehicle Fuel Containers	CAN/US	GH2 storage systems
CSA/ANSI HPRD1	Basic Requirements for Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers	CAN/US	GH2 storage PRDs
CSA/ANSI SPE 2.3.1	Best practices for defueling, decommissioning, and disposal of compressed hydrogen gas vehicle fuel containers	CAN/US	GH2 storage – end of life procedures
ASME B31.12	Hydrogen Piping and Pipelines (part of ASME B31 Series Piping and Pipelines)	US	H2 piping
ASME STP-PT-006	Design Guidelines for Hydrogen Piping and Pipelines	US	H2 piping
ASME BPVC	Boiler and Pressure Vessel Code	US	GH2 storage, piping, and equipment.
CGA Publication G5.5	Hydrogen Vent Systems	US	H2 vent systems
CGA Publication H3	Cryogenic Hydrogen Storage	US	LH2 storage systems
CGA Publication H4	Terminology Associated with Hydrogen Fuel Technologies	US	General H2 comprehension and training. Convention on language and terms.

CGA Publication H5	Installation Standard for Bulk Hydrogen Supply Systems; total process	US	H2 systems / infrastructure, operations, maintenance, and training
CGA Publication H14	HYCO Plant Gas Leak Detection and Response Practices	US	Leak detection for ground H2 storage / re-fueling systems and transfer operations.
CGA Publication P6	Standard Density Data, Atmospheric Gases and Hydrogen	US	Hydrogen density data source
CGA Publication P12	Safe Handling of Cryogenic Liquids	US	LH2 safe handling for operations / maintenance
CGA Publication P28	Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems	US	LH2 HAZOP and Risk Management Planning
CGA Publication P41	Locating Bulk Liquid Storage Systems in Courts	US	LH2 cryogenic storage areas
CGA Publication PS46	Position Statement – Roofs Over Hydrogen Storage Systems	CUS	GH2 storage systems
CGA Publication PS48	CGA Position Statement on Clarification of Existing Hydrogen Setback Distances and Development of New Hydrogen Setback Distances in NFPA 55	US	H2 systems / infrastructure
NFPA 55	Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks	US	H2 storage systems / equipment
EIGA Doc 121/04	Hydrogen Pipeline Systems. Limited to gaseous products with a temperature range between –40C and 175C, total pressure from 1 MPa to 21 MPa.	EUR	GH2 piping / distribution systems

CGA C-1-2016	Methods for Pressure Testing Compressed Gas Cylinders	US	Safety
ISO 9809-1:2019 Gas cylinders	Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 1: Quenched and tempered steel cylinders and tubes with tensile strength less than 1 100 Mpa	INT	Safety
ISO/TR 13086-1:2011 Gas cylinders	Gas cylinders — Guidance for design of composite cylinders — Part 1: Stress rupture of fibres and burst ratios related to test pressure	INT	Safety
ISO/TR 13086-3:2018 Gas cylinders	Guidance for design of composite cylinders — Part 3: Calculation of stress ratios	INT	Safety
CSA-B51 Part 3	Compressed Natural Gas and Hydrogen Refuelling Station Pressure Piping Systems and Ground Storage Vessels	CAN	GH2 piping / distribution systems
ISO 16528-1:2007	Boilers and pressure vessels — Part 1: Performance requirements	INT	GH2 piping, and equipment.
ISO 4126-1:2013	Safety devices for protection against excessive pressure — Part 1: Safety valves	INT	Gas valves
OSHA 29 CFR Part 1910	Standards - 29 CFR 1910.101 - Compressed gases (general requirements).	US	H2 storage
ISO/TS 19883:2017	Safety of pressure swing adsorption systems for hydrogen separation and purification	INT	GH2 piping, and equipment.
ISO 11114-4:2017	Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels	INT	Testing materials for hydrogen Embrittlement

	resistant to hydrogen embrittlement		
NFPA 497	Recommended Practice for the Classification of Flammable Liquids, Gases or Vapours and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas	US	H2 systems / infrastructure
FAA 14 CFR Part 420	License to Operate a Launch Site	US	GH2 safety requirements
ISO 7866:2012	Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing	INT	GH2 storage systems
ISO 11119-1:2020	Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes	INT	GH2 storage systems
ISO 11119-2:2020	Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes	INT	GH2 storage systems
ISO 11119-3:2020	Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes	INT	GH2 storage systems
ISO 11114-1:2012	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials	INT	Material compatibility, GH2 storage systems
CGA Publication H1	Service Conditions for Portable, Reversible Metal Hydride Systems	US	Safety
CGA Publication H2	Guidelines for the Classification and Labeling of Hydrogen Storage Systems with Hydrogen Absorbed in Reversible Metal Hydrides	US	Safety

ISO 16111	Transportable Gas Storage Devices - Hydrogen Absorbed in Reversible Metal Hydrides	INT	Safety
UL 2262A	Borohydride Fuel Cartridges with Integral Fuel Processing for Use with Portable Fuel Cell Power Systems for Similar equipment	US	Safety
CGA Publication C21	Design, Qualification and Testing for Pressure Vessels for Portable, Reversible Metal Hydride Systems	US	Safety
29 CFR 1910, Subpart H	Hazardous Materials	US	Safety
CGA Publication C-1-2016	Methods for Pressure Testing Compressed Gas Cylinders	US	GH2 storage systems
ISO 21029-1:2004	Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 L volume – Part 1: Design, fabrication, inspection and tests	INT	Transportation of H2 fuels

6.4 STANDARDS FOR ELEMENT 47 – FORKLIFTS

The following table includes standards for forklifts. It does not include all the standards that are applicable to all hydrogen installations, which are included in element 69 (e.g., standards for material compatibility, area classification, electrical machinery, hydrogen sensors, etc.). Therefore, the complete list of standards applicable to forklifts are those listed here plus those listed in element 69.

Table 32. Standards related to forklifts

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
IEC 62282-4-101:2014	Fuel cell technologies - Part 4-101: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) - Safety of electrically powered industrial trucks	INT	Safety
IEC 62282-4-600 ED1	Fuel cell technologies - Part 4-600: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) - Fuel cell/battery hybrid systems performance test	INT	Performance
IEC 62282-4-102 ED2	Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods	INT	Performance
UL 2267	Standard for Fuel Cell Power Systems for Installation in Industrial Electric Trucks	US	Safety
ISO 13984	Liquid Hydrogen Land Vehicle Fueling System Interface	INT	LH2 refueling system / equipment
ISO 13985	Liquid Hydrogen – Land Vehicle Fuel Tanks	INT	LH2 storage tanks
ISO 17268	Gaseous Hydrogen Land Vehicle Refueling Connection Devices	INT	GH2 storage systems
ISO 19078:2013	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 (NOTE: many hydrogen	INT	GH2 storage systems

	standards have been adapted from natural gas standards)		
ISO 19881	Gaseous Hydrogen – Land vehicle fuel containers	INT	GH2 storage tanks
ISO 19882	Gaseous Hydrogen – Thermally active pressure relief devices for compressed hydrogen vehicle fuel containers	INT	GH2 storage TPRDs
ISO 19887	Gaseous hydrogen – Land Vehicle fuel system components, including regulators, check valves, manual / automatic valves, gas injectors, pressure indicators, pressure relief devices, excess flow valves, gas-tight housings and ventilation hoses, rigid fuel lines, flexible fuel lines, filters / filter housings, discharge line closures, fittings, and gas-tight housing and leakage capture lines and passages.	INT	GH2 non-storage components; containment concepts for GH2 leaks.
ISO 21029-1:2004	Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 L volume – Part 1: Design, fabrication, inspection and tests	INT	Transportation of H2 fuels
ISO 23273	Fuel Cell Road Vehicle – Safety Specifications	INT	H2 systems safety
ISO 23828	Fuel Cell Road Vehicles – Energy consumption measurement Part 1: Vehicles fueled with compressed hydrogen	INT	H2 consumption monitoring
OIML R 81	Dynamic measuring devices and systems for cryogenic liquids	INT	LH2 filling and/or refueling
OIML R 139	Gaseous fuel measuring systems for vehicles	INT	Refueling and potentially FC hydrogen fuel measuring systems

United Nations Global Technical Regulations (GTR) – Work Party 29, Hydrogen Vehicles	Work Party 29, Hydrogen Vehicles – Liquid Hydrogen, Gaseous Hydrogen	INT	Safety of hydrogen and fuel cell systems
CSA/ANSI HGV2	Standards for Hydrogen Vehicle Fuel Containers	CAN/US	GH2 storage systems
CSA/ANSI HGV3.1	Fuel System Components for Hydrogen Gas Powered Vehicles, including check valves, manual valves, manual / automatic valves, gas injectors, pressure indicators, pressure regulators, pressure relief valves, pressure relief devices, excess flow valve, gas tight housing and ventilation lines and passages, rigid fuel lines, flexible fuel lines, filter housings, fittings, and relief line closures.	CAN/US	GH2 non-storage components; containment / ventilation concepts for GH2 leaks.
CSA/ANSI HPRD1	Basic Requirements for Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers	CAN/US	GH2 storage PRDs
CSA/ANSI SPE 2.3.1	Best practices for defueling, decommissioning, and disposal of compressed hydrogen gas vehicle fuel containers	CAN	GH2 storage – end of life procedures
ASTM Committee D03 Gaseous Fuels / D03.14	Hydrogen and Fuel Cells – Standard Test Methods	US	H2 and FC systems – test methods
CGA Publication P12	Safe Handling of Cryogenic Liquids	US	LH2 safe handling for operations / maintenance
SAE J2601-3	Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks J2601/3_201306	US	filling / fueling systems
SAE J2799	70 MPa Compressed Hydrogen Surface Vehicle Refueling Connection Device and Optional Vehicle to Station Communication	US	H2 fueling systems / operations

SAE J3219	Hydrogen Fuel Quality Screening Test of Chemicals for Fuel Cell Vehicles	US	H2 fuel testing
SAE J2760	Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications	US	H2 comprehension and training
SAE J3089	Technical Information Report (TIR) for Vehicular Hydrogen Sensor Test Method	US	H2 leak detection / safety system validation
US Department of Labour, OSHA 29 CFR 1910.103	Hydrogen	US	H2 operations and maintenance
UN/ECE Regulation 134	Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety related performance of hydrogen fueled vehicles (HFCV): Part (I, II, III)	EUR	H2 storage and refueling systems / infrastructure
EC No. 79/2009	Type-approval of hydrogen powered motor vehicles. This Regulation shall apply to: (i) Hydrogen-powered vehicles of categories M and N, as defined in Section A of Annex II to Directive 2007/46/EC, including impact protection and the electric safety of such vehicles. (ii) Hydrogen components designed for motor vehicles of categories M and N, as listed in Annex I. (iii) Hydrogen systems designed for motor vehicles of categories M and N, including new forms of hydrogen storage or usage.	EUR	H2 vehicle safety
CAN/CSA C22.2 No. 62282-2-2018	Fuel Cell Technologies – Part 2: Fuel Cell Modules (Canadian adaptation of IEC 62282-2, under Part II of Canadian Electrical Code)	CAN	FC systems

CSA/ANSI FC6	Fuel Cell Modules	US	FC systems
CGA Publication G5.3	Hydrogen Product Standard	US	FC systems
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles	US	FC systems
SAE J2615	Performance Test Procedure of Fuel Cell Systems for Automotive Applications	US	FC systems performance validation
SAE J2617	Performance Test Procedure of PEM Fuel Cell Stack Subsystem for Automotive Application	US	FC stack performance validation
SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety	US	FC and H2 storage, operations, and maintenance
SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	US	H2 system design, operations, and maintenance
CSA-HPIT 1- 2015	CSA HPIT 1-2015 - Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage And Handling Components	CAN	establishes minimum requirements for the material, design, manufacture, and testing of newly produced compressed hydrogen gas fuel system components and serially produced HPITs
CSA HPIT 2-2017	Dispensing Systems And Components For Fueling Hydrogen Powered Industrial Trucks	CAN	Dispensing systems and components for fueling hydrogen powered industrial trucks.
CGA Publication C6.4	Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and Hydrogen Vehicle (HV) Fuel Containers and their Installation.	US	GH2 storage, piping, and equipment
SAE J2572	Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fueled by Compressed Gaseous Hydrogen.	INT	Performance

SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices. This document applies to devices which have Pressure Classes of H11, H25, H35, H50 or H70.	INT	filling / fueling systems
SAE J2601/4	Ambient Temperature Fixed Orifice Fueling	INT	H2 fueling systems / operations

6.5 STANDARDS FOR ELEMENT 70 - COMMON INSTALLATION ITEMS

The following table includes standards for common installation items.

Table 33. Standards related to common installation items

STANDARD	STANDARD TITLE	NATIONALITY	APPLICABILITY
BNQ 1784-000	Canadian Hydrogen Installation Code	CAN	Ground H2 systems / infrastructure
International Fire Code (IFC)	Chapter 23 – Hydrogen Motor Fuel-Dispensing and Generation Facilities - Chapter 50 – Hazard Materials – General Provisions - Chapter 53 – Compressed Gases - Chapter 58 – Flammable Gases and Flammable Cryogenic Fluids	INT	H2 systems / infrastructure
International Building Code (IBC)	International Building Code (IBC)	INT	Adjacent buildings and infrastructure in proximity to H2 systems and equipment
International Mechanical Code (IMC)	International Mechanical Code (IMC)	INT	H2 ventilation and indoor fueling
International Fuel Gas Code (IFGC)	Chapter 7 – Gaseous Hydrogen Systems	INT	H2 ventilation and indoor fueling

National Building Code of Canada / relevant provincial building codes	National Building Code of Canada / relevant provincial building codes	CAN	Adjacent buildings and infrastructure in proximity to H2 systems and equipment.
National Fire Code of Canada / relevant provincial codes	National Fire Code of Canada / relevant provincial codes	CAN	H2 systems / infrastructure
National Plumbing Code of Canada 2015 / relevant provincial codes	National Plumbing Code of Canada 2015 / relevant provincial codes	CAN	
CAN/CSA C22.1	Canadian Electrical Code.	CAN	Ground based hazardous area electrical requirements
CAN/CSA-B72-M	Installation Code for Lightning Protection Systems	CAN	Ground based H2 systems lightning protection.
AIAA G-095	Guide to Safety of Hydrogen and Hydrogen Systems	CAN/US	H2 systems / infrastructure, operations, maintenance, and training
CAN/CSA B51-97	Boiler, Pressure Vessel, and Pressure Piping Code	CAN	GH2 storage, piping, and equipment.
ASME B31.12	Hydrogen Piping and Pipelines (part of ASME B31 Series Piping and Pipelines)	US	H2 piping
ASME STP-PT-006	Design Guidelines for Hydrogen Piping and Pipelines	US	H2 piping
ASME BPVC	Boiler and Pressure Vessel Code	US	GH2 storage, piping, and equipment.
CGA Publication G5	Hydrogen	US	H2 storage systems and operations
CGA Publication G5.5	Hydrogen Vent Systems	US	H2 vent systems
CGA Publication H14	HYCO Plant Gas Leak Detection and Response Practices	CAN/US	Leak detection for ground H2 storage / re-fueling systems and transfer operations.
CGA Publication P41	Locating Bulk Liquid Storage Systems in Courts	CAN/US	LH2 cryogenic storage areas

CGA Publication PS46	Position Statement – Roofs Over Hydrogen Storage Systems	CAN/US	GH2 storage systems
CGA Publication PS48	CGA Position Statement on Clarification of Existing Hydrogen Setback Distances and Development of New Hydrogen Setback Distances in NFPA 55	CAN/US	H2 systems / infrastructure
National Fire Protection Association (NFPA): NFPA-2-2020	Hydrogen Technologies Code	US	H2 systems / infrastructure
NFPA 70 Article 692	National Electrical Code – Fuel Cell Systems	US	Safety
NFPA 55	Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks	US	H2 storage systems / equipment
UL 2075	Gas and Vapor Detectors and Sensors	US	infrastructure H2 leak detection
US Department of Energy (DOE) Hydrogen and Fuel Cells Permitting Guide	Hydrogen and Fuel Cells Permitting Guide	US	H2 systems / infrastructure permitting
EIGA Doc 121/04	Hydrogen Pipeline Systems. Limited to gaseous products with a temperature range between –40C and 175C, total pressure from 1 MPa to 21 MPa.	EUR	GH2 piping / distribution systems

7. GAP ANALYSIS AND INDUSTRY FEEDBACK

7.1 Industry feedback

SOLICITATION QUESTIONNAIRE AND SURVEYS

To obtain feedback from Canadian hydrogen companies, a questionnaire (provided in Annex A) was developed and issued to 16 companies. The list of companies approached is provided in Annex B. TSBC, AMA, and TSSA were also approached for input. The feedback received was limited due to the fact that it takes time for the questionnaire to find its way to the appropriate personnel within an organization.

Two surveys were also issued for this project by CSA to stakeholders regarding the use and gaps in Codes and Standards in Canada. Selected CSA standard committee members were surveyed and asked for their feedback on 1) Installation of hydrogen generation using water electrolysis; and 2) Installation of a hydrogen dispenser. The survey results are shown in the following table.

Table 34 Survey results

	Codes and standards currently used	Codes and Standards gaps in Canada	Additional feedback to be considered
INSTALLATION OF HYDROGEN GENERATION USING WATER ELECTROLYSIS			
Installation of hydrogen generation using water electrolysis	BNQ-1784	BNQ-1784 getting out of date	Suggestion to harmonize with NFPA 2. CSA (US) version of ISO 22734 would be adequate; multiple variations based on size or technology is not helpful.
Product/Application Standards for hydrogen generation using water electrolysis	No feedback.	FCTC is working on a binational version of ISO 22734	
Component standard for a hydrogen generation using water electrolysis	No feedback.	The way pressure equipment and vessels are handled in Canada is a hinderance to business. Even though there is one “rule”, CSA B51, there is not a common system for certification. Separate Canadian Registration Numbers (CRNs) have to be obtained for each province. This causes a lot of extra work, delay, and cost without adding anything to safety.	
Use/Implementation of codes and standard for hydrogen generation using water electrolysis	No feedback.		
General feedback		ISO TC197 WG32 will be bringing a water electrolyzer grid connection performance standard forward for vote as a draft TR 22734-2 in the coming months. It will be a Technical Report for Hydrogen generators using water electrolysis - Testing protocols for performing electricity grid services.	

INSTALLATION OF A HYDROGEN DISPENSER			
Installation of a hydrogen dispenser	HGV 4.1, BNQ-1784, HGV 4.9, CEC CSA C22.1, local building codes, NFPA 2, ISO 19880-1, CSA HGV 4.5, CSA B51, CSA C22.2 No. 60079-0:19, CSA C22.2 No. 60079-1, CSA 60079-2, CSA 60079-10-1, CSA 60079-13, NFPA 496, Canadian Pressure Vessel Code	Waiting for updated version of BNQ 1874-000. Adoption of CSA HGV 4.1/4.3/4.9 by AHJ's. A clearly defined method to ensure the safety of the storage tanks and the associated pipe/valves/fittings. There is not clarity here, and it should be noted that the same holds true in USA.	ISO/DIS 19880-2 (publication within 2023-2024 timeframe). To what I understand CHIC and NFPA-2 are fairly harmonized and should remain harmonized so that North American companies can leverage similar designs across boards thus reducing costs and furthering adoption. Harmonization across provinces is key as well. Each province in Canada currently requires different level of due diligence or effort. For example, Alberta who is very familiar with oil and gas may require a higher level of safety when compared to Ontario, BC or Quebec. This is because most installation and inspection officials are familiar with heavy industry practices. Hydrogen dispensers are consumer facing and may or may not need the same level of diligence.
Product/Application Standards for a hydrogen dispenser	HGV 4.1, BNQ-1784, HGV 4.9, CSA HGV 4.3,	Change hazardous area section to two options, one descriptive approach using IEC 60079-10, option two using NFPA and HGV 4.1 prescriptive approach.	ISO/DIS 19880-2 (publication within 2023-2024 timeframe). Need to apply some consideration to hazardous areas as BNQ uses IEC 60079-10 to calculate hazardous areas, where as HGV 4.1 as a prescriptive approach. Furthermore, for very specific applications, CEC CSA C22.1, has a prescriptive approach for CNG and gasoline dispensers. If the CEC updates to include hazardous areas (for consistency as H2 stations become more popular), it will need to be aligned with HGV 4.1. Furthermore, I could see it being beneficial for AHJ's to be able to see stations are designed to a prescriptive approach as it will be less work for them to review hazardous areas, however this approach is also very limiting in design, does not cover every situation (for example would no hazardous area go around the area of a dispenser that has a vapor barrier), and has some risk if the areas are too small or a dispenser is not adequately ventilated.

Component standard for a hydrogen dispenser	HGV 4.2, 4.4, 4.6, 4.7, ISO 19880-3/-5/-6	Everything is there but the enforcement of the requirements is weak.	
Use/Implementation of codes and standard	BNQ-1784, HGV 4.9:2020, ISO 19880-1:2020, AVT / CSA Group Permitting Guide	AVT / CSA Group Permitting Guide currently used to bring consistency of CHIC and HGV 4.9 implementation across Canadian provinces and Territories. There is a knowledge barrier. As well there are regional differences in the use of CSA B51 & BNQ 1784. It is no secret that the application and requirement for CRN's on H2 components/assemblies is a painful process and I think it keeps international vendors from wanting to have a Canadian operation. The engineering time and the general sourcing of the requirements is a painful exercise and could be greatly simplified with a well thought out guide, or maybe a H2 specific standard for piping/valves & fittings that eliminates the CRN requirement.	Current adoption of standards is required by AHJ's. AHJ's are good at having consistent codes adopted. But if these codes don't require the standards then it makes things messy.
General feedback		Few in any customers in North America have required a CSA HGV 4.X certification for any product. Codes to address mobile refuelers, storage and dispensing on a trailer and applications involving H2 storage, fuel cell and BEV chargers on trailers.	Hatch (Mississauga, Ontario) appear to have some experience siting hydrogen equipment in Canada; suggestion to reach out to them for input.

In addition to the results generated by the survey responses, additional feedback on needs for dispensing hydrogen that have been provided (less formally) include the following:

- Need for maintenance guidelines for H2 tanks.
- Need for standards for lightweight containers for UAV.
- Need for standards for Mobile EV charging using stored hydrogen.
- Need to have harmonized codes for hydrogen and fuel cells as they relate to jurisdictional updates.
- Need for consistency in the breakaway force for refueling nozzles. There are codes and standards from many organizations (CSA, SAE, NFPA, ISO, etc.) involved in this particular item, as both the values for the breakaway vary and the methodology for measuring is not always similar. ISO's TC 197 Working Group 5 has offered to take the lead on conducting some research/surveys. This WG is for gaseous hydrogen land vehicle refueling connection devices.

GENERAL COMMENTARY ON THE VALUE CHAIN ELEMENTS DEVELOPED BY THE NRC

The NRC received feedback from three different hydrogen consultants on the developed hydrogen value chain elements as summarized in Annex F.

GENERAL COMMENTARY ON THE CODES, STANDARDS AND REGULATIONS IDENTIFIED BY THE NRC FOR THE EXISTING ELEMENTS

The NRC received feedback from three different hydrogen consultants on the codes, standards and regulations identified as of December 2021 for some of the elements.

Some codes/standards to add;

- ASME B31 Series Pressure Piping Codes
    - ASME B31.3 Process Piping
    - ASME B31.10 Cryogenic Piping Systems Etc.
- Canadian Electrical Code
- SAE J1926 - hydrogen fitting standard commonly referenced

Jurisdiction;

Can the column labeled “Nationality” be broken down further? For example, would something like the BNQ 1784-000 be used by US companies for a project in the US? The same thought on the column labeled “International”. Can that be broken down to regions?

Element 1 and 2 Electrolysis H2 Production: Element 1 has 108 lines of entry for various requirements and safety standards. Element 2, is effectively a similar production concept, with only 11 lines. This disparity is not consistent with the common nature of the two production systems.

Elements 3, 4, 5, 6 Reformer Industrial H2 Production: The production of GH2 from Natural Gas, Bio- Mass (gas or liquid) and Industrial waste are all basically similar processes. The entries for these four in the Master List would be expected to be similar or nearly identical. As the outcome in these production scenarios is gaseous H2 for storage, reference to LH2 and Cryogenic equipment is inconsistent and unnecessary. There also appears to be an entry error in the Master List for columns A, B and C in Element 5.

Elements 7, 8, 9, 10 Solar Energy Based Production Systems: While the production methods being referenced are significantly different chemically, thermally and mechanically, the expectation is that they will all produce H2 gas that needs to be handled, purified and stored. This will require piping and mechanical systems for handling, compression and treatment. The reference to cryogenic systems is more related to specialized high density storage and should not be included in the discussion or standards listing for these production systems.

Element 11- a, 11- b Ammonia and Liquid Conversions for Shipping: The conversion or transformation of GH2 into a liquid carrier to increase storage density is a relatively well understood and utilized industrial process. The predominant North American standards for this would be the basic mechanical and electrical codes, CSA, ANSI/ASME and NACE. Reference to cryogenic materials and design should not be called up for these Elements as there is no cryogenic component to the process.

Element 12, 13 Gas, Liquid Storage Above and Below Ground: Any below ground well or salt cavern storage system will require additional process equipment at the surface for subsequent clean- up, dehydration and pressure control prior to reintroduction into a distribution system. Compression will be required for downhole storage.

Element 19, 20 Dedicated GH2 Pipeline And Pressure Reduction: There should be no reference to cryogenic materials or vessels in these sections. The design and operation of pipelines and regulating stations does not include such low temperatures. Design and operation of pipelines for gas and liquid systems is covered in (ASME) B31.8, Gas Transmission and Distribution Piping Systems and the Canadian Standards Association (CSA) Standard Z662, Oil and Gas Pipeline Systems. These should be referenced in the listing. There will be international standards applicable to other parts of the world.

Element 24- a, 24- b Ammonia and Carrier Conversion to GH2: There should be no reference in these sections to cryogenic storage or systems as temperatures below - 80C should not be encountered.

Element 27 to 32 Portable Power Systems, Heaters, Appliances and Gas Turbines: There should be some addition for metering and custody transfer for distribution accounting.

Element 33 GH2 and Natural Gas Blended Pipeline: Combining two or more different gasses in a distribution system requires some form of system for determination of the end users energy delivery / consumption and subsequent custody transfer and billings. Typically gas is measured and delivered on a volume basis and billing is on a value / energy basis.

Elements 43 to 50 GH2 Dispensing Systems: Any references to cryogenic systems or materials are likely not valid. Some fuel dispensers pre- chill the supplied GH2 in order to speed up the fill process. It is not likely these actually work, but in the event this is included, the minimum temperature is typically - 20C.

Element 64 to 68 Various Industrial Use Applications: These five elements are effectively similar in scope, H2 use, processes and safety requirements. General requirements will be common for all industrial supply applications. Differences can be anticipated for specific environments and jurisdictions.

CSR GAP ANALYSIS

Regulations

As part of the CSR analysis, regulations were reviewed to identify gaps in gas safety regulations in British Columbia, Alberta, and Ontario[7]. Annex C provides details of the review.

Hydrogen gas is generally included as part of the gas definitions in the regulations. This ensures that the regulations apply to hydrogen generation and utilization (end-use) installations. As expected, the regulations specifically address natural gas and propane equipment and have adopted CSA B149 series codes in the regulations. Some provinces have adopted CNG/ LNG refuelling station installation standards into the regulations or by issuing directives.

The Canadian Hydrogen Installation Code CAN/BNQ 1784-000/2007 is adopted only by ON. BC has adopted the CAN/BNQ by issuing a directive limited to hydrogen fueling stations. AB has not adopted the code and no mention is made of how hydrogen installations are addressed.

[7] Due to time constraints only these provinces were chosen. The same study should be performed for other provinces and territories.

In BC, liquefaction facilities are regulated by the BC Oil and Gas Commission. At this stage, the BC Oil and gas commission website is silent on hydrogen generating and liquefaction facilities.

Based on previous reviews into the regulations for CNG applications Canada has a mix of approaches on aftermarket conversions, repair garage upgrades and fueling station applications.

To ensure a smooth and safe rollout of the hydrogen economy it is important to:

- Immediate Term:
    - Adopt the BNQ standard for hydrogen installations by all provinces.
    - Establish training/certification requirements for trades that work on hydrogen installations and aftermarket truck conversions.
    - Decide how hydrogen generation and liquefaction facilities are regulated and develop regulations.
- Mid-term:
    - Develop a common approach for permitting by all provinces and territories for truck conversions, repair garage upgrades, fueling stations, hydrogen generating and utility installations.
    - Adopt standards for hydrogen equipment, hydrogen installations, and hydrogen appliances, as they become available.

All of the 19880-x series of ISO standards have used CSA-HGV-4.x standards as the seed documents. All of the requirements in CSA standards, SAE vehicle interface standards, and the Global Technical Regulations for FCEVs were rolled into ISO 19880-1. ISO 19880-1. Gaseous hydrogen — Fuelling stations — Part 1: General requirements - contains all of the requirements for hydrogen fueling stations. This is being adopted by the EU as IEN standard. The rest of the ISO-19880-x standards will address the various components, fittings, valves, hoses, compressors and dispensers. The plan is to go back in forth between CSA and ISO technical committees with improvements each step.

In the case of valves, CSA gave ISO-TC197 three separate documents on break-away (valves), manual valves and automatic valves. The ISO TC-197 committees decided to incorporate all into one document, ISO 19880-3, published in 2018. The CSA Valve TSC (Technical Sub Committee) then accepted the work of ISO TC-197 and adopted the document and created North American deviations and published CSA/ANSI HGV 4.4 in 2021 as HGV-4.4: "Gaseous hydrogen — Fuelling stations — Valves (Adopted ISO 19880-3:2018, first edition, 2018-06, with North American deviations)". It is expected that other jurisdictions will adopt ISO 19880-3 with local deviations. It is expected that this process will continue over time for the various components, fittings, valves, hoses, compressors and dispensers.

In the case of hoses, the CSA technical committee and ISO technical committee have common chair and convener and have technical experts from Germany, Japan, UK, and the US with a strong Japanese WG lead speaker from Yokohama Rubber who spent many years working in the US. These working groups chose to keep the latest edition of ISO 19880-x standards on hoses separate in format but harmonized and improved over the ISO document. The next edition of the ISO document will add the improvements made to the requirements in the CSA document and then the next ISO document on hoses should be adopted by CSA with North American Deviations.

As the ISO 19880-x standards are reviewed by the global technical communities, the TC-197 technical committee working groups will reopen the various ISO standards to incorporate years of learning and revise the ISO 19880-x standards to improve the quality of the standards. As the valve, hose, dispenser, and compressor ISO standards mature, the core document for gaseous hydrogen fueling stations, ISO 19880-1, will remove specific requirements and point to 19880-3 for valves.

The CSA standards are ANSI-approved Canadian National standards that are recognized in all provinces of Canada and all of the Unites States. The CSA standards include construction requirements and product test methods that allow for certification of products such as hydrogen refilling station modules that include compressor systems, valve manifold systems, dispensers, and any other module in a hydrogen fueling station from production to certification of fuel event preformed at nozzle. The hose and ISO 19880-3 valve standards have been published, however, the dispenser and compressor standards have not been published yet.

In the case of the dispenser, the CSA technical committee chairman worked closely with ISO WG convener and the translator for the Japan TC-197 Mirror committee to evolve the 19880-2 working draft and bring the global learning from IS WG 19 to the 2020 edition of CSA-HGV 4.1. The HGV-4.1 TSC could adopt the first edition of ISO -19880-2 within a year of publishing (with North American deviations).

In the case of the compressor, the CSA technical committee and ISO technical committee have a common chair and convener but the ISO document remains unchanged with the WG on hiatus. The CSA-HGV-4.8 document is out of date and ineffective from a certification perspective, so much so that the latest edition of the Canadian Hydrogen Installation Code has the most complete set of specific requirements for hydrogen compressors for use in hydrogen fueling stations.

Canadian Hydrogen Installation Code

The second edition of the CAN/BNQ 1784-000/2007 standard will be published in 2022. Unfortunately, the revised standard was not be available for the gap analysis. The Canadian Hydrogen Installation Code sets the installation requirements for hydrogen-generating equipment, hydrogen-powered (utilization) equipment, hydrogen dispensing equipment, storage containers, piping systems, and related accessories. The code applies to all gaseous and liquid applications. The main topic of interest in this review is the exclusion of onboard fuel systems and liquefaction systems.

The code addresses most of the end-use elements identified in the NRC Canadian value chain mapping. It applies to installations with a product or uses a maximum limit of 21 kg/h of hydrogen on a continuous basis for industrial installations. The code excludes hydrogen generation or utilization in petrochemical plants, chemical production, and excludes micro fuel cells. It is called an installation code but also addresses system and equipment integration requirements as well as minimum clearance distances to exposures. The standard has been approved by the interprovincial Gas Advisory Council. In our view, this document is very important and as recommended should be considered for adoption into the regulations as soon as possible.

The standard was reviewed to verify if all the value chain elements are addressed in the standard and if any gaps should be addressed. The elements specifically reviewed are hydrogen production (smaller decentralized plants) and end-use facilities. The review focused on safety and gaps that would stifle the rollout of the hydrogen economy due to the lack of CSR.

Annex D shows the details of the review. A summary of the recommendations follows:

- Element 1 and elements related to end-use equipment: Without the definition of industrial use in the BNQ standard, it is not clear whether bus and train fueling, decentralized power generation, and larger process heating equipment are excluded from the limits of 21 kg/h of hydrogen generation or utilization. In addition, the rationale for the limit is unclear.
- Element 1: The 21 kg/h generation/utilization limit should be increased to allow for decentralized generation. A 100 kg/h per module seems to be more in line with product offerings. It is recommended that several modules could be used in series with a limit of 100 kg/h for each up to a maximum number of 400 kg/h. This requires additional analysis and understanding of the rationale.
- Element 1, 12: BNQ does not address larger facilities (exceeding the 21 kg/h). A standard is required for larger generation and end-user facilities. The standard could be similar to the small LNG facilities standard CSA Z276 Annex B. This standard could also include decentralized liquefaction facilities and include gas, liquid, and underground storage requirements.
- Element 43, 44, 45: No reference is made to a dispenser standard in the BNQ. It is recommended to include a reference to HGV4.1 as an acceptable standard for vehicle fueling and reference other relevant dispenser standards that are acceptable. No standards are available for the train, truck, and bus fueling, therefore, clause 5.1 applies which means the application must be approved by the AHJ. This is an acceptable approach.
- Element 44, 45: No safety requirements are provided in the BNQ standard for liquefied hydrogen fueling requirements. Clause 8 limits the BNQ application to storage, piping, accessories, and vaporizers up to their outlets. Installations are underway in the US for liquid refuelling for buses, trucks, and trains. Minimum safety and siting requirements for LH2 fueling dispenser should be addressed in the BNQ standard. The CSA B108 part 2 and LNG4.1 standard could be used as the basis for the requirements.

- Element 25: H2 gas storage. The BNQ should list the CSA B51 part 2 tank as requirements for acceptable ground storage.

- Element 25: For liquid storage some additional safety requirements should be addressed such as relief valve sizing requirements and design requirements to CSA B51 (only ASME VIII is mentioned). The CSA B108 part 2 and CSA Z276 Annex B could be useful standards or could be expanded to cover liquid hydrogen.

- Element 25: Clearance from liquid hydrogen systems to exposures; the clearance distances may not be practical for hydrogen refuelling stations or small industrial applications. The LNG standard has recognized this and has allowed reduced clearance based on the use of multiple tanks. The minimum clearance table for storage volume then applies to the largest single tank rather than the aggregate storage. Each tank has individual shut-off valves reducing the risk of large releases with multiple smaller tanks. This justifies the smaller clearance requirements. This should be considered if this approach applies to LH2 systems.

- Element 25 fuel storage: In the LNG and CNG industry, the use of mobile fueling/storage and mobile compressors for permanent installations in commonplace. This is usually part of the virtual pipeline that allows the industry to become established more quickly, before major capital investments occur. In some applications for small fleet refuelling and decompression stations, mobile refuelling and storage are the most practical approach. This is already happening with hydrogen gas systems. This should be addressed in the standards. This has been addressed in both the CSA Z276 and CSA B108 standards for LNG.

- Element 26, 27, 29: LH2 vaporization, power generation: As indicated for element 1, the BNQ code has a limit of 21 kg/h for end-use equipment. This flow rate limits power generation to approximately 300 kW power output. It is expected that this limit will be too low as the H2 market expands. It is recommended that the rationale for the limit be reviewed and increased.

- Element 29, 30: The fuel train requirement should be addressed in the BNQ standard similarly as is provided in CSA B149.1 for engines, power generation equipment and CSA B149.3 for burner equipment.

- Element 30: The BNQ clause 9 covers H2 appliances for residential applications. The scope is limited and a standard similar to the CSA B149.1 standards may have to be developed in the midterm.

- The cost to certify equipment to a standard is often prohibitive in an emerging market. As design development and the manufacturing volume is low in the early years, the cost of certification is prohibitive. If certified equipment is not available and the standard requires a certified product this will lead to a delay in the rollout. The BNQ uses words like “shall comply with standard XXX”. Comply is not defined in the standard and can mean that the equipment must be certified to carry a third-party testing agency label. To overcome this hurdle, it is suggested that “or approved” be added, which would mean that the manufacturer must provide adequate proof to the AHJ that the safety aspects of the product standard are addressed and that the equipment is safe. When certified equipment is available the industry will automatically use certified equipment as a more cost-effective approach.

- The BNQ code in clause 6.2 deals with electrical area classification and refers to CEI/IEC standard 60079-10-1 for the determination of the area classification. There is a concern that the application of this standard will lead to unsafe installations. Based on experience the method is complex and very dependent on the assumptions and leak rates used. It is recommended that prescriptive area classifications are provided similarly as in the other alternative fuel codes (CNG and LNG) with the IEC 60079-10-1 standard as an alternative method where the prescriptive methods are not practical. An application for reduced requirements should be proven on a performance basis to the satisfaction of the AHJ.

- Leakages from valves can be dangerous. Not every valve is suitable for hydrogen applications. It is recommended that valves are certified for hydrogen use and comply with the HGV or ISO valve type testing requirements. The BNQ standard should reference the acceptable standards.

General C&S

General comments and recommendations related to some of the hydrogen value chain elements for end-use equipment are provided below.

- Element 49 aftermarket onboard fueling: Currently Hydra is marketing hydrogen dual fuel options for existing diesel trucks to reduce gas emissions and lower fuel costs. A standard should be developed to address safety requirements, similar to CSA B109 Part 1 and 2 for retrofitting hydrogen gas or liquid fuel systems to diesel trucks. The certification of the installers and training should be addressed by developing of a common approach throughout all Canada. This is required to ensure safe products and remove roadblocks for rollout.

- Element 50 - H2 onboard trains: Ballard and others offer commercial fuel cells for train applications. More details will be added to the report once the connection has been made with the industry regarding CSR gaps.

- H2 liquefaction facilities are not addressed in the BNQ code. No standards or regulations could be found addressing these facilities. It is also not clear who regulates these facilities in BC. Due to time limitations, other Provinces have not been checked as of yet.

- Element 34-36 gas appliance blended fuels: CSA B149.1 does not include blended gas applications. The standard should be updated to include specific requirements for blended gas appliances and installations.

- Element 70 – Repair garage for H2 vehicles. The repair garage must be upgraded to service and repair H2 fueled vehicles (Trucks, buses, trains). A new standard or expansion of the CSA B401 standard is recommended.

- A review of other codes was carried out for specific hydrogen requirements. The detailed review is presented in Annex E. A summary is provided below:

    - CSA B51-1: Boiler, Pressure Vessel, and piping code: Part 1 applies to hydrogen systems; no changes or additions are required.

    - CSA B51 Part 2 applies to CNG and hydrogen onboard storage cylinders. No changes are required.

    - CSA B51 Part 3 applies to CNG and hydrogen refuelling stations. This could be expanded to include piping systems for high-pressure hydrogen generation/ utilization equipment.

    - CSA Z662-19 Oil and Gas Pipeline Systems: The standard does not cover hydrogen or hydrogen blended natural gas. This standard could be expanded to include hydrogen blended natural gas.

    - CSA C22.1-18 Canadian Electrical Code, Part I, Safety Standard for Electrical Installations: Hydrogen is referenced as follows. The standard adequately covers hydrogen installations.

        - References CAN/BNQ code for hydrogen installations.

        - Article 18-050 – defined hydrogen area classification.

        - 64-708 Grounding and bonding - Grounding & Bonding requirements for hydrogen containers

        - Rule 26-506 - Hydrogen battery room ventilation requirements

        - Rule 64-710 Fuel cells should be considered fuel-burning equipment and be installed by the National Building Code of Canada. Hydrogen-fueled systems should be installed by CAN/BNQ 1784-000.

    - Building and fire codes. It is recommended that the CAN/BNQ code be referenced in the building and fire codes.

    - Lithium batteries and fuel cells. Fuel cell equipment for transportation applications may be installed with lithium batteries. Standards are required to address the hazards that lithium batteries pose to fuel cells and vice versa.

Component Gaps

Gaps in CSRs exist for components in Canada. For example, Canadian requirements specific to hydrogen regulators have not been published. Therefore, current Canadian standards reference regulator standards for gaseous fuels. Similarly, a CSRs gap currently exist for some components that have electrical and mechanical parts when used inside classified areas. For example, according to CSA C22.2 NO. 108:14 (R2019), liquid pumps can only be used in ordinary locations (non-hazardous applications). However, if the pump is used inside a classified area, the motor can be covered by hazardous location standards such as CSA C22.2 NO. 145:22: electric motors and generators for use in hazardous (classified) locations (tri-national standard with NMX-J-652-ANCE and UL 674). However, evaluation criteria for the pump mechanical components for hazardous locations are missing (static, temperature, etc.). A standard exists in Europe that can be used to evaluate mechanical systems for hazardous locations and that could be harmonized with Canada to help cover this gap. Similar issues exist with other components such as valves.

Gaps in Mobility and Transportation Technologies

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), created in 2003, is an international governmental partnership involving 21 countries and the European Commission (member countries include Canada, Australia, Germany, Brazil, Japan, United Kingdom, USA, China, South Africa, Korea, etc.). Its role is to help the transition mobility systems to hydrogen and fuel cell technologies. A working group (Regulations, Codes, Standards and Safety Working Group, or RCSSWG) created by the IPHE performed a survey to understand gaps in hydrogen and fuel cell regulations from its participant countries. Table 35 illustrates a heat map of critical areas as identified by the IPHE – RCSSWG. In this table, the red cells are critical, the orange cells are moderately critical, and the yellow cells are less critical [13].

Table 35: Heat map of critical areas identified by the RCSSWG [13].

Hydrogen Infrastructure						Hydrogen for Mobility/Transportation		
Hydrogen injection at transmission level	Hydrogen injection at distribution level	Methanation and injection of Methane (SNG) via methanation from hydrogen at transmission / distribution level	H2 refilling station (HRS)		Maritime Infra	Mobility infra (tunnel, bridge, underground parking…)	Heavy Duty vehicles	H2 and H2-based fuel vessels
Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Land use plan (zone prohibition)		Off-shore refueling	Restrictions & Incentives	Type approval & Individual vehicle registration - Process	Legal framework: permissions and restrictions (and Ownership constraints (unbundling))
Permission to connect/ inject	Permission to connect/ inject	Permission to connect/inject	(LH2) Permitting requirements/ process	(GH2) Permitting requirements/ process	On-shore refueling		Restrictions & Incentives	Safety requirements (compliance with safety regulation/ risk control expectations)
Safety requirements and process (safety distances internal / external)	Safety requirements and process (safety distances internal / external)	Safety requirements (compliance with safety regulation / risk control expectations)	(LH2) Safety requirements and process (safety distances internal/ external)	(GH2) Safety requirements and process (safety distances internal/ external)			Service and maintenance	H2 on-board storage
Gas quality requirements	Gas quality requirements	H2/ SNG quality requirements	H2 quality requirements					
			Quality measurement requirements					

This report [13] also includes regulation gap details for infrastructure, mobility, and transportation sectors (from its participant countries), and classifies them as regulatory gaps, research & development gaps, or both. The critical gaps identified in this report [13] are listed separately in Table 36 below.

Table 36: Member countries' critical H2 infrastructure regulations gaps from table 1 of the RCSSWG report [13].

Hydrogen Infrastructure			
Topic Area	**Sub-Topic**	**Gap Description**	**Type of Gap**
Hydrogen Injection at Transmission Level	Legal Framework: Permissions and Restrictions	Hydrogen injection into the natural gas pipeline is not even considered in some countries. The maximum hydrogen allowable is inconsistent and is set on a country by country basis. Allowable hydrogen injection levels are not yet well understood.	Regulatory
Hydrogen Injection at Distribution Level	Legal Framework: Permissions and Restrictions	Little to no national regulation information is available regarding injection at distribution level.	Regulatory
Hydrogen Refilling Station	Liquid Hydrogen (LH2) Permitting Requirements/Process	Permitting is performed at the regional level in most cases. While most countries report a consistent procedure in place, interpretation of specific regulations is at the discretion of the local jurisdiction. Similarly, commissioning of completed stations involves interpretation/approval by the local jurisdiction. Gaps relating to storage and delivery of LH2, as well as siting requirements, are generally considered more significant than for GH2.	Both
Hydrogen Refilling Station	LH2 Safety Requirements/Process	For several responding countries, setback distances are regulated at the national level. For others, it is handled at a regional level. In all cases, certain safety elements are inconsistent (risk assessment, personnel safety requirements) and whether they were required. In many cases, there are substantial R&D gaps regarding the setback distances for LH2 installations. Large scale on-site storage poses R&D and regulatory gaps.	Both
Hydrogen Refilling Station	Quality Measurement Requirements	Little to no national requirements exist for the monitoring of hydrogen quality. All responding countries identified this as a barrier. Fuel quality assurance processes/equipment (largely for GH2) are still in development.	Both
Methanation and Injection of Methane via Methanation from Hydrogen at Transmission/ Distribution Level	Legal Framework: Permissions and Restrictions	For some responding countries, there is clear legislation regarding injection of methane via methanation from hydrogen. For other, the incumbent technology is natural gas and therefore natural gas requirements form the basis of the regulations.	Regulatory

Table 37: Critical Hydrogen for Mobility/Transportation gaps from table 2 of the RCSSWG report [13].

Hydrogen for Mobility/Transportation			
Topic Area	**Sub-Topic**	**Gap Description**	**Type of Gap**
Hydrogen and Hydrogen-Based Fuel Vessels (Maritime)	Safety Requirements and Process	Safety guidelines for maritime vessels appear to be nonexistent in national regulations.	Both
Hydrogen and Hydrogen-Based Fuel Vessels (Maritime)	Hydrogen On-Board Storage	On-board storage for maritime vessels was identified as a gap here as well as at the 2020 Research Priorities Workshop. Few regulations were reported in this space.	Both
Mobility Infrastructure	Restrictions and Incentives	Most countries reported some level of restriction for operation of FCEVs in tunnels, with varied regulatory frameworks (national versus regional). Fewer countries reported restrictions on parking these vehicles in covered places (e.g., garages). Tunnel and bridge access continue to be inconsistent at the global scale. There is a consistent need to distinguish between hydrogen as a fuel and hydrogen as a cargo to enable access.	Both

RECOMMENDATIONS AND PRIORITY

The recommendations below are a summary of the gap analysis and are in the order of priority. Both the codes, standards and regulatory development should be executed in parallel.

Codes/standards:

- Increase the 21 kg/h hydrogen generation/utilization limit and define industrial installation in the CAN/BNQ hydrogen installation.
- Expand the CAN/BNQ to include liquid fueling facilities.
- Adopt the CAN/BNQ code in the building codes and fire codes.
- Provide prescriptive requirements for area classification in the CAN/BNQ code.
- Develop appliance standards and reference these as these become available into the CAN/BNQ code.

- Develop a hydrogen facilities design and installation standard for generation/utilization and liquefaction facilities that are outside the scope limits of the CAN/BNQ standards.
- Develop new standards for field approval of fuel-burning appliances and equipment and include hydrogen generation and utilization equipment.

Regulations (All of Canada):

- Adopt the BNQ standard for hydrogen installations.
- Develop a common approach for permitting throughout Canada for truck conversions, repair garage upgrades, fueling stations, and hydrogen generating and utilization installations.
- Establish training/certification requirements for hydrogen installations and dual fuel truck conversions.
- Decide how hydrogen generation and liquefaction facilities are regulated and develop regulations.
- Adopt standards for hydrogen equipment, hydrogen installations, hydrogen appliances, as they become available.

8. PRIORITIZATION TOOL

The NRC recommends the creation of a tool for federal labs to be able to prioritize the elements to address if resources are limited. In other words, this prioritization tool could help federal labs decide where and when to put resources into the work required in the different elements. To this end, it is important to understand the current state of the hydrogen value chain codes and standards to figure out what work needs to be performed for each element. For example, standards may need to be created for some elements, standards may need to be harmonized with international standards in other elements, or there may not be enough public awareness of existing Canadian standards for some other elements (thus requiring increased awareness).

The tool could list and rank the priorities from federal labs. For example, the priorities from the NRCan-led OERD Hydrogen Codes & Standards Workshop on Nov 16, 2021 could be integrated into the tool. It could also include priorities from industry, and could have a similar look to the table below. The federal labs and industrial entities could complete this table by rating different work proposals. A total score could be calculated to determine the best priorities.

Table 38: Example of a prioritization tool.

Element No.	Work Proposal	Assessed Priority From Participating Federal Labs (from 0 to 10 where 0 is no impact and 10 is very high impact)	Number of Companies In Canada Active in the Element (number)	Assessed Priority from Industry (from 0 to 10 where 0 is no impact and 10 is very high impact)	Completeness of the CSR Landscape for the Element (Percentage) / Level of effort to perform the work. / Cost	Total Score

This is a suggestion to be refined or changed in consultation with other federal labs in the future.

9. REFERENCES

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[12] Sudi Apak, Erhan Atay, and Güngör Tuncer, "Renewable hydrogen energy regulations, codes and standards: Challenges faced by an EU candidate country", International Journal of Hydrogen Energy 37, p.5481-5497, 2012.

[13] A Working Paper Prepared by the IPHE Regulations, Codes, Standards and Safety Working Group, Compendium of Regulatory Areas for Action in Hydrogen Infrastructure and Mobility/Transportation Technologies, September 2021.

[14] European Standards Organizations, European Commission's Joint Research Centre, "Putting Science into Standards: Power-to-Hydrogen and HCNG-Results and main outcomes", 21-22 October 2014. https://ec.europa.eu/jrc/sites/default/files/hcng-2014-final-report.pdf.

Annex A – Industry Questionnaire

Questionnaire

H2 Fuel Implementation - Codes, Standards, and Regulations (CSR) Gap Analysis

Focus of the study is on equipment/appliances and installation of H2 equipment at the end-user.

Contact name: Ryan Milligan

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Email: ryan.milligan@technicalsafetybc.ca

Company name: Technical Safety BC

Address: 310-771 Vernon Ave. Victoria BC

Business Description: Regulator for gas systems, as well as multiple other technologies, in BC.

About Technical Safety BC

Technical Safety BC is an independent, self-funded organization mandated by the Provincial Government to oversee the safe installation and operation of 7 types of technical systems & equipment in BC. This oversight includes everything from participation in code development to implementation and enforcement of those codes. This also includes overseeing the safe installation and operation of these technical systems and equipment through permitting and assessments.

Development of a hydrogen economy in BC will require interaction with multiple technologies Technical Safety BC oversees in BC including gas, boiler, pressure vessels and refrigeration Systems, and electrical systems. Similar to other commodities such as Natural Gas, and Electricity, there will be multiple levels of oversight required involving Technical Safety BC, BC Oil and Gas Commission, BC Utilities Commission, Canada Energy Regulator and Transport Canada depending on the scale and scope of Hydrogen integration into existing infrastructure.

The information provided here is based on Technical Safety BC's mandate to administer and enforce the *Safety Standards Act* and associated technology specific regulations in BC.

1. Are there specific codes, standards, and/or regulations that need to be developed to support the H2 industry? What are the gaps?

Regulations:

Oil and Gas Activities Act/ Safety Standards Act/BC Utilities Commission Act – It needs to be which regulations hydrogen production facilities of various size and scale fall under. Today, only small-scale production facilities associated with a vehicle fueling station are clearly covered under the Gas Safety Regulation. The Electrical Safety Regulation would apply to all facilities regardless of scale unless exempt *Utilities Commission Act*, and the Power Engineers, Boiler, Pressure Vessel, and Refrigeration Safety Regulation would apply unless exempt under section 2 of the *Safety Standards Act.*

Codes:

- CSA Z662 -Oil and Gas Pipeline Systems

The CSA Z662 code has gone through the process of development of content for Hydrogen and hydrogen blend pipeline systems for the 2023 version of the standard. This content is currently at the public review stage and has yet to be published or adopted.

- CSA B149 series codes

The B149 series of codes applies to downstream gas systems and equipment supplied either by utility natural gas, propane, manufactured gas, propane air mixes, propylene and butane, but not hydrogen or hydrogen blends with natural gas. The content of these codes is intended to provide a minimum standard for the construction of gas systems and the installation of gas equipment to address the risks associated with natural gas and propane fuel.

A determination would need to be made whether hydrogen enriched natural gas is within scope of each of these codes, and what blend the blended gas presents a risk outside of those addressed within the scope of these codes. For Hydrogen enriched natural gas that is above a level that is determined to be within the scope of the B149 series of codes, either new content will need to be developed within these codes to address the risks, or new codes will need to be developed specific to the application.

Standards:

Similar to comments above regarding B149 series of codes, appliance and equipment standard for equipment across the gas technology address risks associated with natural gas, propane, manufactured gas, propane air mixes, propylene and butane, but not hydrogen or hydrogen blends with natural gas. A determination would need to be made whether hydrogen enriched natural gas is within scope of each of these standards, and what blend the blended gas presents a risk outside of those addressed within the scope of these standards.

For hydrogen blends above an acceptable limitation, or hydrogen specific equipment and appliances, new content will need to be added to existing standards, or new standards developed to address the risks associated with this gas.

This list of standards would include all Fuels and transportation standards (ANSI/CSA) relating to natural gas systems, equipment, appliances, and storage. Also impacted would be the efficiency standards relating to gas appliances.

2. Are there specific safety concerns with the rollout of the H2 economy that should be addressed by the codes, standards, or regulations?

Hydrogen is a very different molecule than other fuel gases industry has become accustomed to as a utility fuel gas, and as a constituent additive to utility natural gas. It is a much smaller molecule, which must be assessed and addressed in piping construction standards as well as component standards to ensure safe installation and operation of systems and equipment with hydrogen or hydrogen enriched natural gas as a fuel source. Another concern exclusive to hydrogen is hydrogen embrittlement. There are many contributing factors to hydrogen embrittlement including temperature, pressure, and materials which must all be considered at all levels of the gas industry, from pipeline materials, to regulators controlling systems pressures, to appliance components in furnaces and fireplaces.

Hydrogen also has much wider limits of flammability that traditional fuel gases, this must be considered when assessing risk associated with installations. Due to its wider limits of flammability, a lower tolerance for leaks should designed into construction and operation standards for systems and equipment. Standard practices for leak detection such as odorization or leak detection systems must account for not only chemical compatibility, but a lower threshold for allowable concentrations.

Hydrogen enriched natural gas as a method to lower the carbon footprint of the natural gas utility grid must consider the current infrastructure. When implementing a change to a population consisting of wide variety of existing operating systems and equipment, the approach must consider the least compatible component in the system as the benchmark in order to ensure the safety of all affected equipment downstream.

3. Please feel free to provide additional comments below or on a separate page.

Annex B – List of Companies

Company Name	Product or expertise	Address	Website	Contact Name	Contact Details	Questionnaire Completed	Notes
NextGen	Equipment manufactured/Packager of compressor/Storage/ etc.			Peter Copic	1 604 468 8035 pkopic@nextgen-sys.com	No	Phone call conversation .
Linde Engineering	Cryogenic tanks and air-heated vaporiser, liquefaction.		Hydrogen | Linde Engineering (linde-engineering.com) https://www.linde-engineering.com/en/hydrogen/index.htm	?	**Contact sent thru website**	No	
Fortis BC	Blending/ Fuelling Stations?	Surrey ,BC	Sustainable energy options (fortisbc.com)	John Quinn	John.Quinn@fortisbc.co m 1-800-773-7001 VM left and email sent	No	
Hydra Energy	Diesel Conversion and refuelling equipment on site, and H2 supply from H2 suppliers (waste product). (Hydrogen as a service - HaaS)	15 - 1610 DerwentWay, Delta BC.	Hydra Energy - Real hydrogen now	Jo Borck	7784008804 - **VM left**	No	
Air Product	Fuelling station for vehicles, trucks, marine, buses and trains, Hydrogen for processes, Hydrogen generators on-site (Steam reforming, Electrolysers),		Home | Industrial Gas Supplier | Air Prod	Eric Guter Vice president Hydrogen for Mobility.	18006544567 - **Left VM at 562-756-6673**	No	
Hydrogen Optimized	Large scale H2 production, high-current water electrolysis	1800 17th Street East,Owen Sound, Ontario	Contact Us - Hydrogen Optimized™	?	1-705-444-7992 - **VM Left (Harry Rhodes? - Bus. Dev.)**	No	
Siemens	Electrolyser/ Power generation/ H2 production???		Hydrogen Solutions | Renewable Energy | Siemens Energy Global (siemens-energy.com)	Derek Hosking	14032992590 (no good) derek.hosking@siemens.co m **(request sent by email)**	No	
Hydrogenics, now Cummins	Hydrogen engines IC Engines and Fuel Cells for vehicle and power.	Mississauga, Canada	New Power | Cummins Inc.	Thad Ewald?	**email sent**	No	
Chart	LH bulk storage, transport trailers,metering systems, plate fin heat exchangers, LH2 liquefaction, Lh2 vehicle tanks, LH2 fuelling stations, LH2 dispensers. LH2 systems for fuelling, other use.		Hydrogen Energy | Chart Industries	Erik Langetik Seong Oh	seong.oh@chartindustrie s. com mailto:erik.langeteig@cha r tindustries.com	No	
CryoPeak	Check currently bulk transport,equipment supply, equipment own and operate.		Connection timed out (cryopeak.com)	Calum McClure	1 604 761 4868 calum.mcclure@cryopeak . com	No	
Atco gas	Train Fuelling. Belding pipe line with up to 5% of H2 gas. Green hydrogen generation.	ATCO Natural Gas Distribution, Customer Correspondence, POBOX2409, Edmonton, AB	ATCO Gas | Contact Us	Scott Torrance	scott.torrance@atco.com	No	Reply email receivedset up conference call. Involvement with H2 blending.
Loop Energy	Fuel cells, fuel cell systems for road, power generation, forklifts, construction equipment.	2880 Production Way,Burnaby, BC	Home - Loop Energy - Hydrogen Fuel Ce	Darren VanderHeide Rob Stevenson Mathew Geunther	16042223400	No	

Ballard	Fuel cell systems for trains, busses, trucks, marine, Back up,power generation, appliances	Burnaby, BC	Contact Us | Ballard Power | Fuel Cell Te	Terry How	1-604-454-0900	No	Phone call with Terry Now Sales Director. Codes and Standards expert away will set up conference call when back.
TSBC	Regulatory /Safety	BC		Brian Zinn	brian.zinn@technicalsafe	No	Received reply that will provide reply.
AMA	Regulatory /Safety	AB		Cluade Valliere	claude.valliere@gov.ab.c	No	
TSSA	Regulatory /Safety	ON		B. Gillis	bgillis@tssa.org	No	

Annex C – Regulatory Review Details

Regulatory Review Summary 2022-03-10

	Answer Summary		
Questions	**Alberta**	**British Columbia**	**Ontario**
What provincial laws and/or regulations govern the design, construction and installation of hydrogen gas equipment and facilities?	- Safety Codes Act - Pressure Equipment Safety Regulation	- Safety Standard Act - Gas Safety Regulation - Safety Standards General Regulation - Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation	- Technical Standards and Safety Act
What is the main authority body that enforces laws and regulations of hydrogen gas equipment and facilities?	- Alberta Boilers Safety Association (ABSA) - Alberta Municipal Affairs	- Technical Safety BC	- Technical Standards and Safety Authority (TSSA)
Are there any directives/regulations specific to hydrogen gas refueling stations?	No, however CSA B51 design code is adopted under the Pressure Equipment Safety Regulation which has requirements for hydrogen ground storage at refueling stations.	Yes, directive D-GA 2014-03 details design and installation requirements for hydrogen dispensing stations.	Yes, Compressed Gas Regulation and Compressed Gas Code Adoption Document - Amendment FS-143-09.
Are there any directives/regulations specific to hydrogen storage/distribution?	No, however CSA B51 design code is adopted under the Pressure Equipment Safety Regulation which has requirements for hydrogen ground storage at refueling stations and onboard storage as fuel for automotive vehicles.	No, however CSA B51 design code is adopted under the PEBPVR Safety Regulation which has requirements for hydrogen ground storage at refueling stations and onboard storage as fuel for automotive vehicles.	Yes, Compressed Gas Regulation applies to the storage of compressed hydrogen only.

Are there any directives/regulations specific to hydrogen liquefaction?	No information found.	No information found.	No information found.

Annex D – CAN/BNQ Hydrogen Installation Code Review Details

GAP REVIEW OF - CAN/BNQ 1784-000/2017 - Canadian Hydrogen Installation Code

Review approach: The BNQ code is a Hydrogen installation code. This reviews contains a review of h2 (gas or liquid) industry application. The NRC report has indicated these as elements. This review focusses mainly if the BNQ codes addresses the end user applications.

ID	NRC Element	Question	Covered in the BNQ standard?	Gap
1.1	1	Element 1: Electrolysis installation decentralizedcentralized.	Yes, Clause 1 : Includes hydrogen generating equipment. Purpose and Scope, industrial installations up to 21 kg/h continuous flow rate.	GAP: Yes *21 kg/h could be a limiting factor, for industrial installations. *Recommend that the rationale for the limit is addressed to allow larger production capacities. *Decentralized production PEM electrolyser - 1500 kig/day = 62 kg/hr. (https://www.energy.gov/sites/prod/files/2014/08/f18/fcto_2014_electrolytic_h2_wkshp_colella1.pdf) *McPhy offers modules of 9, 20, 35 and 71 kg/h h2 generation. * Cummins offers a electrolyser module of 85 kg/h H2 generation.
1.2	1	Element 1: Electrolysis installation covered, centralized.	Not sure. Clause 1: Centralized is not specifically mentioned. The scope excludes industrial hydrogen production on a continuous basis that exceeds 21 kg/h. Based on the capacity centralized facilities are excluded.	GAP: YES *no regulations or installation standards currently exist in Canada for centralized installation. *Cummins HyLyzer is 5MW producing 85/kg per electrolyser module. 4 modules are installed. (https://www.cummins.com/news/2021/10/04/video-case-study-cummins-hylyzerr-pem-electrolyzer-becancour-quebec)
2.1	12	Gas Storage above ground	NO: Storage design and installation not covered for larger facilities.	YES: Regulations, Codes and standards for larger scale production, storage and compression facilities.
2.2	12	Liquid storage above ground	NO: Storage design and installation not covered for larger facilities.	YES: Regulations, Code for H2 production facilities Centralised. See CSA Z276 main standard for LNG main plant, and Annex B for smaller LNG facilities.
2.3	12	Underground storage	NO: Storage design and installation not covered for larger facilities.	YES: Regulations, Code for H2 production facilities Centralised. See CSA Z276 main standard for LNG main plant, and Annex B for smaller LNG facilities.
3.1	43	Gas Dispensing indoors cars and lift trucks	YES: design Clause 7.9, installation 7.11.2 (Outdoor), and 7.11.4 for clearance distances, and 7.12.5 for indoor fuelling. Both low flow and high flow indoor fuelling is covered for motive fuelling. The BNQ standard does not limit to use of the standard and applies to all gaseous and liquid hydrogen application (see purpose and scope) thus to all refuelling installations. The standard does apply to public or private refuelling, attended or unattended installation for cars, lift trucks, trucks, busses, trains, marine, etc. refueling. It applies to private, commercial or industrial applications. Indoor fuelling for public stations is not covered.	YES: *The BNQ standard covers high-level requirements for dispensing systems. *HGV4.1 is a product standard for H2 gas dispensers it should be referenced in the BNQ?

GAP REVIEW OF - CAN/BNQ 1784-000/2017 - Canadian Hydrogen Installation Code

Review approach: The BNQ code is a Hydrogen installation code. This reviews contains a review of h2 (gas or liquid) industry application. The NRC report has indicated these as elements. This review focusses mainly if the BNQ codes addresses the end user applications.

ID	NRC Element	Question	Covered in the BNQ standard?	Gap
3.2	43	Gas Dispensing outdoors cars and lift trucks	YES: design Clause 7.9, installation 7.11.2 (Outdoor), and 7.11.4 forclearance distances. The BNQ standard does not limit to use of the standard and applies to all gaseous and liquid hydrogen application (see purpose and scope) thus to all refuelling installations. The standard does apply to public or private refuelling, attended or unattended installation for cars, lift trucks, trucks, busses, trains, marine, etc. refueling. It applies to private, commercial or industrial applications.	YES: *The BNQ standard covers high-level requirements for dispensing systems. *HGV4.1 is a product standard for H2 gas dispensers it should be references in the BNQ. * It is not 100% clear if the 21 kg/h applies to generation or use at a fuelling station. Many fuelling systems exclude the 21 kg/h which would limit the BNQ standard to smaller fuelling stations. ** Train fuelling station in Germany is 1600 kg/day = 66 kg/h. (Linde) **Power to gas plant in Germany for H2 bus fueling produces 300 kg/8 hours = 38 kg/hfor 8 fuel cell buses. (Linde) **H2 fuelling station for buses stored in JH2 then compressed into GH2, 100 kg/hstation for 30 fuel cell buses per day. (Linde)
4.1	44	Gas dispensing trucks/busses	YES: see element 43. This applies to truck, bus fuelling as well.	YES: see element 43.
4.2	44	Liquid dispensing trucks/buses	NO: liquid fueling is not covered.	YES: Develop LH2 refuelling standard as the market is installing liquid fuelling stations today.
5.1	45	Gas dispensing train	YES: see element 43. This applies to truck, bus fuelling as well.	YES: see element 43.
5.2	45	Liquid dispensing train	NO: liquid fueling is not covered.	YES: Develop LH2 refuelling standard as the market is installing liquid fuelling stations today.
	25	H2 liquid storage at end use site	YES: Clause 8.2 covers LH2 storage containers. Clause 8.8 covers clearance distances.	YES: *Liquid refuelling is not covered. This should be considered. * Sizing requirements (fire case and others) for relief valves is not addressed. Canreference CGA standards. * CSA B51 for storage vessel design is not addressed. *Clearance distances could be based on the largest tanks size rather then aggregatevolume of H2 stored on site. * Size of total H2 storage is limited to 283,000l. (74,000 USG). For industrial applicationsthis could be too small. It is recommended that this is reviewed. *Clearance liquid transfer from trailer / dispenser should be addressed.
	25	H2 gas storage	Yes. Clause 7.8.1.1.2/ 7.8.1.1.3 covers acceptable design /constructioncodes. 7.11.1 covers siting	YES *No reference is made to CSA B51 Part 2 onboard fuel tanks as acceptable groundstorage. (Only ISO standards)

GAP REVIEW OF - CAN/BNQ 1784-000/2017 - Canadian Hydrogen Installation Code

Review approach: The BNQ code is a Hydrogen installation code. This reviews contains a review of h2 (gas or liquid) industry application. The NRC report has indicated these as elements. This review focusses mainly if the BNQ codes addresses the end user applications.

ID	NRC Element	Question	Covered in the BNQ standard?	Gap
	25	H2 Storage vaulted	YES: Clause 7.11.1.2 covers underground gas containers.	YES: *Underground containers LH2 is not addressed. *Underground Metal hydride container is not addressed.
	25	Metal Hydride Storage	YES; Clause 7.8.1.2 covers design/construction.	YES: *Siting of metal hydride tanks is not addressed.
	25	Mobile storage gas or liquid	NO:	YES: *Hydrogen gas and liquified gas storage will very likely be provided at the end user site in bulk trailers. Siting / Transfer operations should be covered in the BNQ standard.
	26	LH2 vaporization at end use site	YES: Equipment design Clause 8.6 siting clearance clause 8.8	YES: Industrial Generation or end-use equipment is limited to 21 kg/h = 21*141.88 = 71 GJ/Day- HHV. This would be a single IC or fuel cell generator of 300 kw electrical output.
	27	Portable fuel cell power systems	YES: Clause 10.2 shall comply to the CSA TIL R-18.	YES: Larger transportable equipment is not included. It is not clear what standards apply to mobile equipment, mobile refuelling equipment, mobile compressor equipment, mobile storage, mobile generator etc.
	28	Stationary fuel cell systems	YES: Clause 1 purpose and scope include hydrogen utilization equipment. Definition clearly states that hydrogen utilization equipment includes items such as fuel cells and internal combustion engines. Clause 7.2.1 requires fuel cells to comply with ANSI/CSA America FC1.	YES: what is the limit on FC1? FC1 covers packages, self contained or factory matched packages of fuel cell power systems. No limit specific in the scope on size.
	29	H2 gas turbine power production	YES: Clause 1 purpose and scope include hydrogen utilization equipment. Definition clearly states that hydrogen utilization equipment includes items such as fuel cells and internal combustion engines. Clause 7.2.2 requires IC engines and gas turbines to be approved by AHJ.	YES: Require reference for equipment requirements and installation similar to CSAB149.1 CSA B149.3.
	29	H2 IC engine power production	YES: Clause 1 purpose and scope include hydrogen utilization equipment. Definition clearly states that hydrogen utilization equipment includes items such as fuel cells and internal combustion engines. Clause 7.2.2 requires IC engines and gas turbines to be approved by AHJ.	YES: Require reference for equipment requirements and installation similar to CSAB149.1. Approval by the AHJ complicates approval processes.
	49	Powered by H2 gas OEM installations	NO: Excluded from scope. Clause 1 excludes hydrogen installations onboard vehicles, boats, airplanes and space vehicles.	YES: It is assumed that trains also are excluded. Suggest update to the standard to exclude all onboard fueling systems.

GAP REVIEW OF - CAN/BNQ 1784-000/2017 - Canadian Hydrogen Installation Code

Review approach: The BNQ code is a Hydrogen installation code. This reviews contains a review of h2 (gas or liquid) industry application. The NRC report has indicated these as elements. This review focusses mainly if the BNQ codes addresses the end user applications.

ID	NRC Element	Question	Covered in the BNQ standard?	Gap
	49	Powered by H2 Land vehicles After Market (Include H2 supported diesel engines.	NO: Excluded from scope.	YES: Hydra a company in BC installs H2 fueling system to assist diesel engine combustions. A standard is required similar to CSA B109 part 1 and /or 2 to cover installations.
	50	H2 on board train fuelling	NO: Excluded from scope.	YES: Commercial product are available for commuter trains and companies are working on freight trains. (Ballard, Linde, etc.). A review of onboard systems for trains should be reviewed.
	30	H2 gas burning appliances	YES: Clause 9 residential applications. Clause 9.2.2 covers generating and utilization equipment including dispensing.	YES: The BNQ standard is very limited in scope and does not cover the gas supply into the building, appliance standards, venting, pressure limitations for residential use and apartment use.
	30	H2 gas burning appliances industrial, large scale	YES: utilization equipment includes gas appliances.	YES: Requirements for non appliance type equipment is not covered. CSA B149.3 can be used as reference or expended to include H2 combustion systems. CSA B149.3 does not cover Hydrogen. *The 21 kg/h limit is expected to limit hydrogen applications in specialty burner equipment for process heating applications.
	13	H2 liquefaction large scale	No: excluded from the standard	YES: No standard or regulation currently exist in BC.
	13	H2 liquefaction facilities small scale	No: excluded from the standard	YES: No standard or regulation currently exist in BC.
	69	Hazardous area classification	YES: Clause 6.2 refers to IEC 60079-10	YES: IEC 60079-10 method is relatively complex and results could vary largely based on assumptions. The standard does not specifically cover high-pressure equipment and small lines and fittings typically see on H2 equipment. Leak rates have to be determined for equipment and piping systems but the guidance given does not apply to high pressure small tubing systems. It is recommended that a minimum area classification method is also provided in the standard with IEC standard as another option. This can be based on some NFPA 497 , NFPA 2.
	69	Material compatibility	YES: Clause 5.2.2 addresses material compatibly and reference Annex C of ISO/TR standard 15916. Clause 7.4.2 list typical materials that are used for H2 generating and utilization equipment. ISO standard 11114-4 is listed for materials recognized as being suitable for hydrogen service.	NO: In this limited review material compatibility seems to be adequately covered.
	69	Valves (Leakage)	YES: Valves are addressed with respect to system design and maintenance requirements.	YES: Valves specifically for H2 are not addressed. The main reason for addressing valves is to ensure low leakage rates. This is important for packaged equipment to prevent gas leakage and potential for explosions.
	69	Gas valve trains	NO: Use equipment valves trains / or combustion equipment valves trains are not addressed.	YES: See previously comments on gas appliance element 30.

GAP REVIEW OF - CAN/BNQ 1784-000/2017 - Canadian Hydrogen Installation Code

Review approach: The BNQ code is a Hydrogen installation code. This reviews contains a review of h2 (gas or liquid) industry application. The NRC report has indicated these as elements. This review focusses mainly if the BNQ codes addresses the end user applications.

ID	NRC Element	Question	Covered in the BNQ standard?	Gap
	69	H2 sensors	YES: Hydrogen detection systems are covered in clause 7.12.3 and other sections. It covers mainly system requirements and maintenance requirements.	YES: A product standard for gas detectors is recommended to ensure reliable product with a minimum quality and integrity. This is important as H2 system will leak and the gas detector is used to shutdown the potential leak source.
	69	Electrical seals	NO: electrical seals for liquified equipment is not specifically mentioned.	YES: submergible pumps may be used for LH2 equipment. The cable seals need to comply with a minimum standard. Accidents have happened in the LNG industry with inadequateseals preventing gas migration to electrical panels.
		Other equipment:		
		Compressors	YES: Clause 7.7 addresses compressors and compressor packages.	
		Dispensers (Gas and Liquid)	YES: Gaseous dispensers covered in clause 7.9, Liquid dispensers are not covered.	YES: Liquid dispensers are not covered see also element 43,44,45
		Pumps	NO: LH2 pumping and dispensing is not covered in the BNQ standard,	YES: Add safety requirements for pumps in BNQ standard or dedicated standard for LH2 end user systems.

	Answer Summary		
Questions	**Alberta**	**British Columbia**	**Ontario**
Are there any directives/regulations specific to hydrogen onsite production?	No information found.	No information found.	No information found.
Are there any directives/regulations specific to hydrogen heating appliances?	No information found.	No, however Hydrogen gas appliances regulations are covered under the Gas Safety Regulation	No information found.
Are there any directives/regulations specific to hydrogen fuel cell power generation?	No information found.	No information found.	No information found.
Is the CAN/BNQ 1784-000 Canadian Hydrogen Installation Code an adopted standard?	No information found.	Partially, the code is adopted under directive D-GA 2014-03 for Hydrogen Refueling Stations only.	Yes, the code is adopted for the installation of hydrogen fueled appliances and equipment except for Hydrogen piping, tubing and fittings (shall be designed to ASME B31.3).
Are there any required permits specific to hydrogen equipment or systems?	No, general provincial and municipal permits are required.	No, general provincial and municipal permits are required.	No, general provincial and municipal permits are required.
Does the provincial Building Code have any regulations specific to hydrogen applications?	No, however regulations of this code still apply to all hydrogen gas applications.	No, however regulations of this code still apply to all hydrogen gas applications.	No, however regulations of this code still apply to all hydrogen gas applications.
Does the provincial Fire Code have any regulations specific to hydrogen applications?	No, however regulations of this code still apply to all hydrogen gas applications.	No, however regulations of this code still apply to all hydrogen gas applications.	No, however regulations of this code still apply to all hydrogen gas applications.

Recommendations:

Following the review of the provincial regulations and directives, there is little reference specific todesign, construction and installation of hydrogen equipment and systems. There are gaps in the provincial regulations and directives in relation to most hydrogen applications.

To fill the gaps, the following is recommended from the regulatory authorities:

- Clearly define the term “gas” to include or dis-include hydrogen gas from the regulations.

- Adopt the CAN/BNQ 1784-000 standard as the main standard for installation of hydrogen equipmentand systems.

- Adopt other standards as necessary to cover the design, construction, and installation of all hydrogenapplications.

- Provide more directives specific to hydrogen applications such as hydrogen liquefaction, production, appliances, power generation, indoor equipment, service garage, H2 conversion, and trades certification.

Annex E – Code Review Details

Codes & Standards Review Summary 2022-03-10

CSA B51-19 Boiler, Pressure Vessel and Pressure Piping Code:

- Part 1 of this standard applies to all boilers, pressure vessels, pressure piping, and fittings, as provided for by the Act and identified in Part 1 of this Standard.
- Part 1 of this standard does not specifically mention Hydrogen, but it is implied that the scope covers some Hydrogen applications
- "Act" means the Acts, regulations, or ordinances governing the design, fabrication, installation, repair, and alteration of boilers, pressure vessels, fittings, and piping.
- Part 2 of this Standard applies only to cylinders for the on-board storage of high-pressure compressed natural gas and/or compressed hydrogen as fuels for automotive vehicles to which the cylinders are to be fixed. Cylinders may be of any material (steel, aluminum, or non- metallic) and constructed in accordance with any design or method of manufacture suitable for the specified service conditions.
- The pressure piping systems covered in Part 3 of this Standard are systems used in compressed natural gas (CNG) and hydrogen refueling stations
- between the termination of the utility's piping, usually at the meter, and the inlet to the compressor assembly if the design pressure exceeds 414 kPa (60 psi); and
- from the inlet to the compressor assembly through to the dispenser nozzle, except for the mechanical parts of the compressor and any subsystems designed for 414 kPa (60 psi) or less.
- The ground storage vessels covered in Part 3 of this Standard are pressure vessels that are installed at CNG, and hydrogen refueling stations and intended to store CNG or hydrogen at pressure for delivery to vehicle fuel tanks.

CAN/BNQ 1784-000/2007 Canadian Hydrogen Installation Code:

The purpose of this code is to establish the installation requirements for hydrogen generating equipment (by electrolysis, reforming, chemical reaction, or other), hydrogen utilization equipment(ex. fuel cells, internal combustion engines), hydrogen dispensing equipment, hydrogen storage containers, hydrogen piping systems and their related accessories.

It applies to all gaseous and liquid hydrogen applications except the following:

- The use of hydrogen in petroleum refineries and chemical plants as feedstock and directly in-process production.

- industrial hydrogen installations that produce and/or use on a continuous basis mass flow rates that are in excess of 21 kg/h.

- Industrial installations that produce hydrogen as a by-product;

- Hydrogen installations that produce liquid hydrogen;

- Hydrogen installations onboard vehicles, boats, airplanes and space vehicles;

- Micro fuel cell systems for electronic equipment;

- Hydrogen transportation including the hydrogen utility pipeline distribution and transmission pipelines;

- Hydrogen marine and pipeline terminals.

<u>CSA Z276 LNG – Production, Storage, and Handling:</u>

- This Standard establishes requirements and standards for the design, installation, and safe operation of liquefied natural gas (LNG) facilities.

- This standard does not apply to any hydrogen applications.

<u>CSA B108-18 Natural Gas Refuelling Stations Installation Code:</u>

- Part 1 of this Code applies to all compressed natural gas refuelling stations, including thosethat are intended for fleet or public dispensing operations.

- Part 2 of this Code applies to the design, location, construction, operation, operator training, and maintenance of LNG refuelling stations, including mobile refuelling units, with single containment storage tanks up to 265 cm3 (70 000 gal) water capacity employed for vehicle LNG dispensing operations. Part 2 of this Code also applies to shop-fabricated and assembled refuelling stations when used to receive and store LNG to dispense LNG into vehicle fuel tanks.

- Part 2 of this Code does not apply to the following:

    - indoor refuelling
    - marine vessel LNG fuelling facilities;
    - rail locomotive LNG fuelling facilities;
    - equipment or piping downstream of the L/CNG odorizer discharge isolation valve
    - CNG equipment including storage, compression, and/or dispensing equipment;
    - equipment or piping downstream of the gas pressure regulator for closed boil-off gas systems;
    - dispensing of LNG other than into vehicle or cargo fuel tanks;

- liquefaction equipment;
- LNG engine fuel systems;
- LNG and CNG repair garages;
- underground piping for LNG; and
- LNG storage tanks, pumps and process piping when an LNG refuelling station issharing the LNG plant storage tank.

CSA Z662-19 Oil and Gas Pipeline Systems

- This Standard covers the design, construction, operation, maintenance, deactivation, and abandonment of oil and gas industry pipeline systems that convey liquid hydrocarbons, oilfield water, oil field steam, liquid carbon dioxide and gas.
- This standard does not cover hydrogen.

CSA C22.1-18 Canadian Electrical Code, Part I, Safety Standard for Electrical Installations:

- This Code applies to all electrical work and electrical equipment operating or intended to operate at all voltages in electrical installations for buildings, structures, and premises, including factory-built relocatable and non-relocatable structures, and self-propelled marinevessels stationary for periods exceeding five months and connected to a shore supply of electricity continuously or from time to time.
- This code references CAN/BNQ 1784-000/2007
- 18-050 Electrical equipment / J18-050 Electrical equipment - Defines hydrogen equipment hazardous area classification:
- Group IIC (Zone system)
- Group B (Division system)
- 64-708 Grounding and bonding - Grounding & Bonding requirements for hydrogen containers
- Rule 26-506 - Hydrogen battery room ventilation requirements
- Rule 64-710 Fuel cells should be considered fuel-burning equipment and be installed in accordance with the National Building Code of Canada. Hydrogen-fuelled systems should be installed in accordance with CAN/BNQ 1784-000.

CSA B109-17 Natural Gas for Vehicles Installation Code:

- This code applies to the installation, inspection, repair, and maintenance of the fuel storage and delivery system installed in powered industrial truck applications and vehicles for use with compressed natural gas (CNG). This includes fuel system on self-propelled vehicles for the provision of motive power
- This code does not cover any hydrogen applications

CSA B401-18 Vehicle Maintenance Facilities Code:

- This Code applies to the portions of a motor vehicle maintenance facility where natural-gas-fuelled vehicles are maintained, repaired, or stored during maintenance or repair, including areas and systems ancillary thereto.
- The scope of this Code does not include
  - indoor or outdoor refuelling operations;
  - parking facilities; or
  - other fuels used for vehicles.
- This code does not cover hydrogen applications

	Answer Summary							
Questions	**CSA B51**	**BNQ 1784-000**	**CSA Z276**	**CSA B108**	**CSA Z662**	**CSA C22.1**	**CSA B109**	**CSA B401**
1. Is Hydrogen specifically covered in the code/standard?	Yes	Yes	No	No	No	Yes	No	No
2. If the code/standard does not list hydrogen specifically does it still apply to Hydrogen	Yes	Yes	No	No	No	Yes	No	No
3. What does the code specifically cover in relation to hydrogen applications?	- Boiler, Pressure Vessel and Pressure Piping Requirements - Hydrogen ground storage at refueling stations - Hydrogen onboard storage as fuel for automotive vehicles.	Installation requirements for hydrogen generating equipment, utilization equipment, dispensing equipment, storage containers, piping systems and their related accessories	-	-	-	- Classifies hazardous area - Grounding & Bonding requirements for hydrogen containers - Hydrogen battery room ventilation requirements	-	-
4. Does it cover fuel cell generation or electrolyzes or appliances?	No	Partly, references Iso Standard 22734-1	No	No	No	- Fuel cell systems to be installed in accordance with the National Building Code of Canada	No	No

	Answer Summary							
Questions	**CSA B51**	**BNQ 1784-000**	**CSA Z276**	**CSA B108**	**CSA Z662**	**CSA C22.1**	**CSA B109**	**CSA B401**
5. Does it cover blended gas (up to 15 % with NG)?	No	No	No	No	No	No	No	No
6. Does it cover H2 combustion equipment?	No	No, it states “requires approval by the authority having jurisdiction.”	No	No	No	No	No	No
7. Does it reference standard that H2 equipment must comply with?	No	Yes, it references many standards.	No	No	No	Yes, it references BNQ 1784-000	No	No

Recommendations:

To fill the gaps, the following is recommended from the regulatory authorities and standards associations:

- Develop the CAN/BNQ 1784-000 standard such that it contains comprehensive requirements. Pleasereview the CAN/BNQ code gap analysis.
- Adopt other standards as necessary to cover the design, construction and installation of all hydrogen applications that are outside the scope of the CAN/BNQ standard.
- Amend existing standards to include requirements for hydrogen blending with other gases or liquids, CSA Z662, CSA B149.1.
- Expand the scope of current standards to cover current and future technological advances.

Annex F – General Commentary on the Value Chain Elements Developed By the NRC

1. Industry Training Requirements;

This Codes/Standards summary should include training and technician licensing requirements. This is an area to discuss further with industry as they have experiences to share.

The overall scope of this package of work is considerable, from H_2 production, purification, storage, transport and general safety and handling. The number of different potential jurisdictions (Nationality) adds a further multiplying effect to the scope of the project.

As currently laid out, an observation is that there is an excessive number of Elements involved and there is a great deal of overlap in referenced standards for design, materials requirements, operating specifications and general safety.

The suggestion would be to consider separating out the scope for the various Elements into categories such as, Production Methods, Jurisdictions, Storage, Transportation Systems, End Use Applications, Safety and others.

The goal being to simplify the process of gathering the requirements for a specific production project, to produce a set form of product, to be transported by an available means to serve customers in a specific jurisdiction and meet all safety requirements for the various aspects and for the local conditions. This would be a less onerous method of covering more of the potential combinations of the various Elements.

Suggested Break- Down of Categories (Preliminary for discussion only)

A. Production Method: The current listing of Elements is quite comprehensive in terms of outlining different production methods. These could and likely should be kept separate and independent from storage and from transportation options. These being separate from production and very much dependent on the end user, local markets and existing infrastructure.
B. Storage Systems: Hydrogen storage is a challenge due to the nature of the product. Specific projects will match storage systems with available infrastructure, end use for the H2, transportation requirements and economic considerations. A detail listing of codes and standards relating to storage systems would and should be independent from those focused on production methods or power production applications, both stationary and transportation / mobile.
C. Transportation and Shipping: The use of H2 as a transportation fuel is very much influenced by the form of the transport, ship, plane, rail or road. The fuel storage and dispensing means will differ in many cases and will require appropriate infrastructure. As with most installations, this will be controlled by economics, safety (real and perceived) and reliability. Application of standards and

design controls will be very much influenced by local requirements and the nature of where the H2 fuel is sourced.

D. Jurisdiction: Since the various standards for equipment processes, procedures, safety, and product quality will be jurisdiction specific, a suggestion is to consider mapping out the overall scope based on where the project or equipment is destined. This could start with International, Europe, Canada, USA, Can/USA and the potential for off- shore marine, which could encounter any of a number of location specific requirements. There is little or no benefit to designing and building a plant or process to an international standard that is in excess of what is required in the jurisdiction where the equipment is destined to be installed. Yes, it still needs to be safe and effective, but overlapping standards will increase costs and limit equipment selection and availability. As a minor example: Element 1, Line 102, H2 Fuel Quality for PEM Fuel Cells. The expectation is that this is a Performance Requirement more than it is a Safety issue. Likely that Mercedes Benz, BMW, Toyota, Ballard Power, etc. would all have their own product requirements. The SAE J2719 may be adopted internationally by individual users, but it is primarily a US standard. The requirements for a project in Norway or Finland would be different than one destined for Johannesburg SA.

The following additions to the existing NRC hydrogen chain value elements were recommended:

- *Element 44 – Liquid hydrogen dispensing trucks and busses*
- *Element 45 – Liquid hydrogen dispensing rail applications*
- *Element 25 – Hydrogen gas storage*
- *Element 25 – Hydrogen Metal Hydride storage*
- *Element 25 – Hydrogen mobile gas storage in gaseous or liquid form*
- *Element 29 – IC engine power generation*
- *Element 49 – Hydrogen assist (dual fuel) land vehicles for aftermarket applications*
- *Element 30 – Hydrogen gas industrial gas burning equipment*
- *Element 13 – H2 liquefaction small scale (decentralized)*
- *Element 43,44,45 – Hydrogen mobile dispensing equipment*
- *Element XX – Include slide for hydrogen vehicle repair, service, and parking garages*

These additions are recommended based on industry direction and experience with CNG and LNG. Examples are provided as follows:

- A liquid hydrogen fueling station is currently being installed in the US and is used for larger fleet truck and bus refueling. Similarly, for freight trains, refuelling of liquid hydrogen into onboard storage is the preferred option.

- The hydrogen storage options at end-use applications are gaseous and liquid storage. The slides can be expanded to include all storage options including metal hydride.

- Hydrogen IC engine generators are available on the market

- Hydrogen onboard fuel is retrofitted on existing diesel trucks to reduce emissions and improve fuel economy. They see similar applications in both LNG and CNG dual fuel trucks.

- Hydrogen burners are available in the market and process heating applications in all industries are expected. The equipment is not certified as an appliance and field certification is usually required.

- Liquefaction equipment is currently in the natural gas industry. Liquefaction for the hydrogen industry is expected to follow.

- A very important storage method in the virtual pipeline is mobile storage. This is both used for liquid and gaseous storage. Instead of offloading the bulk transport trailer into stationary storage the trailer is parked and connected at the plant site and is used for storage and fuel transfer.

- Due to the high cost of fueling stations, small fleets often start with mobile refuelling. They see this in the CNG industry where companies offer CNG refuelling service by bringing the CNG to the client site with mobile storage and mobile compressor/ dispensing systems. This allows the fleet to grow and de-risks the investment. This service is offered for hydrogen as well.

Elements 55 Transportation LH2 Shipping: Same loading scenario as Slide 51.

Element 56 LH2 Aircraft Fueling: Same fuel loading scenario as Slide 52

Element 57 GH2 Dispenser Aircraft: Same loading scenario as slide 53

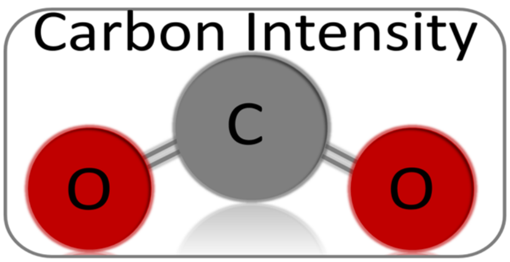
Element 58 GH2 Airport Trucks and Tugs: Same fuel loading scenario as slide 44.

Element 59 to 62 GH2 Dispenser, Truck Fueling: Same fuel loading scenario as slide 44.

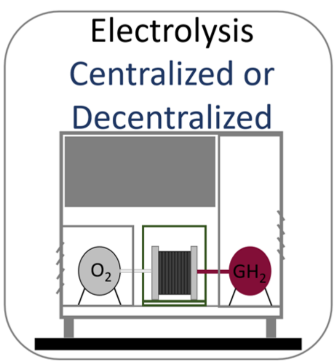
Element 63 Portable Fuel Cell Mining Operations Bellow Ground: Same fuel loading scenario as slides 27 and 28.

Annex G – Canadian Hydrogen Value Chain Element Details

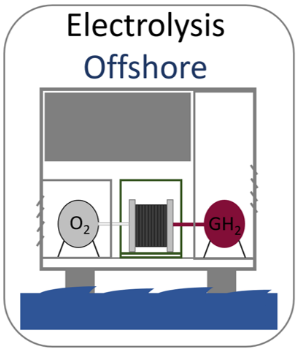
Element No.	Value Chain Segment
0	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

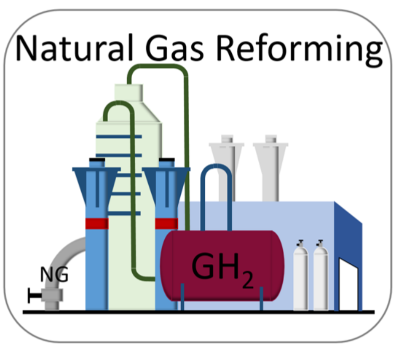
Element No.	Value Chain Segment
1	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

Element No.	2	Value Chain Segment	H_2 Production and Purification

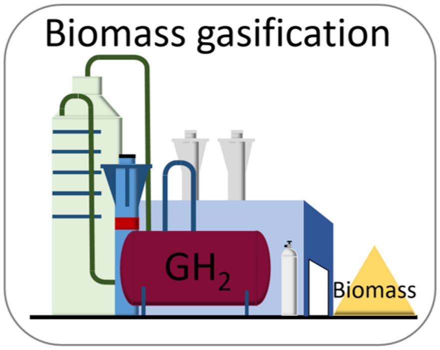
Element Name	Coverage Details (If Applicable)
	

Element No.	3	Value Chain Segment	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	This Element includes: ▪ Natural gas reforming ▪ H_2 extraction - in-situ well gasification ▪ Methane pyrolysis

Element No.	4	Value Chain Segment	H_2 Production and Purification

Element Name



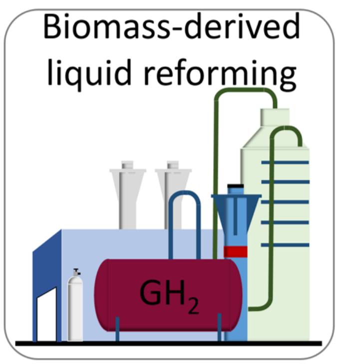
Coverage Details (If Applicable)

This Element includes:

- Wood
- Organic waste
- Land fill

Element No.	5	Value Chain Segment	H_2 Production and Purification

Element Name

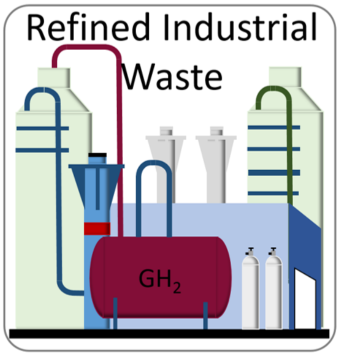


Coverage Details (If Applicable)

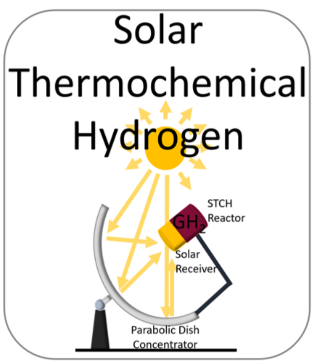
This Element includes:

- Biomass-derived liquid reforming
- Extracting H_2 from bio-ethanol alcohol production
- Methanol fuel cell power plants

Element No.	6	Value Chain Segment	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

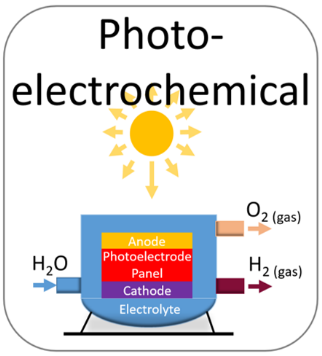
Element No.	7	Value Chain Segment	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

Element No. **8**

Value Chain Segment: **H_2 Production and Purification**

Element Name

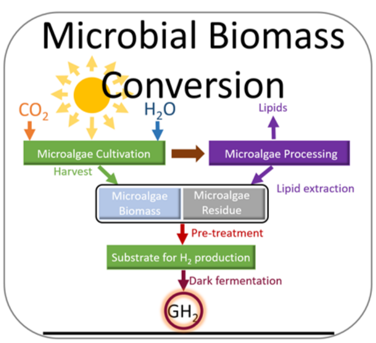


Coverage Details (If Applicable)

Element No. **9-a**

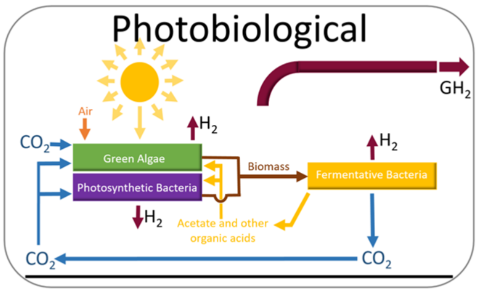
Value Chain Segment: **H_2 Production and Purification**

Element Name

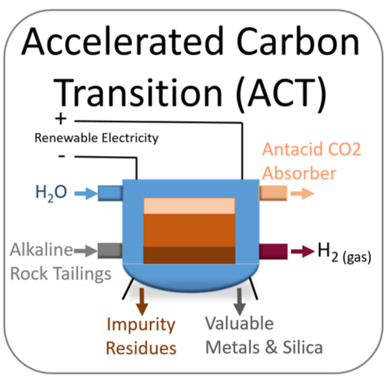


Coverage Details (If Applicable)

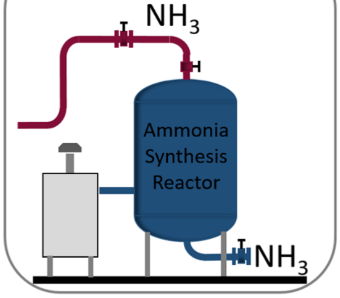
Element No.	9-b	Value Chain Segment	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

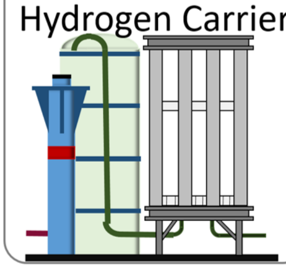
Element No.	10	Value Chain Segment	H_2 Production and Purification

Element Name	Coverage Details (If Applicable)
	

Element No.	11-a	Value Chain Segment	H_2 Conversion, Storage and Liquefaction

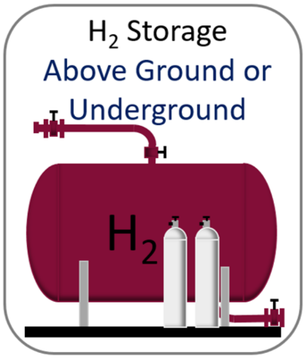
Element Name	Coverage Details (If Applicable)
H_2 Conversion to NH_3 	

Element No.	11-b	Value Chain Segment	H_2 Conversion, Storage and Liquefaction

Element Name	Coverage Details (If Applicable)
H_2 Conversion to Liquid Organic Hydrogen Carrier 	

Element No.	12	Value Chain Segment	H_2 Conversion, Storage and Liquefaction

Element Name

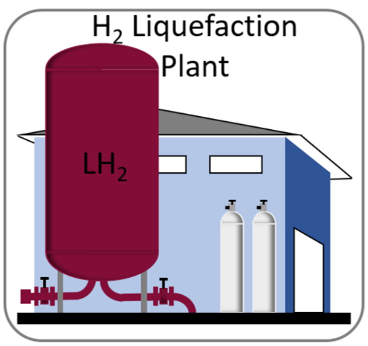


Coverage Details (If Applicable)

This Element includes:
- GH_2 storage
- LH_2 storage
- Solid state storage
- Swappable H_2 tank for isolated communities and small equipment
- Underground well and salt cavern storage
- Compression stations and compressors
- Hydrogen mobile storage in gaseous or liquid form

Element No.	13	Value Chain Segment	H_2 Conversion, Storage and Liquefaction

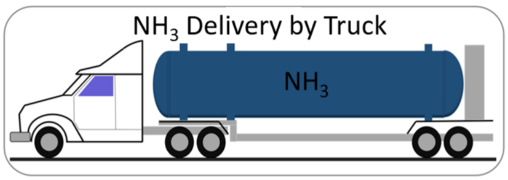
Element Name



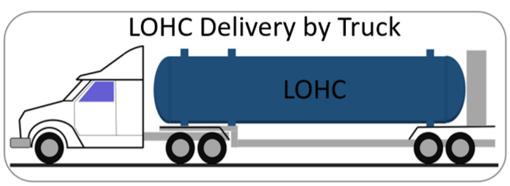
Coverage Details (If Applicable)

This Element includes:
- H_2 liquefaction centralized
- H_2 liquefaction small scale (decentralized)

Element No.	14-a	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
	

Element No.	14-b	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
	

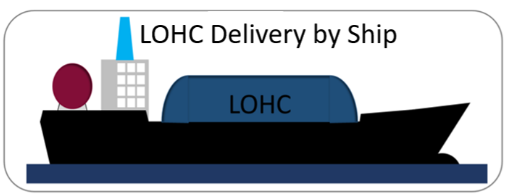
Element No.	15-a	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name

Coverage Details (If Applicable)

Element No.	15-b	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name



Coverage Details (If Applicable)

Element No.	16-a	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
NH$_3$ Delivery by Rail 	

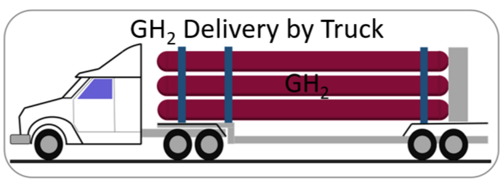
Element No.	16-b	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
LOHC Delivery by Rail 	

Element No.	17	Value Chain Segment	Gas and Liquid Delivery and Distribution

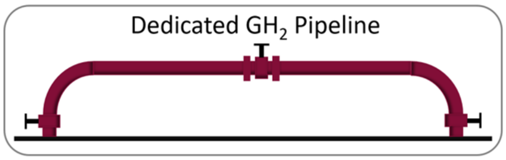
Element Name	Coverage Details (If Applicable)
	

Element No.	18	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
	

Element No.	19	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name



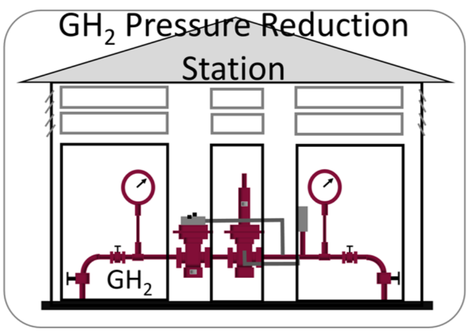
Coverage Details (If Applicable)

This Element includes:

- Distribution lines (low pressure)
- Transmission lines (high pressure)

Element No.	20	Value Chain Segment	Gas and Liquid Delivery and Distribution

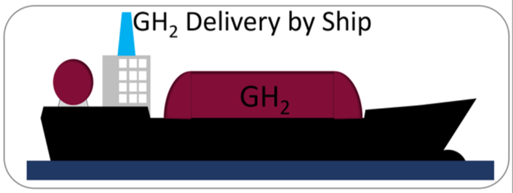
Element Name



Coverage Details (If Applicable)

Element No.	21-a	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name

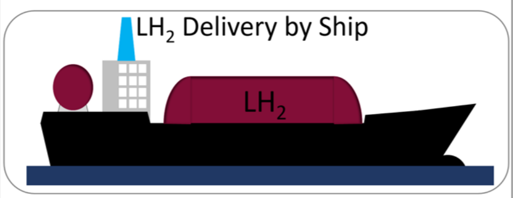


Coverage Details (If Applicable)

This Element includes:
- GH_2

Element No.	21-b	Value Chain Segment	Gas and Liquid Delivery and Distribution

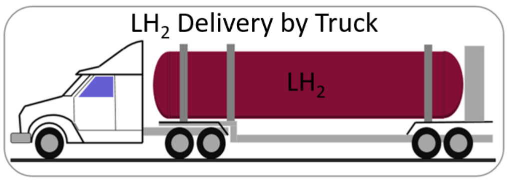
Element Name



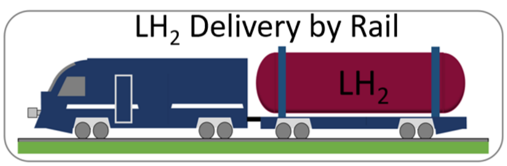
Coverage Details (If Applicable)

This Element includes:
- LH_2

Element No.	22	Value Chain Segment	Gas and Liquid Delivery and Distribution

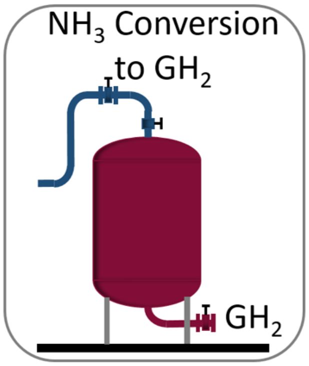
Element Name	Coverage Details (If Applicable)
	

Element No.	23	Value Chain Segment	Gas and Liquid Delivery and Distribution

Element Name	Coverage Details (If Applicable)
	

Element No.	Value Chain Segment
24-a	H_2 at End Use Site

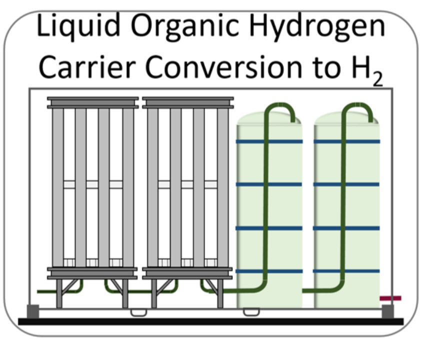
Element Name



Coverage Details (If Applicable)

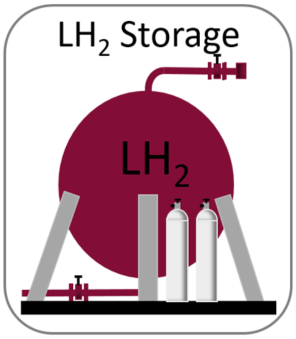
Element No.	Value Chain Segment
24-b	H_2 at End Use Site

Element Name

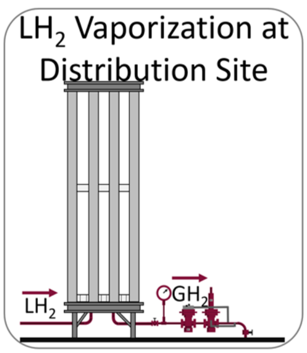


Coverage Details (If Applicable)

Element No.	25	Value Chain Segment	H_2 at End Use Site

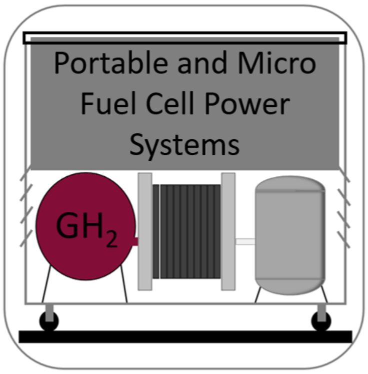
Element Name	Coverage Details (If Applicable)
	

Element No.	26	Value Chain Segment	H_2 at End Use Site

Element Name	Coverage Details (If Applicable)
	

Element No.	27	Value Chain Segment	Power Production

Element Name

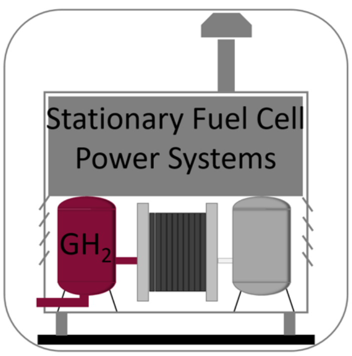


Coverage Details (If Applicable)

This Element includes:
- Portable fuel cell power systems
- Micro fuel cell power systems

Element No.	28	Value Chain Segment	Power Production

Element Name

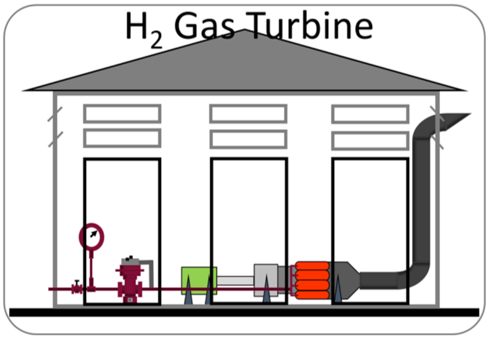


Coverage Details (If Applicable)

This Element includes:
- Stationary fuel cell power systems
- Stationary - indoor UPS systems

Element No.	29-a	Value Chain Segment	Power Production

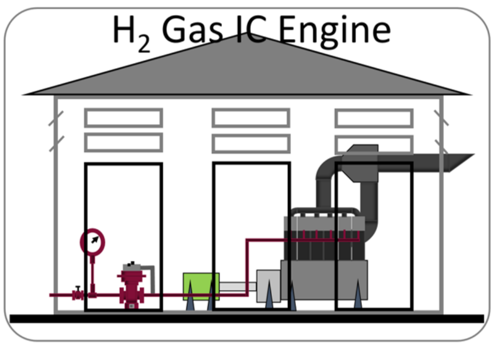
Element Name



Coverage Details (If Applicable)

Element No.	29-b	Value Chain Segment	Power Production

Element Name



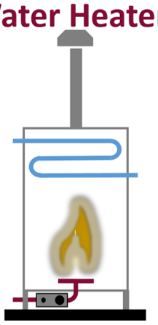
Coverage Details (If Applicable)

Element No. **30**

Value Chain Segment: **H_2 Gas Burning Appliances**

Element Name

GH_2 Boilers & Water Heaters



Coverage Details (If Applicable)

This Element includes:

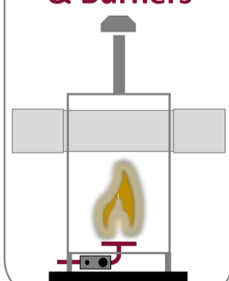
- Hot water tank heaters
- Instantaneous tankless water heaters
- Pool heaters
- Boilers
- Industrial and commercial water heaters

Element No. **31**

Value Chain Segment: **H_2 Gas Burning Appliances**

Element Name

GH_2 Furnaces & Burners



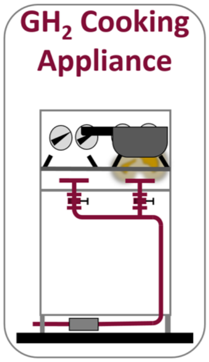
Coverage Details (If Applicable)

This Element includes:

- Residential furnaces
- Industrial and commercial furnaces
- Industrial burners for process heating applications

Element No.	32	Value Chain Segment	H_2 Gas Burning Appliances

Element Name



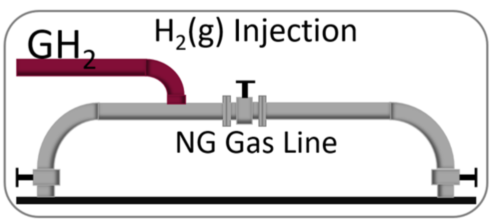
Coverage Details (If Applicable)

This Element includes:

- Industrial and commercial cooking appliances
- Residential cooking appliances

Element No.	33	Value Chain Segment	H_2 Blending into Natural Gas Lines

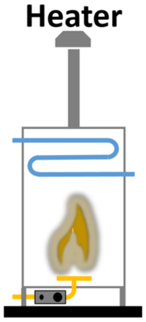
Element Name



Coverage Details (If Applicable)

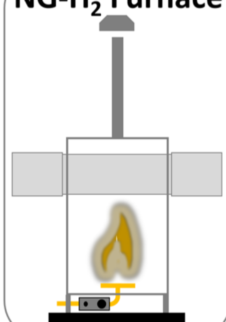
Element No.	Value Chain Segment
34-a	NG-H_2 Burning Appliances

Element Name	Coverage Details (If Applicable)
NG-H_2 Water Heater	

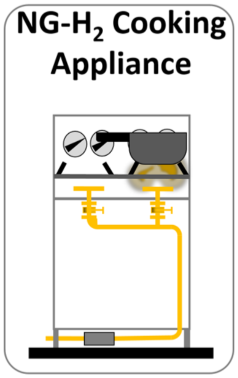


Element No.	Value Chain Segment
34-b	NG-H_2 Burning Appliances

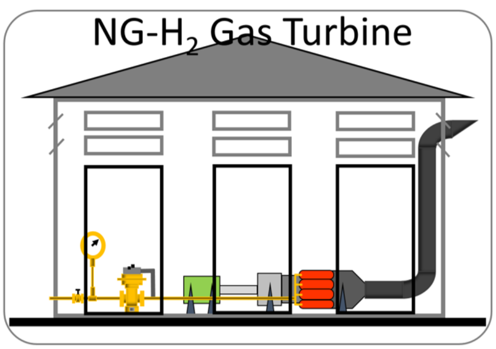
Element Name	Coverage Details (If Applicable)
NG-H_2 Furnace	



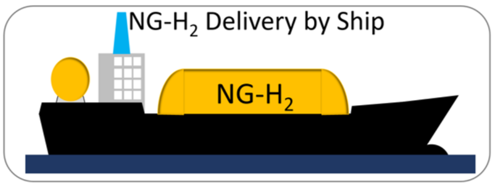
Element No.	34-c	Value Chain Segment	NG-H_2 Burning Appliances

Element Name	Coverage Details (If Applicable)
	

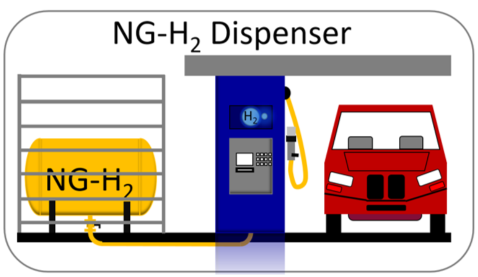
Element No.	35	Value Chain Segment	NG-H_2 Gas Turbine

Element Name	Coverage Details (If Applicable)
	

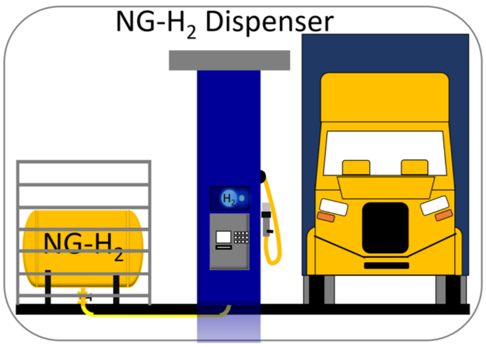
Element No.	36	Value Chain Segment	NG-H_2 Delivery by Ship

Element Name	Coverage Details (If Applicable)
	

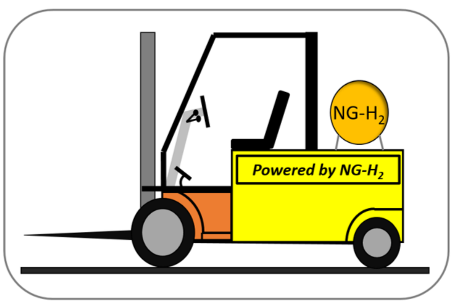
Element No.	37	Value Chain Segment	NG-H_2 Dispensing

Element Name	Coverage Details (If Applicable)
	

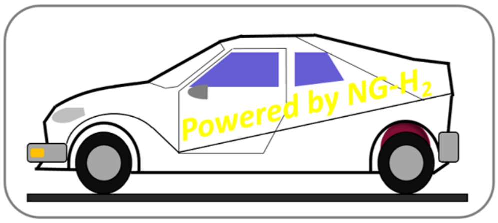
Element No.	38	Value Chain Segment	NG-H_2 Dispensing

Element Name	Coverage Details (If Applicable)
	

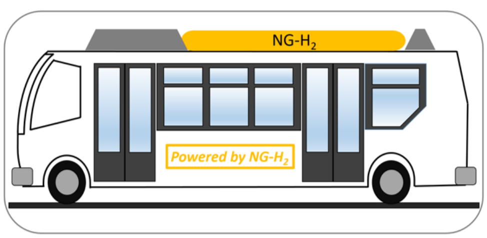
Element No.	39	Value Chain Segment	NG-H_2 Vehicles

Element Name	Coverage Details (If Applicable)
	

Element No.	40	Value Chain Segment	NG-H_2 Vehicles

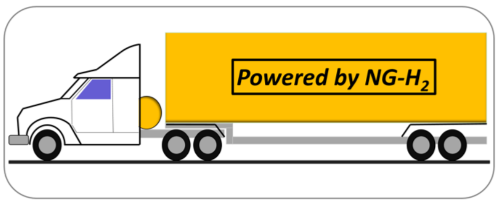
Element Name	Coverage Details (If Applicable)
	

Element No.	41	Value Chain Segment	NG-H_2 Vehicles

Element Name	Coverage Details (If Applicable)
	

Element No.	42	Value Chain Segment	NG-H_2 Vehicles

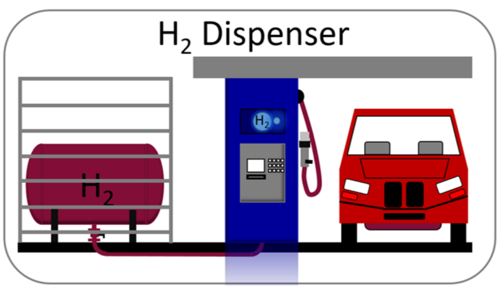
Element Name



Coverage Details (If Applicable)

Element No.	43	Value Chain Segment	H_2 Dispensing - Cars and Lift Trucks

Element Name



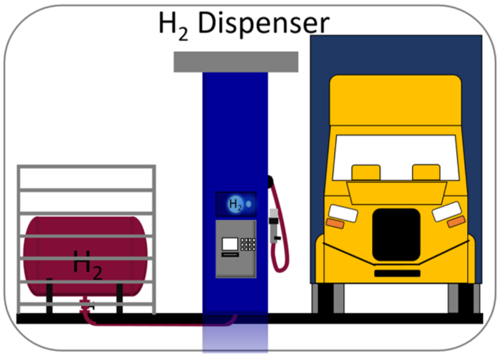
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- High pressure and low pressure dispensing

Element No.	44	Value Chain Segment	H_2 Dispensing - Trucks

Element Name



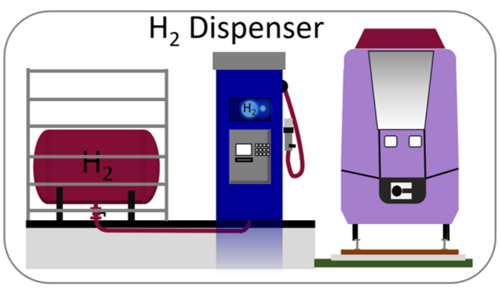
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	45	Value Chain Segment	H_2 Dispensing - Train

Element Name



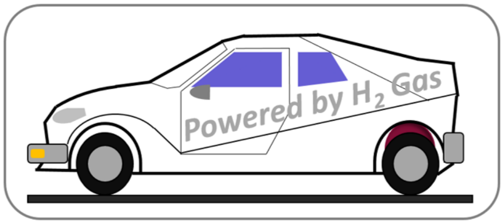
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	46	Value Chain Segment	Transportation – H_2 Land Vehicles

Element Name



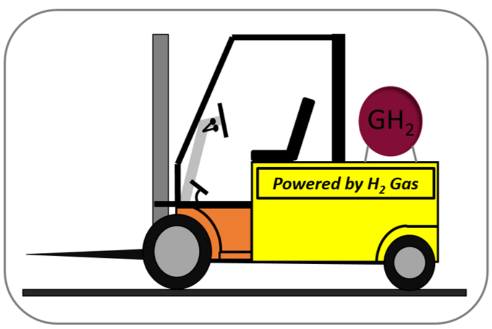
Coverage Details (If Applicable)

This Element includes:

- Cars
- SUV
- Utility vehicles
- Off-road vehicles
- Ice resurfacers

Element No.	47	Value Chain Segment	Transportation – H_2 Land Vehicles (Materials Handling)

Element Name



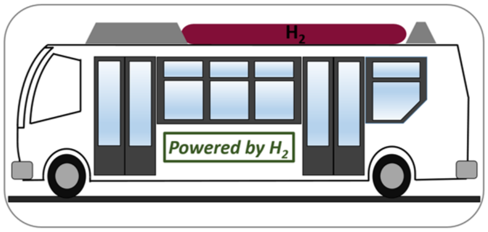
Coverage Details (If Applicable)

The materials handling element covers:

- Retail
- Storage
- Ports
- Airports
- Etc.

Element No.	48	Value Chain Segment	Transportation – H_2 Land Vehicles

Element Name



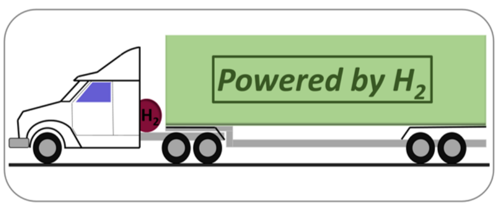
Coverage Details (If Applicable)

This Element includes:

- LH_2 buses
- GH_2 buses

Element No.	49	Value Chain Segment	Transportation – H_2 Land Vehicles

Element Name



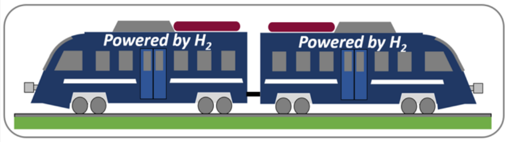
Coverage Details (If Applicable)

This Element includes:

- LH_2 trucks
- GH_2 trucks

Element No.	50	Value Chain Segment	Transportation – H_2 Land Vehicles (Hydrail)

Element Name



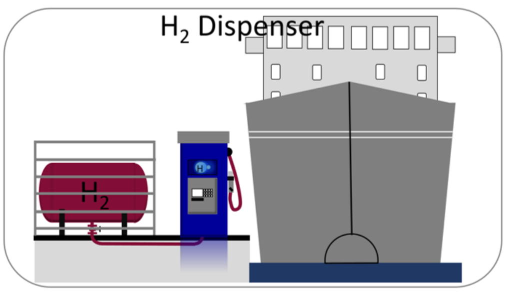
Coverage Details (If Applicable)

This Element includes:

- LH_2 trains
- GH_2 trains
- Passenger trains
- Freight trains
- Switcher locomotives

Element No.	51	Value Chain Segment	H_2 Dispensing - Ship

Element Name



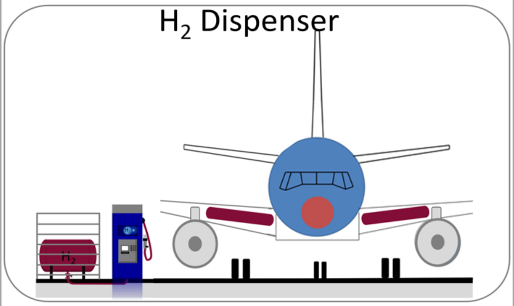
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	52	Value Chain Segment	H_2 Dispensing - Aeroplanes

Element Name



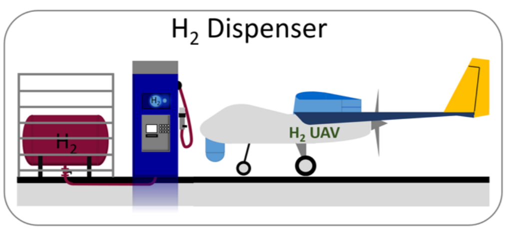
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	53	Value Chain Segment	H_2 Dispensing - Unmanned Arial Vehicles

Element Name



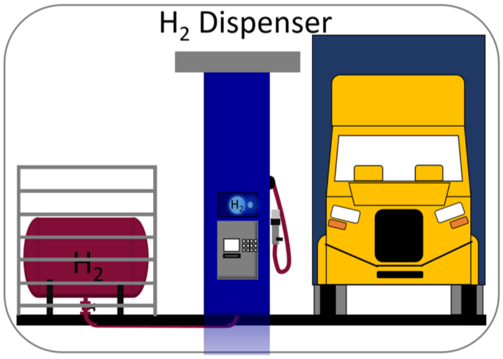
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	54	Value Chain Segment	H_2 Dispensing - Aeroplane Tugs and Trucks

Element Name



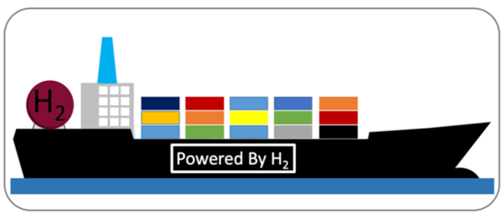
Coverage Details (If Applicable)

This Element includes:

- Permanently installed dispensers
- Portable dispensers
- LH_2 dispensers
- GH_2 dispensers
- High pressure and low pressure dispensing

Element No.	55	Value Chain Segment	Transportation - H_2 Ship

Element Name



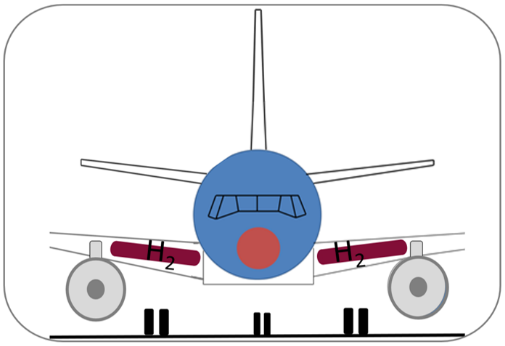
Coverage Details (If Applicable)

This Element includes:

- LH_2 marine
- GH_2 marine
- Ships
- Tug boats
- Boats
- Submarines
- Unmanned Marine Vehicles

Element No.	56	Value Chain Segment	Transportation - H_2 Airplane

Element Name



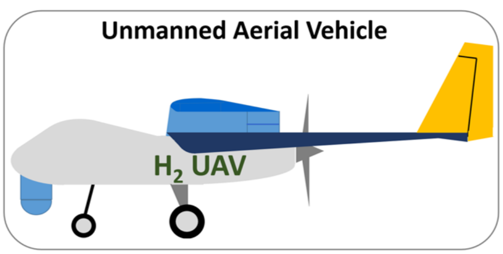
Coverage Details (If Applicable)

This Element includes:

- LH_2 airplanes
- GH_2 airplanes
- Rigid blimps
- Dirigibles
- Helicopters

Element No.	57	Value Chain Segment	Transportation - Unmanned Aerial Vehicles

Element Name



Coverage Details (If Applicable)

This element includes:

- LH_2 Unmanned Aerial Vehicles
- GH_2 Unmanned Aerial Vehicles
- Drones

Element No.	58	Value Chain Segment	Transportation - Airport Trucks and Airplane Tugs

Element Name

Coverage Details (If Applicable)

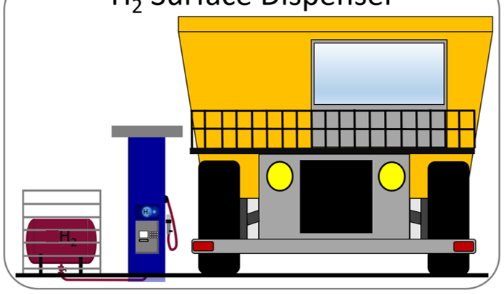
This Element includes:

- LH_2 airport vehicles
- GH_2 airport vehicles
- Airplane tugs
- Airplane Ground Power Units (GPU)
- Airport trucks
- Airport baggage handling trucks
- Etc.

Element No.	59	Value Chain Segment	Mining H_2 Dispensing - Above Ground

Element Name

H_2 Surface Dispenser

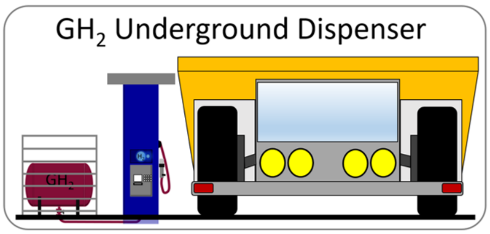


Coverage Details (If Applicable)

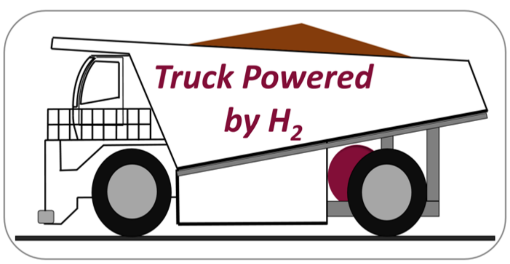
This Element includes:

- LH_2 surface vehicles dispensers
- GH_2 surface vehicles dispensers
- High pressure and low pressure dispensing

Element No.	60	Value Chain Segment	Mining H_2 Dispensing - Underground

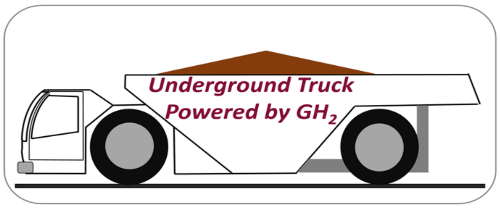
Element Name	Coverage Details (If Applicable)
	This Element includes: ▪ High pressure and low pressure dispensing

Element No.	61	Value Chain Segment	Mining Operations - Above Ground

Element Name	Coverage Details (If Applicable)
	

Element No.	62	Value Chain Segment	Mining Operations - Underground

Element Name



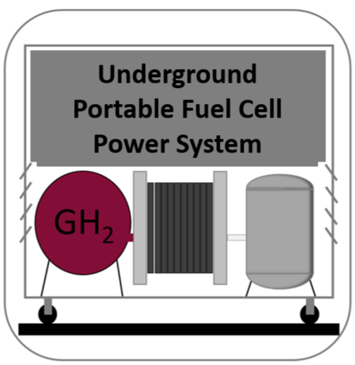
Coverage Details (If Applicable)

This element includes:

- Underground trucks
- Underground locomotives

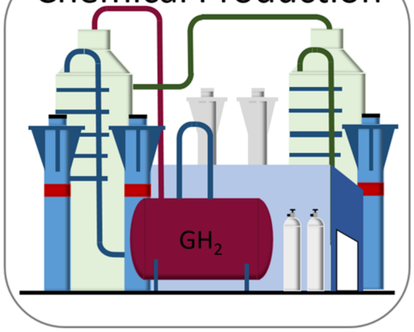
Element No.	63	Value Chain Segment	Mining Operations - Underground

Element Name

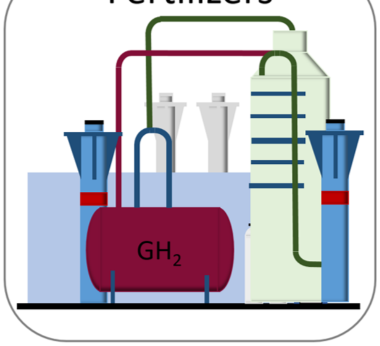


Coverage Details (If Applicable)

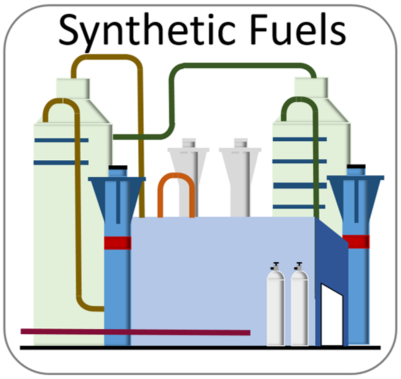
Element No.	64	Value Chain Segment	H_2 Industrial Use

Element Name	Coverage Details (If Applicable)
Chemical Production 	

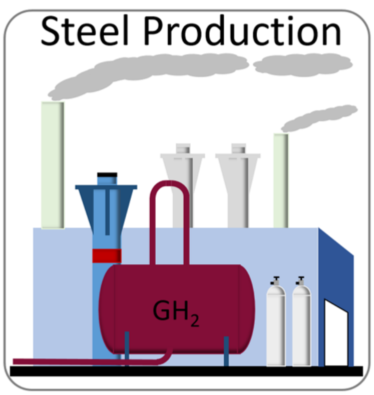
Element No.	65	Value Chain Segment	H_2 Industrial Use

Element Name	Coverage Details (If Applicable)
Fertilizers 	

Element No.	66	Value Chain Segment	H_2 Industrial Use

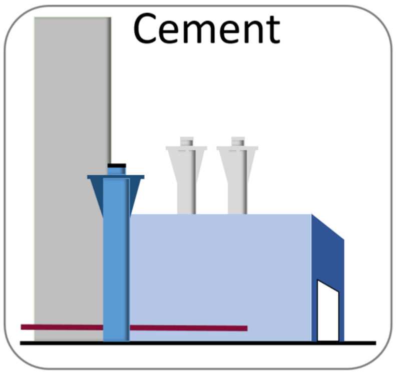
Element Name	Coverage Details (If Applicable)
	

Element No.	67	Value Chain Segment	H_2 Industrial Use

Element Name	Coverage Details (If Applicable)
	

Element No.	68	Value Chain Segment	H_2 Industrial Use

Element Name



Coverage Details (If Applicable)

Element No.	69	Value Chain Segment	Items Common to All Applications

Element Name

Coverage Details (If Applicable)

This element includes:

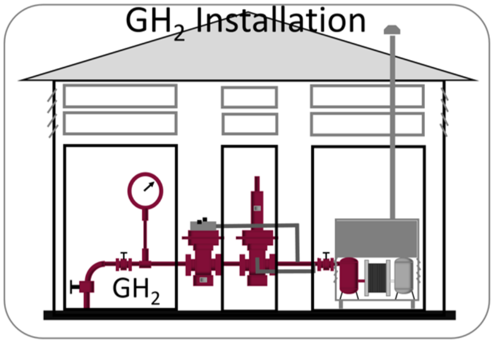
- Components
  - Enclosures
  - Fuel cell stack
  - Air compressors
  - Compressors
  - Gas valve train
  - Pressure regulating equipment
  - Pressure relief devices
  - Hydrogen sensors
  - Flame sensors
  - Electrical equipment
  - Control equipment
  - Fire alarm systems
  - Lightning protection
  - Component testing
    - ✓ Fuel cells
    - ✓ Material properties and fire ratings
- Hydrogen quality
- Pressure vessels
- Material compatibility
- Area classification
- Hydrogen venting
- Static electricity
- Risk assessment
- Functional safety
- EMC
- Disposal
- Recycling
- Refurbishment
- Personnel qualification and training
- Emergency response
- Etc.

Element No. **70**

Value Chain Segment

Installation Standards Relevant to All Value Chain Segments (Except Transportation)

Element Name



Coverage Details (If Applicable)

This element includes:

- Installation codes
- Building codes
- Fire codes
- Electrical codes
- Plumbing codes
- Gas metering
- Etc.

This element is relevant to installations as follows:

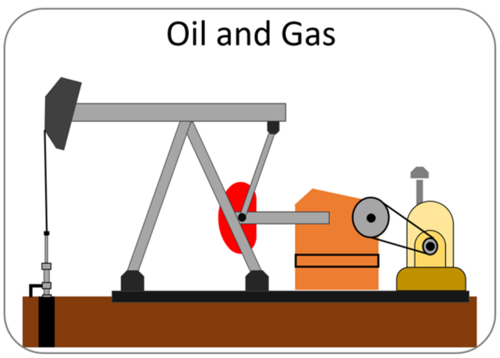
- Hydrogen equipment and appliance installations for elements:
  - 1 - 13
  - 19
  - 24 - 38
  - 43 - 45
  - 51 - 54
  - 59 - 60
  - 63
  - 71
- Hydrogen installations including, but not limited to:
  - Element 20
  - Elements 64 - 68
  - Repair garage for H_2 vehicles

Element No. **71**

Value Chain Segment

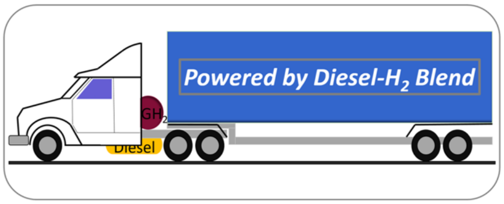
Oil and Gas

Element Name



Coverage Details (If Applicable)

Element No.	72	Value Chain Segment	Diesel-H_2 Mix Trucks

Element Name	Coverage Details (If Applicable)
	This element represents hydrogen injection systems intended to increase the efficiency and lower the emissions of diesel trucks.