Canadian Hydrogen Codes and Standards Roadmap

Canada

DISCLAIMER

This roadmap reflects the work of Natural Resources Canada's (NRCan's) Codes and Standards Working Group (CSWG), which was established in April 2021 to support the implementation of the recommendations of the Hydrogen Strategy for Canada. The CSWG brings together numerous stakeholders from across governments, industry associations, businesses, regulatory authorities, technology developers, and hydrogen end-users.

This work underscores the fact that efforts to have necessary codes and standards is a long-term process that requires collaboration, resources, and commitment. Hence, the results presented herein reflect the best available information and focus on identifying and prioritizing the most critical gaps for the deployment of the hydrogen economy, including areas for which additional expertise may be required.

Gaps and priorities that were identified by stakeholders do not necessarily reflect the position of individual members of the CSWG nor the organizations to which they are affiliated and may not be unanimously endorsed by all participating individuals and/or organizations. While the Government of Canada led the development of this roadmap, highlighted initiatives and examples of activities should by no means be interpreted as endorsements or exemptions from regulatory approvals.

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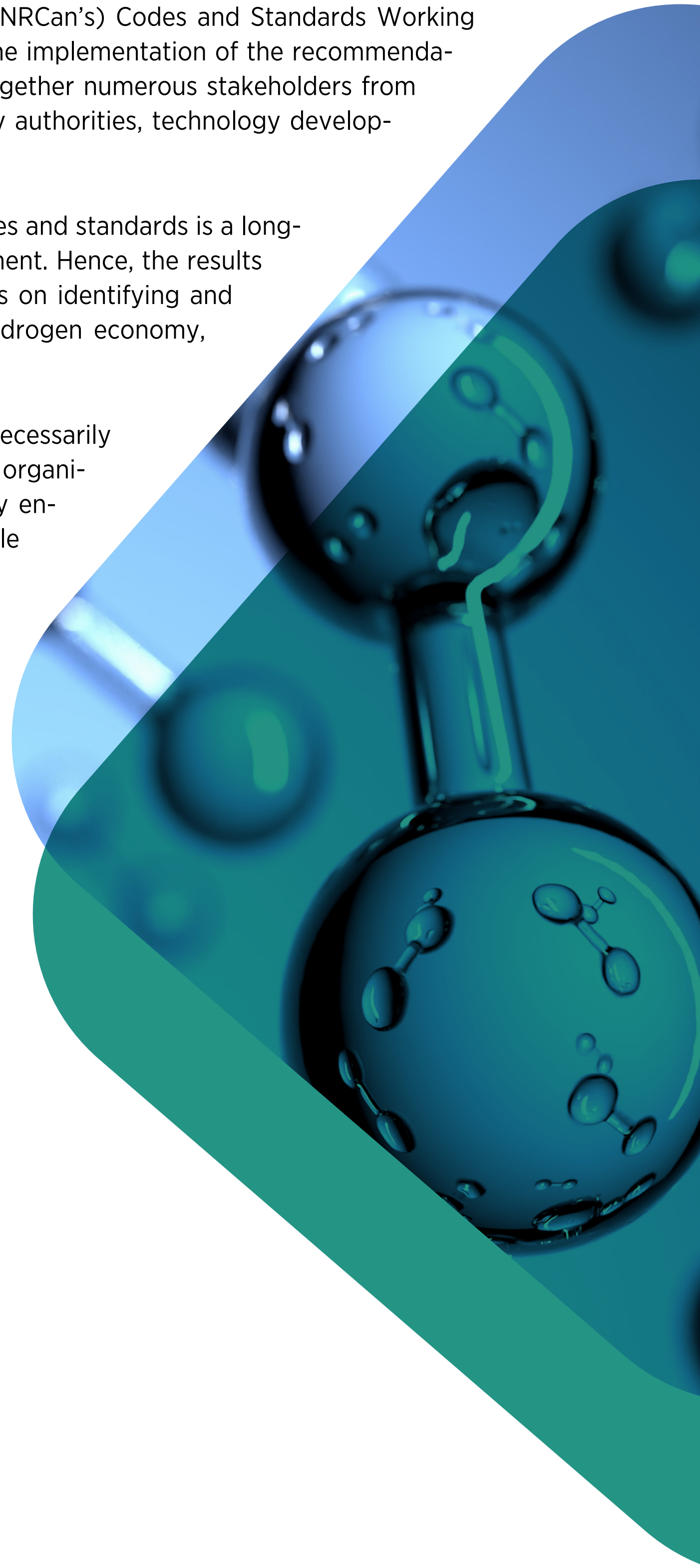

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Feuille de route canadienne des codes et normes sur l'hydrogène

MESSAGE FROM THE MINISTER OF ENERGY AND NATURAL RESOURCES OF CANADA

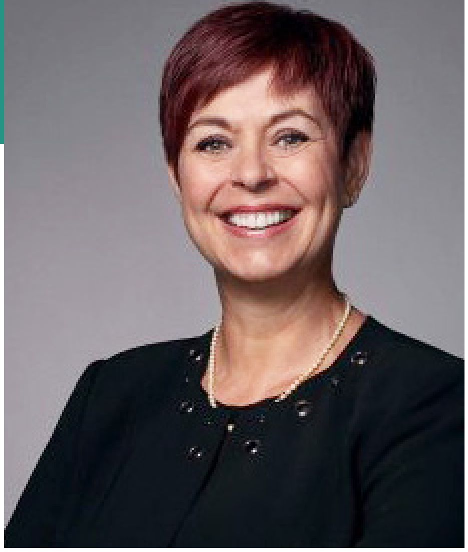
In Canada, each region of our vast and beautiful country has a unique mix of their own natural resources and areas of technology leadership. As we continue to build Canada's clean economy, significant investments and progress are being made in the production, distribution, and use of clean fuels, including clean hydrogen. For several years now, Natural Resources Canada has engaged with stakeholder groups, provincial and territorial governments, and Indigenous partners on the deployment of our hydrogen strategy. *The Hydrogen Strategy for Canada* enables us to create sustainable jobs, decarbonize our economy, add to our diverse energy mix, and fulfill the world's energy requirements within the framework of energy security and the broader climate imperative.

Canada's energy workers are powering the world, and Canada will always be a global energy supplier. As the demand for clean hydrogen grows, Canada is positioning itself as a worldwide leader in clean technology and hydrogen production. For example, to facilitate export opportunities, Canada signed a Memorandum of Understanding with Germany to advance a bilateral funding window through Germany's H2Global Foundation to enable commercial transactions between Canadian hydrogen exporters and German buyers.

Harmonizing codes and standards and addressing gaps is crucial to clean hydrogen adoption and deployment. It provides investors certainty across the hydrogen value chain, allowing for growth in technologies and infrastructure, and it can provide confidence to Canadians that clean hydrogen products are safe and reliable. With this roadmap, Canada takes another step towards the realization of the hydrogen opportunity. Through ongoing innovation and active collaboration, we can ensure that Canadian hydrogen will be an important tool for Canada to achieve its goal of net-zero emissions by 2050 and build a thriving, sustainable, made-in-Canada clean economy.

The Honourable Jonathan Wilkinson
Minister of Energy and Natural Resources of Canada

MESSAGE FROM THE CEO OF THE STANDARDS COUNCIL OF CANADA



As Canada continues to pursue net-zero emission targets, SCC recognizes that hydrogen is one of the most promising solutions available to us today. Hydrogen has the potential to play a significant role in decarbonizing various sectors, including transportation, industry, and buildings, while providing opportunities for job creation and economic growth.

Deploying hydrogen on a large scale requires the development of robust and harmonized regulatory and standardization frameworks that promote safe and efficient use. These frameworks are necessary to enable the widespread deployment of hydrogen technologies and ensure their compatibility with existing infrastructure.

We believe Canada can develop and implement these sustainable frameworks with collaboration between industry, government, regulatory authorities, standard development organizations, and conformity assessment bodies. Given that codes and standards crosscut the hydrogen value chain and are the basis on which safety and quality are assessed, it is essential to continue working together to better define them, achieve alignment across the country, and to create new internal and international trade opportunities. Canada's standardization system is well positioned to support these efforts in leading the race to a more sustainable future.

Chantal Guay
Chief Executive Officer of the Standards Council of Canada


Helium

ABOUT CODES, STANDARDS, AND CONFORMITY ASSESSMENT

Codes refer to a set of rules or guidelines established to ensure consistency, safety, and quality in various industries. Codes serve as a reference for practitioners to follow best practices and comply with industry norms. They are often prescriptive and may be legally enforceable. Examples include building, electrical, and gas installation codes.

Standards provide a set of agreed-upon rules, guidelines, or characteristics for activities or their results. Standards establish accepted practices, technical requirements, and terminologies for various fields. They can be mandatory or voluntary and are distinct from acts, regulations, and codes. A standard that is incorporated by reference in a regulation is mandatory and legally binding.[1] National Standards of Canada (NSCs) are maintained through periodic review (e.g., 5-year cycle) or as needed to ensure their continued relevance.

Conformity assessment is the practice of determining whether a product, service, or system meets the requirements of a particular standard. Conformity assessment ensures consumer safety, as well as product and service quality, compatibility, efficiency, and effectiveness.[2] Conformity Assessment Bodies (CABs) are independent bodies that audit and issue a written assurance (e.g., certificate) confirming that a product, service, system, person, or process meets specific requirements of standards or regulations. CABs are usually accredited by a recognized accreditation body (e.g., Standards Council of Canada (SCC) in Canada or the American National Standards Institute (ANSI) in the United States).

Standards Council of Canada
SCC is Canada's voice on standards and accreditation on the national and international stage. SCC works closely with a vast network of partners to promote the development of effective and efficient standards that protect the health, safety, and well-being of Canadians while helping businesses prosper.

SCC accredits Standards Development Organizations (SDOs) to develop NSCs. SCC-accredited SDOs are bodies that specialize in the development of standards using a consensus-based process and who participate in the regional and international standardization process. A list of SCC-accredited SDOs can be found on SCC's webpage titled *Standards Development Organizations*. More information on the process for developing NSCs and international standards can be found on the webpage titled *How standards are developed.*

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1 Standards Council of Canada (2018). *Guidelines for Incorporating Standards by Reference in Regulations to Support Public Policy Objectives.* Retrieved from https://scc-ccn.ca/resources/publications/guidelines-incorporating-standards-reference-regulations-support-public

2 Standards Council of Canada (2018). *Conformity Assessment in Canada: Understanding the Value and Implications for Internal Trade*. Retrieved from https://scc-ccn.ca/resources/publications/conformity-assessment-canada-understanding-value-and-implications-internal

As Canada's National Standards Body and National Accreditation Body, SCC creates market confidence at home and abroad by ensuring that SDOs and CABs meet the highest national and international standards. SCC advances Canada's interest on the international scene as a member of the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) by connecting thousands of people to global networks and resources.

Developing a National Standard of Canada (NSC)

Developing a new standard is a significant, highly detailed, and time-consuming undertaking for several reasons. NSCs incorporate international best practices, requiring thorough research, consultation, and adaptation to ensure alignment with global standards.

The process safeguards Canadian interests by rigorously developing standards that meet local needs, safety requirements, and industry expectations. Timing is crucial, considering market readiness, technological advancements, and economic impact. Sufficient funding is also essential for research, drafting, and review processes.

Technical committees must have balanced representation to ensure various stakeholder interests are considered and require experts from relevant fields to collaborate, influencing the timeline of NSC development.

NSCs undergo rigorous reviews by stakeholders, industry representatives, and the public, ensuring consensus-based decisions for broad acceptance and relevance. The development can be national or involve adopting international standards, with the latter requiring careful consideration of the local context and balancing national needs with global harmonization.

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ACT	Accelerated Carbon Transition
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ATR	Autothermal Reforming
BNQ	Bureau de normalisation du Québec
CABs	Conformity Assessment Bodies
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CGA	Compressed Gas Association
CHIC	Canadian Hydrogen Installation Code
CI	Carbon Intensity
CNG	Compressed Natural Gas
CSA	Canadian Standards Association, operating as CSA Group
CSWG	Codes and Standards Working Group
DBPM	Decision-Based Priority Matrix
DRI	Direct Reduction of Iron
FCEV	Fuel Cell Electric Vehicle
GH_2	Gaseous Hydrogen
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
H_2	Hydrogen
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IFC	International Fire Code
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LH_2	Liquid Hydrogen
LOHC	Liquid Organic Hydrogen Carrier
NFPA	National Fire Protection Association
NG	Natural Gas
NH_3	Ammonia
NRC	National Research Council Canada
NSC	National Standard of Canada
SAE	Society of Automotive Engineers, operating as SAE International
SDO	Standards Development Organization
SMR	Steam Methane Reforming
TIL	Technical Information Letter
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle

EXECUTIVE SUMMARY

The Hydrogen Strategy for Canada (the "Strategy") identified that harmonizing hydrogen codes and standards and addressing gaps is essential to enable low-carbon hydrogen adoption and deployment.[3,4] Developing codes and standards was one of the Strategy's key pillars, with four corresponding recommendations for action addressed to governments, industry, and Standards Development Organizations (SDOs). Gaps in codes and standards can present a significant obstacle to widespread clean hydrogen production, delivery and storage, and end-use. Such challenges need to be addressed at an early stage to establish a strong foundation for clean hydrogen deployment across Canada.

To act on the Strategy's recommendations, NRCan established several working groups. The Canadian Hydrogen Codes and Standards Working Group (CSWG) was established in April 2021 as part of that effort. CSWG members included governments, industry associations, businesses, regulatory authorities, end-users, and accredited SDOs.

This Roadmap is a key deliverable of the CSWG to address the Strategy priority and is a call to action for the development of hydrogen standards. Its content will serve a wide audience, ranging from the general public to technical specialists and policymakers. Readers will find specific value in certain sections, depending on their background and expertise, with:

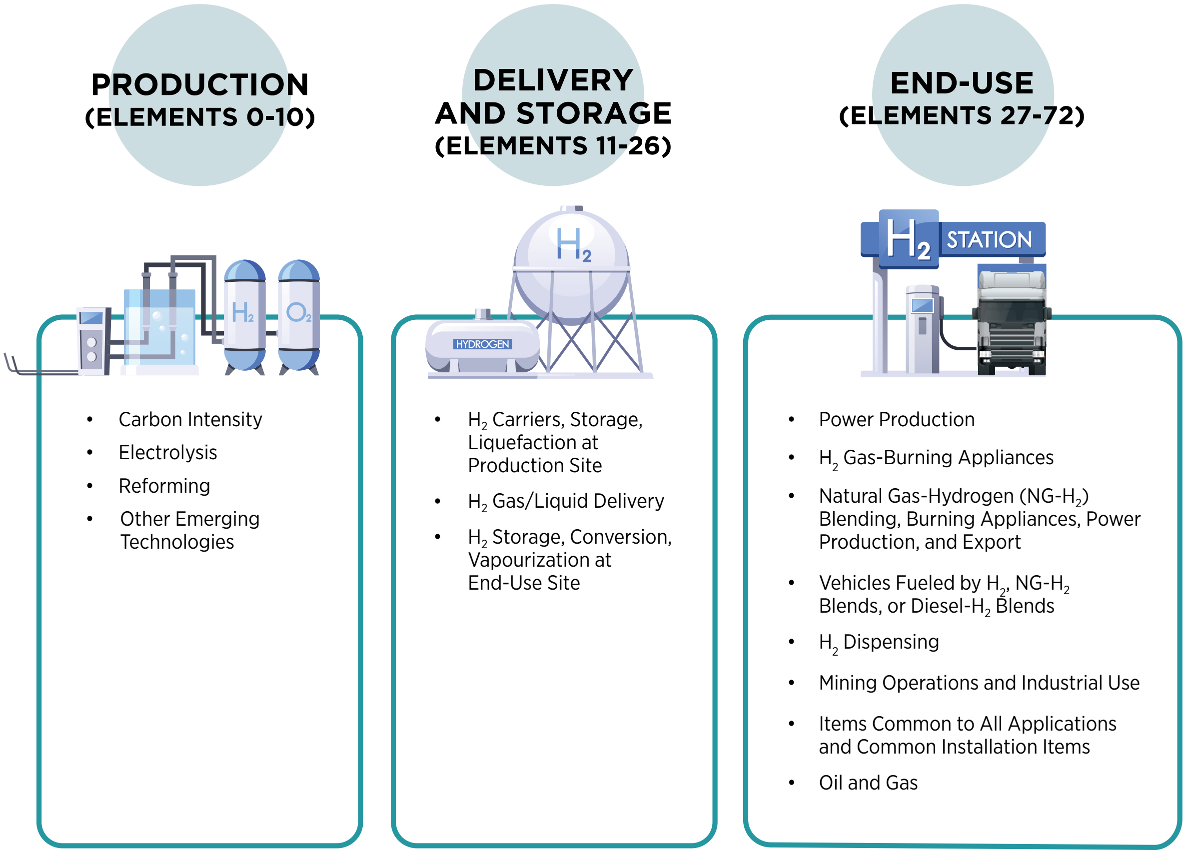
- Sections 1 and 2 providing information on why and how this Roadmap was developed;
- Section 3 containing the most detailed and technical information, where hydrogen professionals can find descriptions of standards gaps for a multitude of specific hydrogen technologies and processes;
- Section 4 summarizing the results of this Roadmap's work;
- Section 5 calling to action the decision-makers and stakeholders that can make meaningful policy-related change to achieve Canada's hydrogen codes and standards goals.

[3] Natural Resources Canada (2020). *The Hydrogen Strategy*. Retrieved from https://natural-resources.canada.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/the-hydrogen-strategy/23080

[4] Throughout this document, "low-carbon hydrogen" or "clean hydrogen" means hydrogen that is expected to have an average life cycle carbon intensity of less than 4 kg of carbon dioxide equivalent per kg of hydrogen produced.

i. Defining the hydrogen value chain

The scope of this Roadmap is based on a system that classifies the hydrogen value chain into 72 elements, which are grouped under three segments: 1) Production, 2) Delivery and Storage, and 3) End-Use. Each element is an aspect of the hydrogen value chain and can correspond to multiple existing codes or standards and/or to new standards to be developed.



ii. Carrying out the gap analysis

The CSWG performed a gap analysis across the hydrogen value chain, which included:

- identifying the scope, industry, and equipment associated with each element in the value chain;
- researching existing Canadian, regional, and international standards potentially applicable for hydrogen applications, including standards in development;
- determining the codes and standards gaps.

iii. Identifying standards-based options

The CSWG developed a methodology to identify possible actions to address standardization gaps, referred to as standards-based options, depending on the nature and status of the gaps. In line with best practices, the harmonization and adoption of regional and/or international standards were preferred over new developments.

iv. Prioritizing gaps

Rating systems were devised to evaluate the significance of identified standardization gaps in facilitating safe hydrogen deployment by considering factors such as:

- Number of Canadian companies
- Impact of addressing gaps
- Urgency for standardization solutions
- Criticality
- Scope
- Activity within the sector
- Technology Readiness Level (TRL)
- Achievability
- Effect

CSWG members, provincial and territorial governments, and Authorities Having Jurisdiction (AHJs) were invited to take part in this exercise. The ratings were based on criteria that represent current hydrogen deployment or may enable successful future deployment.

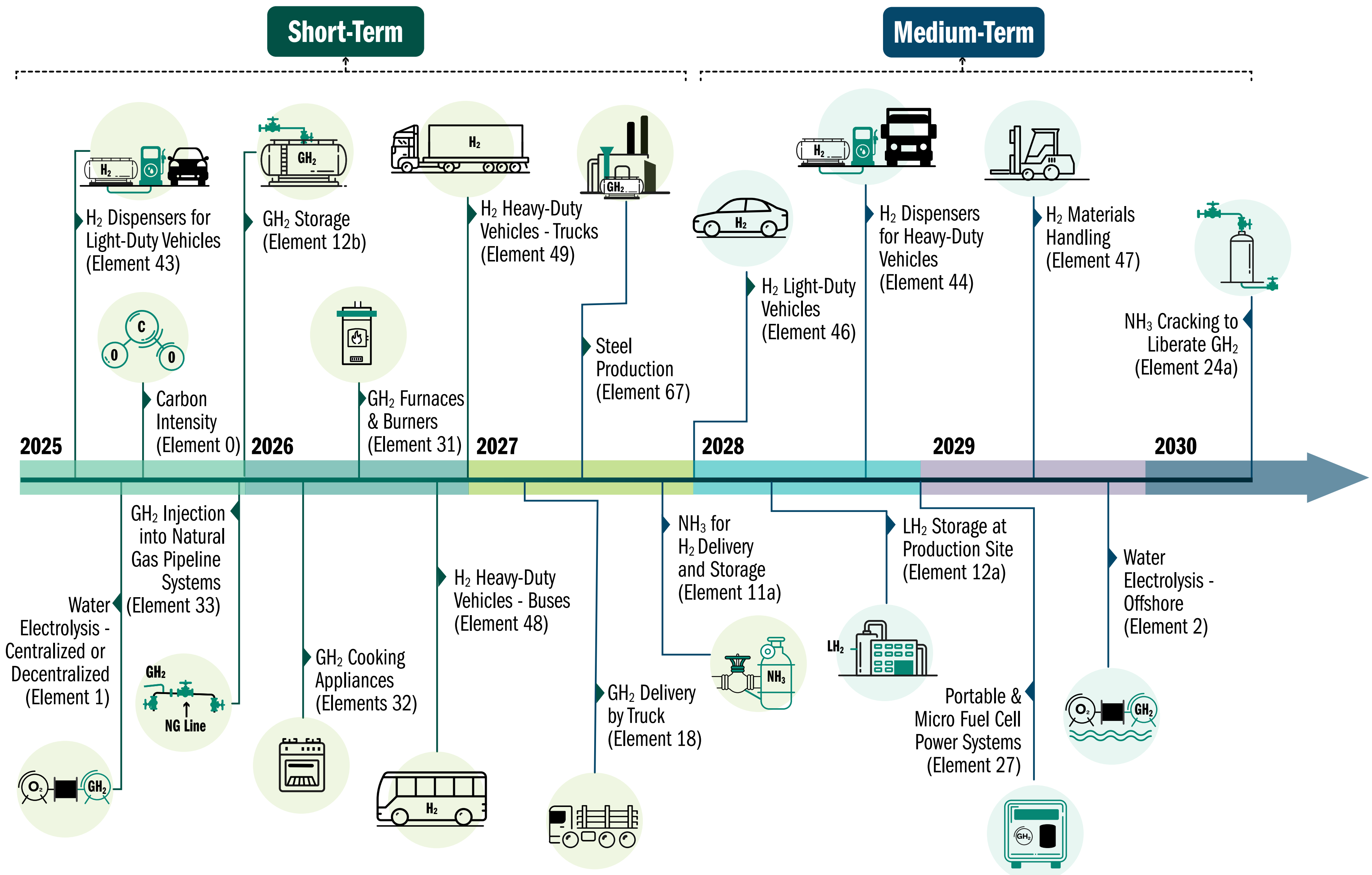
Timelines were recommended to apply the standards-based options to address identified gaps:

- **Short-term:** Gaps associated with these elements are the highest priority and necessary to address. This Roadmap recommends relevant codes and standards to be published within three years of this report's publication (i.e., before 2028). This aligns with typical Canadian standard development timelines of 18 to 36 months.
- **Medium-term:** Gaps are critical to fill, but do not need to be addressed immediately. This Roadmap recommends codes and standards to be published in the next three to six years (i.e., 2028–2030).
- **Long-term:** No gap exists, or gaps are non-critical but potentially beneficial to address eventually. Codes and standards can be published in six years or more (i.e., 2031 and beyond).

Based on these four steps, the top short-term priorities were determined to be addressing standards gaps for the following elements:

Production	Delivery and Storage	End-Use
• Water Electrolysis – Centralized or Decentralized • Carbon Intensity	• Gaseous Hydrogen (GH_2) Storage • GH_2 Delivery by Truck • Ammonia for H_2 Delivery and Storage	• H_2 Dispensers for Light-Duty Vehicles • GH_2 Injection into Natural Gas Pipeline Systems • GH_2 Cooking Appliances • GH_2 Furnaces & Burners • Heavy-Duty Vehicles – Buses • Heavy-Duty Vehicles – Trucks • Steel Production

Effective and targeted action should be initiated for the prioritized elements. The figure below demonstrates a potential timeline for addressing gaps deemed short-term and medium-term priorities. The elements have been listed in order of overall rating, while respecting short-term and medium-term timelines as described above. Actual timelines of work will be subject to SDOs forming technical committees for standards development and/or updates for the specific element. Recognizing that a typical standard development timeline in Canada is 18–36 months, actions related to short-term elements should begin immediately.



Short-Term
Medium-Term
2025
2026
2027
2028
2029
2030
H_2 Dispensers for Light-Duty Vehicles (Element 43)
GH_2 Storage (Element 12b)
H_2 Heavy-Duty Vehicles - Trucks (Element 49)
Carbon Intensity (Element 0)
GH_2 Furnaces & Burners (Element 31)
Steel Production (Element 67)
H_2 Light-Duty Vehicles (Element 46)
H_2 Dispensers for Heavy-Duty Vehicles (Element 44)
H_2 Materials Handling (Element 47)
NH_3 Cracking to Liberate GH_2 (Element 24a)
Water Electrolysis - Centralized or Decentralized (Element 1)
GH_2 Injection into Natural Gas Pipeline Systems (Element 33)
GH_2 Cooking Appliances (Elements 32)
H_2 Heavy-Duty Vehicles - Buses (Element 48)
GH_2 Delivery by Truck (Element 18)
NH_3 for H_2 Delivery and Storage (Element 11a)
LH_2 Storage at Production Site (Element 12a)
Portable & Micro Fuel Cell Power Systems (Element 27)
Water Electrolysis - Offshore (Element 2)

Collaboration between stakeholders is vital for filling gaps in codes and standards, and this Roadmap highlights the standards-based options that organizations can use to streamline the process of addressing gaps. Coordinated approaches to fill the identified gaps will be required to reduce fragmentation of efforts and achieve a better harmonization while ensuring regional priorities are incorporated in strategic planning.

This Roadmap identifies a series of 19 recommended actions to support the codes and standards development objectives, broadly categorized as follows:

- Governance
- Policy Measures and Regulatory Action
- International Cooperation
- Innovation and Capacity Building
- Information Technology and Access
- Communication and Harmonization

This Roadmap calls upon stakeholders to act on the urgent development of critical hydrogen standards, representing a necessary milestone in Canada's plan for the global clean energy transition.

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1. BACKGROUND

1.1 Hydrogen Strategy for Canada

The Hydrogen Strategy for Canada (the "Strategy") was launched by Natural Resources Canada (NRCan) in 2020. It identifies challenges that may hinder progress on hydrogen commercialization and deployment in Canada and makes 32 associated recommendations. Four of these recommendations are specific to codes and standards and are addressed to governments, industry, utilities, and Standards Development Organizations (SDOs):

- **Recommendation 13:** Update, harmonize, and recognize codes and standards (including the Canadian Hydrogen Installation Code (CHIC)) to enable deployment and to facilitate new technology and infrastructure adoption in early markets.
- **Recommendation 14:** Establish a codes and standards working group, which includes representatives from interprovincial Authorities Having Jurisdiction (AHJs), to share lessons learned and identify gaps in codes and standards.
- **Recommendation 15:** Develop performance-based, versus prescriptive standards, and ensure hydrogen is not excluded from broader codes, standards, and regulations due to restrictive language.
- **Recommendation 16:** Facilitate Canadian leadership and participation in international standard and certification efforts (e.g., development of global carbon intensity (CI) metrics, blending levels for hydrogen in natural gas systems), simplifying international trade.

In May 2024, NRCan published a Progress Report of the Hydrogen Strategy for Canada, which confirms that low-carbon hydrogen continues to have a role to play in meeting national and global energy needs in the context of energy security, the energy transition, and the broader climate imperative.[5,6] Canada's low-carbon hydrogen produced for export will contribute to sustainable green job creation, international energy security, and global emissions reductions.

In Canada's net-zero climate objectives, low-carbon hydrogen will supplement electrification and other carbon mitigation approaches by helping to decarbonize hard-to-abate sectors where electrification alone would be less economical or technically unfeasible. It also reinforces the need to continue to develop codes and standards as one of four strategic priorities for 2024–2026 to support the deployment of hydrogen technologies and provide investor certainty across the value chain.

Please refer to the appendices for additional information on:

- the role of AHJs in supporting a hydrogen economy (***Appendix B***);
- SDOs accredited by the Standards Council of Canada (SCC) and currently involved in or have planned activities for codes and standards development in the hydrogen space (***Appendix C***).

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[5] Natural Resources Canada (2024). *Hydrogen Strategy for Canada: Progress Report*. Retrieved from https://natural-resources.canada.ca/climate-change/canadas-green-future/the-hydrogen-strategy/hydrogen-strategy-for-canada-progress-report/25678

[6] Throughout this document, "low-carbon hydrogen" or "clean hydrogen" means hydrogen that is expected to have an average life cycle carbon intensity of less than 4 kg of carbon dioxide equivalent per kg of hydrogen produced.

1.2 Current Landscape and the Need for Canadian Codes and Standards

Currently, at least 59 countries plus the European Union have hydrogen strategies or roadmaps in place that highlight hydrogen's importance as a clean energy vector for decarbonization. Most of these also acknowledge that codes and standards are closely tied to legislation and critical for deploying hydrogen across various sectors of their economies. As countries take action to increase hydrogen's role in the economy, the time could not be better to convene Canadian stakeholders to establish Canada as a leading clean hydrogen economy.

The pipeline of proposed Canadian hydrogen projects continues to evolve, representing more geographical and technological diversity. Over 80 hydrogen production projects have been announced by industry or are in development as of early 2024. In western Canada, natural gas reforming with carbon capture is the principal production pathway under development, including both autothermal reforming (ATR) and steam methane reforming (SMR). In central and eastern Canada, the main production pathway being pursued is water electrolysis, using electricity from existing grids or from new, dedicated sources like wind or solar. As for hydrogen use, most hydrogen used in Canada today is in industrial processes, though there are projects emerging that expand its use to commercial, residential, and transportation applications.

This exemplifies both the significant interest in hydrogen projects across the country and the immediate need for a wide range of codes and standards to be developed and/or updated. Gaps in existing codes and standards represent a significant obstacle for widespread clean hydrogen production, delivery and storage, and end-use, which should be addressed at an early stage to establish a strong foundation for deployment.[7]

Establishing relevant codes and standards can lead to more effective execution of projects by streamlining design processes and increasing safety assurance. Having codes and standards for designers, constructors, manufacturers, regulators, and utilities to reference makes more efficient use of resources, costs, personnel, and materials, which can otherwise be challenging when there is no precedence and learning curves are steep.

The Government of Canada recognizes the need to create, update, or adapt codes and standards to accommodate hydrogen across the value chain. This Roadmap serves as a call to action for the urgent development of critical standards, representing a necessary milestone in Canada's plan for the global clean energy transition.

However, no sole country can address all gaps in the timeframe expected for the demand of large-scale production, trade, and export of hydrogen to be realized. To ensure key enabling standardization is established in a timely manner:

- Methods or guidance developed by individual countries or partnerships based on needs identification can serve as foundational documents for country-specific or International Organization for Standardization (ISO) standards.
- Existing international standards, such as those from ISO or the International Electrotechnical Commission (IEC), can be directly applied or adopted at national levels with necessary modifications.
- Countries can leverage international initiatives to share information and identify critical gaps, such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), which includes focused working groups.

Canada participates in several avenues for collaboration on codes and standards development. Information on Canada's international activities related to hydrogen codes and standards can be found in ***Appendix D***.

[7] Another common term used for delivery is "distribution". As this term can be interpreted to include hydrogen dispensing or being used as a fuel in transportation, which is part of the End-Use segment, we opted to use "delivery."

CODES AND STANDARDS ACTIVITIES IN OTHER JURISDICTIONS

The development of codes and standards varies by jurisdiction. The United States, like Canada, follow a consensus-based process led by accredited SDOs. Both governments participate as an interest group within technical committees alongside industry, regulatory bodies, and consumer advocacy groups. While the governments play a significant role in setting priorities and supporting SDOs, neither has the authority to mandate development. Conversely, the European Commission can mandate the European Committee for Standardization and the European Electrotechnical Committee for Standardization ("CEN" and "CENELEC") to develop specific standards in alignment with European Union strategies and regulations. Through a transposition process, European Union directives are incorporated into national laws of member states, making European standards common. Another approach is seen in Japan, where the Japanese Industrial Standards Committee, under the Ministry of Economy, Trade, and Industry, oversees a unified national system for industrial standardization.

Outside Canada, two other hydrogen codes and standards roadmaps are known to have been published:

i. The German government-supported Standardization Roadmap for Hydrogen Technologies, which presents a detailed analysis of existing and necessary standards and technical regulations across the value chain[8]. This includes areas such as production, infrastructure, industrial applications, training, certification, and safety. Recommended actions include standardization in hydrogen delivery, storage, and end-use in rail.

ii. The European Clean Hydrogen Alliance Roadmap on Hydrogen Standardisation, which identifies issues, gaps, challenges, and priorities within the current standardization framework across the value chain[9]. It outlines the status of ongoing standardization activities and identifies high-priority areas, including end-use of hydrogen in industry, heavy-duty road vehicles, maritime applications, and aviation. Areas requiring pre-standardization research include material compatibility, hydrogen leakage, and hydrogen carriers. Based on this roadmap, a coordination group on hydrogen was set-up by CEN and CENELEC, and 53 existing technical committees have been identified to act on standards development.

Several national hydrogen strategies propose addressing gaps in codes and standards by:

i. Coordinating efforts domestically to address gaps, while engaging industries and key stakeholders;

ii. Adopting codes and standards available from international standards organizations;

iii. Harmonizing standards, where possible, to avoid fragmentation.

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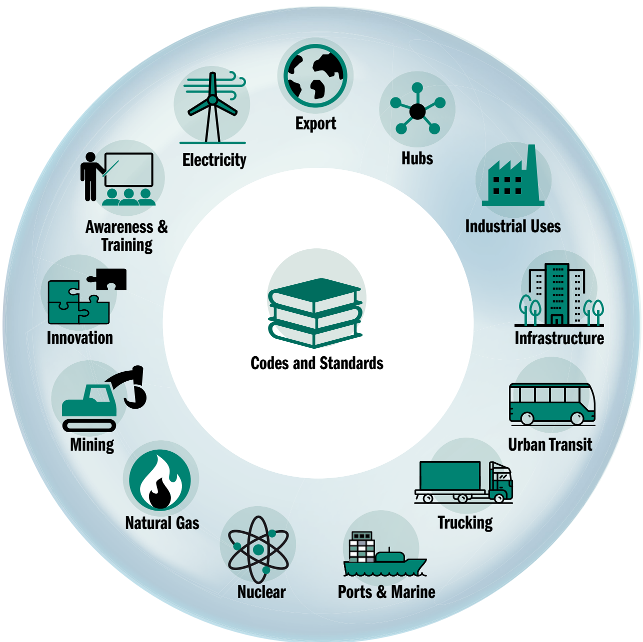
[8] Project partners Standardization Roadmap for Hydrogen Technologies (2024). *Standardization Roadmap for Hydrogen Technologies 2024*. Retrieved from https://www.dke.de/resource/blob/2348516/775822063b19703b5e2dd5e41c1c4f3a/standardization-roadmap-for-hydrogen-technologies---download-data.pdf

[9] European Clean Hydrogen Alliance (2023). *Roadmap on Hydrogen Standardisation*. Retrieved from https://ec.europa.eu/docsroom/documents/53721/attachments/1/translations/en/renditions/native

1.3 Hydrogen Codes and Standards Working Group

As a key step stemming from the Strategy, NRCan established several working groups spanning various sectors and areas of interest to enable focused and cross-sectoral action on the Strategy's recommendations (***Figure 1***). The Hydrogen Codes and Standards Working Group (CSWG) was established in April 2021 as part of that effort. Codes and standards intersect all other working groups.

Figure 1: Hydrogen Sectors and Areas of Interest, Organized by Working Groups (as of 2023)



1.3.1 Membership

The CSWG, co-chaired by NRCan and SCC, has had continuous momentum since its inception. The group has over 250 members from:

- multiple levels of government
- regulatory authorities/AHJs
- industry, including utility companies and technology developers
- academia
- Standards Development Organizations (SDOs)
- Conformity Assessment Bodies (CABs)
- other national and international experts

CSWG members have extensive collective expertise in hydrogen. Many are affiliated with organizations developing hydrogen products or are engaged in hydrogen research, development, and deployment. Others possess specific technical knowledge of codes and standards-related activities and challenges in their respective fields.

1.3.2 Objective and Activities

The objective of the CSWG is to engage all relevant parties to coordinate and harmonize national efforts to address codes and standards-related barriers to and opportunities for hydrogen deployment from both safety and commercialization perspectives. The CSWG mandate includes:

- carrying out a codes and standards gap analysis;
- identifying standards-based options to address those gaps;
- determining opportunities for development, including prioritization of the most pertinent short-to medium-term standards, and communicating these priorities through a roadmap.

During this Roadmap's development, the CSWG met on a quarterly basis, and meetings served as both a vehicle for information sharing on hydrogen codes and standards and an opportunity for broader learning from international stakeholders undertaking similar efforts. The CSWG engaged other working groups, government, and regulatory authorities on providing insight on hydrogen priorities and jurisdictional practices, and exchanged lessons learned with Canadian and international hydrogen communities.

The CSWG invited speakers from several SDOs, Canadian and United States governmental departments, the European Standardization Organization and Hydrogen Alliance, and an engineering consultancy firm. These presentations informed the CSWG about the latest standardization advancements affecting hydrogen projects in Canada and gain insights from other economies that are progressing in the hydrogen sector. The activities of networking and collaboration fostered, in large part, the acquisition of expertise and resources deployed for the development of this Roadmap.

1.3.3 Structuring into Task Forces

Three task forces were established as subgroups within the wider CSWG to align with the three segments of: 1) Production, 2) Delivery and Storage, and 3) End-Use. The task forces comprised approximately 80 total members with competencies and networks from industry, government, regulatory authorities, SDOs, and CABs.

Each task force was charged with identifying gaps and opportunities for development, harmonization, adoption, and revision of standards. The actual development of, or update to, standards was not an objective of the task forces or the CSWG.

WHO CAN DEVELOP NATIONAL STANDARDS IN CANADA?

Only the technical committees of accredited SDOs, having experienced and competent representation from industry, consumers, government, and regulatory authorities, have the expertise to act on the standards development or update recommendations.


2
H2

2. CHARTING THE COURSE: THE ROADMAP DESIGN PROCESS

2.1 Overall Approach

A methodical and robust approach was followed during this Roadmap's design, which comprised the following steps. More details of each step can be found in ***Sections 2.2*** to ***2.5***.

Defining the hydrogen value chain: The process began by adopting a classification system previously created by National Research Council Canada (NRC), which differentiates parts of the hydrogen value chain into 72 elements. Each element can relate to multiple existing codes or standards and/or to new standards to be developed.

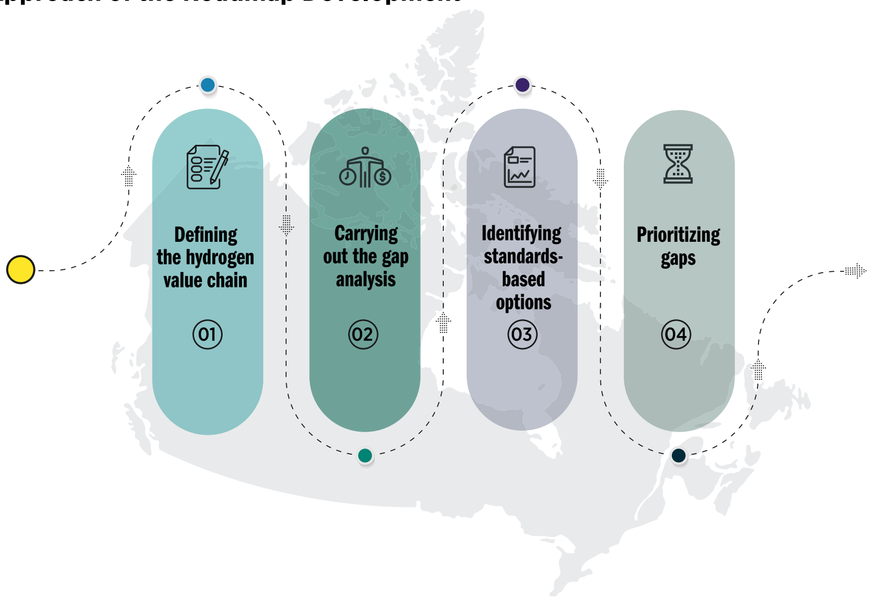
Carrying out the gap analysis: Members of the three task forces (production, delivery and storage, and end-use) performed an environmental scan of Canadian, United States, regional, and international codes and standards for each element. All value chain elements were determined as having either no gap, a partial gap, or a full gap.

Identifying standards-based options: A suite of actions was developed as potential pathways to address the gaps identified. These potential actions are called "standards-based options" throughout this report and are based on the nature and extent of the gap, the current global standardization landscape, and the urgency of implementing compliance measures.

Prioritizing gaps:

- To gain clarity on the significance of the identified codes and standards gaps, the CSWG devised a rating system to prioritize them. Criteria used for ratings focused on the significance, feasibility, and urgency of addressing the identified gaps. Stakeholders, including those from the CSWG, government, and regulators, were invited to participate in this exercise, contributing to its thorough and comprehensive nature.
- The CSWG proposed timelines to act on the standardization actions based on the results of the prioritization exercise. Timelines of short-term and medium-term were proposed to address the most critical gaps.

Figure 2: Overall Approach of the Roadmap Development



2.2 Defining the Hydrogen Value Chain

The scope of this Roadmap is based on a system that classifies the different parts of the hydrogen value chain into 72 elements. ***Figure 3*** depicts these elements.

This classification system was developed by NRC prior to the development of this Roadmap with the objective to map and illustrate the vast amount of information related to hydrogen codes and standards.[10] NRC's classification system was adopted for this Roadmap, but it is understood that there may be opportunities for improvement considering the everchanging hydrogen industry.

Future work by the CSWG, or future Roadmap iterations, may warrant adjustments. Additionally, if an internationally accepted classification system is developed, it may be adopted.

To ensure a comprehensive gap analysis, the 72 elements were divided into three groups, each focused on a specific segment of the value chain: 1) Production, 2) Delivery and Storage, and 3) End-Use. The scope of each group is summarized in ***Table 1***.

Table 1: Segments of the Hydrogen Value Chain

Production (Elements 0–10)	Delivery and Storage (Elements 11–26)	End-Use (Elements 27–72)
Includes carbon intensity and various pathways for producing hydrogen from natural resources and primary energy, such as: • water electrolysis • natural gas reforming • biomass gasification • refined industrial waste • other emerging technologies	Includes the transfer of hydrogen from production sites to end-users and intermediate storage, as well as: • conversion, storage, liquefaction at production sites • gaseous and liquid hydrogen delivery • storage, conversion, vapourization at end-use sites	Includes the use of hydrogen in industrial, commercial, transportation, and residential applications, such as: • power production • gas-burning appliances • natural gas-hydrogen (NG-H_2) blending • hydrogen dispensing and use as fuel in road, air, rail, mining, and maritime applications • industrial feedstock use • oil and gas applications

[10] National Research Council Canada (2022). *NRCan Hydrogen Codes and Standards Gap Analysis Project*. Retrieved from https://nrc-publications.canada.ca/eng/view/object/?id=6d14bc19-30b8-4c59-bb26-513dd983d3d7. A mapping site with updated information and value chain classification is available at https://csres-cnrse.nrc-cnrc.gc.ca/en/canadian-hydrogen-value-chain-2024.

PRODUCTION

0. Carbon Intensity
1. Water Electrolysis - Centralized or Decentralized
2. Water Electrolysis - Offshore
3. Natural Gas Reforming
4. Biomass Gasification
5. Biomass-Derived Liquid Reforming
6. Refined Industrial Waste
7. Solar or Nuclear Thermochemical Hydrogen
8. Photo-Electrochemical
9. Microbial Biomass Conversion / Photobiological
10. Accelerated Carbon Transition (ACT)

DELIVERY AND STORAGE

H_2 CARRIERS, STORAGE, LIQUEFACTION AT PRODUCTION SITE

11a. NH_3 for H_2 Delivery and Storage

11b. Liquid Organic H_2 Carriers (LOHCs) for H_2 Delivery and Storage

11c. Methanol for H_2 Delivery and Storage

12a. LH_2 Storage at Production Site

12b. GH_2 Storage

13. H_2 Liquefaction Plant

H_2 GAS/LIQUID DELIVERY

14a. NH_3 Delivery by Truck

14b. LOHC Delivery by Truck

15a. NH_3 Delivery by Ship

15b. LOHC Delivery by Ship

16a. NH_3 Delivery by Rail

16b. LOHC Delivery by Rail

17. GH_2 Delivery by Rail

18. GH_2 Delivery by Truck

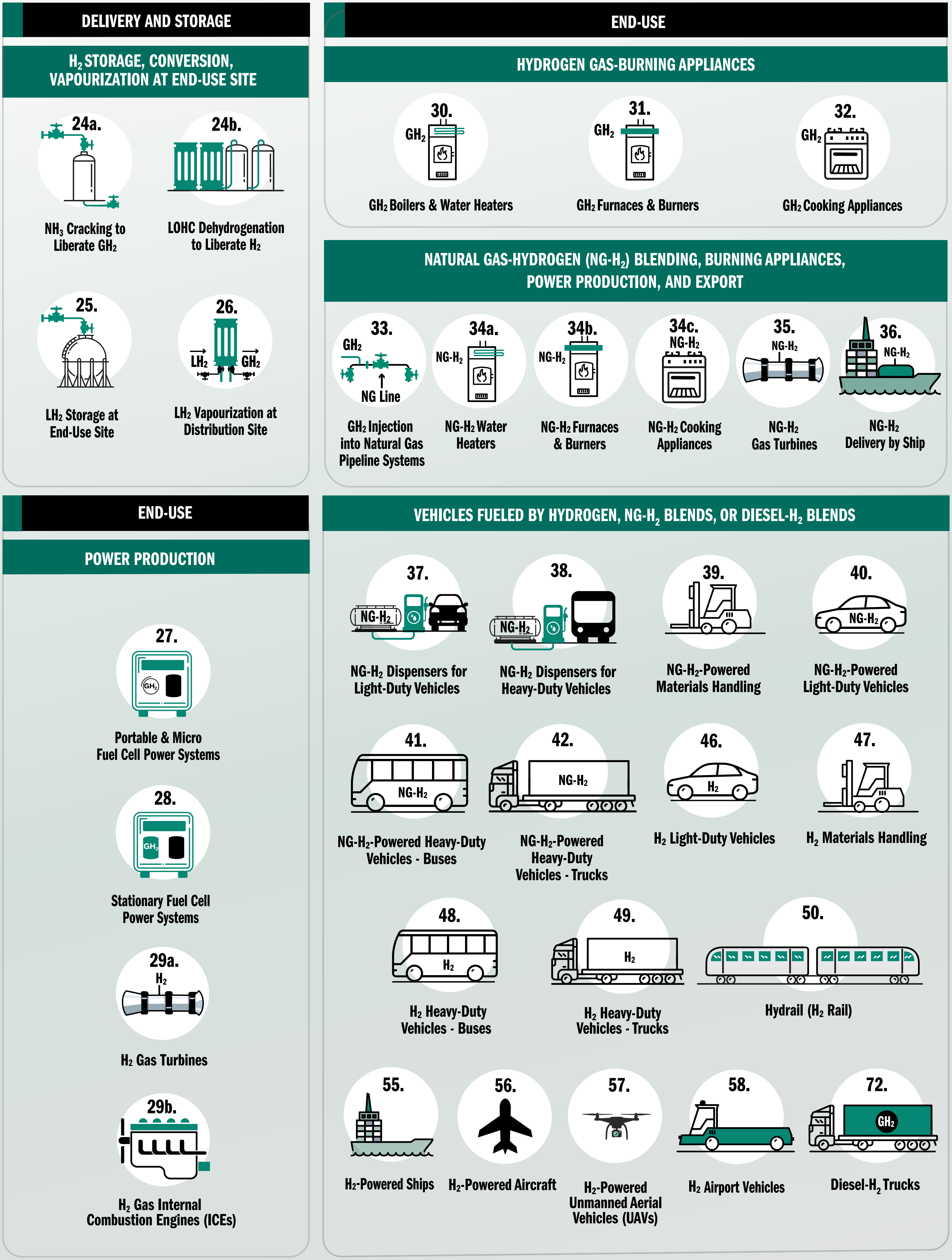
19. and 20. H_2 Gas Pipeline Systems / GH_2 Pressure Reduction Stations

21a. GH_2 Delivery by Ship

21b. LH_2 Delivery by Ship

22. LH_2 Delivery by Truck

23. LH_2 Delivery by Rail



DELIVERY AND STORAGE
H_2 STORAGE, CONVERSION, VAPOURIZATION AT END-USE SITE
24a.
NH_3 Cracking to Liberate GH_2
24b.
LOHC Dehydrogenation to Liberate H_2
25.
LH_2 Storage at End-Use Site
26.
LH_2
GH_2
LH_2 Vapourization at Distribution Site
END-USE
HYDROGEN GAS-BURNING APPLIANCES
30.
GH_2
GH_2 Boilers & Water Heaters
31.
GH_2
GH_2 Furnaces & Burners
32.
GH_2
GH_2 Cooking Appliances
NATURAL GAS-HYDROGEN (NG-H_2) BLENDING, BURNING APPLIANCES, POWER PRODUCTION, AND EXPORT
33.
GH_2
NG Line
GH_2 Injection into Natural Gas Pipeline Systems
34a.
NG-H_2
NG-H_2 Water Heaters
34b.
NG-H_2
NG-H_2 Furnaces & Burners
34c.
NG-H_2
NG-H_2 Cooking Appliances
35.
NG-H_2
NG-H_2 Gas Turbines
36.
NG-H_2
NG-H_2 Delivery by Ship
END-USE
POWER PRODUCTION
27.
GH_2
Portable & Micro Fuel Cell Power Systems
28.
GH_2
Stationary Fuel Cell Power Systems
29a.
H_2
H_2 Gas Turbines
29b.
H_2 Gas Internal Combustion Engines (ICEs)
VEHICLES FUELED BY HYDROGEN, NG-H_2 BLENDS, OR DIESEL-H_2 BLENDS
37.
NG-H_2
NG-H_2 Dispensers for Light-Duty Vehicles
38.
NG-H_2
NG-H_2 Dispensers for Heavy-Duty Vehicles
39.
NG-H_2-Powered Materials Handling
40.
NG-H_2
NG-H_2-Powered Light-Duty Vehicles
41.
NG-H_2
NG-H_2-Powered Heavy-Duty Vehicles - Buses
42.
NG-H_2
NG-H_2-Powered Heavy-Duty Vehicles - Trucks
46.
H_2
H_2 Light-Duty Vehicles
47.
H_2 Materials Handling
48.
H_2
H_2 Heavy-Duty Vehicles - Buses
49.
H_2
H_2 Heavy-Duty Vehicles - Trucks
50.
Hydrail (H_2 Rail)
55.
H_2-Powered Ships
56.
H_2-Powered Aircraft
57.
H_2-Powered Unmanned Aerial Vehicles (UAVs)
58.
H_2 Airport Vehicles
72.
GH_2
Diesel-H_2 Trucks

END-USE

HYDROGEN DISPENSING

43. H_2 Dispensers for Light-Duty Vehicles

44. H_2 Dispensers for Heavy-Duty Vehicles

45. H_2 Dispensers for Rail

51. H_2 Dispensers for Ships

52. H_2 Dispensers for Aircraft

53. H_2 Dispensers for UAVs

54. H_2 Dispensers for Airport Vehicles

MINING OPERATIONS AND INDUSTRIAL USE

59. H_2 Dispensers for Surface Mining Vehicles

60. GH_2 Dispensers for Underground Mining Vehicles

61. H_2 Heavy-Duty Surface Mining Equipment

62. H_2 Heavy-Duty Underground Mining Equipment

63. H_2 Heating & Ventilation Systems for Underground Mining

64. Chemical Production

65. Fertilizers

66. Synthetic Fuels

67. Steel Production

68. Cement Plants

ITEMS COMMON TO ALL APPLICATIONS AND COMMON INSTALLATION ITEMS

69. Items Common to All Applications

70. Common Installation items

OIL AND GAS

71. Oil & Gas

2.3 Conducting the Gap Analysis

2.3.1 List of Codes, Standards, and Guidance Documents

Members of the three task forces (i.e., Production, Delivery and Storage, and End-Use) performed an environmental scan of Canadian, United States, regional, and international codes, standards, and guidance documents for each of the elements in their respective task force. This included existing documents, as well as ones in development.

Codes, standards, and guidance documents that were deemed by the CSWG members as either relevant or informative to an element were collected. A detailed list of these documents, organized by element and categorized as "validated" or "unvalidated," is available at *List of Codes, Standards, and Guidance Documents*. Each item in the validated list has been vetted by an SCC-accredited SDO representative in terms of applicability to the element in which the document is attached.

2.3.2 Defining No Gap, Partial Gap, and Full Gap

To provide simplified results of the gap analysis, the extent of the gaps was defined as:

- **No gap** – A relevant and applicable standard is published and may be used as-is.
- **Partial gap** – There is a relevant, but not necessarily completely applicable, published standard or standards that can be leveraged and modified or adopted.
- **Full gap** – There is no published Canadian, United States, regional, or international standard available. If there is a relevant standard under development but not yet published, a full gap was still assigned.

2.4 Identifying Standards-Based Options

Defining the exact solution to address a standardization gap would require a thorough assessment of the subject matter and an in-depth analysis of existing standards, which was beyond the scope for the task forces and is typically the responsibility of a technical committee. However, a list of potential actions to address standardization gaps, called *standards-based options*, was generated for consideration. These options are summarized in ***Table 2*** and shown with more detail in ***Figure 4***.

Table 2: Summary of Standards-Based Options Assigned to Elements

1	No immediate action; periodically update existing Canadian standard(s)
2	Use as-is or update existing Canadian standard(s)
3.1	Reference or adopt existing U.S. standard(s)
3.2	Reference or adopt existing regional standard(s)
3.3	Reference or adopt existing international standard(s)
4	Develop new standard(s)
5	Wait for standard(s) under development to be published
6	No immediate action; wait until technology is more mature or commercialized

If the gap analysis revealed a Canadian standard exists:[11]

- **Option 1** was selected if the pre-existing standard is relevant to the hydrogen equipment or can be enhanced by incorporating elements from regional or international standards. There is no immediate action with this option, and the standard will undergo its regular periodic review.
- **Option 2** was selected if the pre-existing standard was related to similar equipment or industry but may not be directly applicable to the hydrogen element in question. The probable options comprise using the similar standard as-is or expanding the scope of the existing standard to cover hydrogen.

If the gap analysis revealed that no Canadian standard exists, but a standard exists elsewhere:

- **Option 3 (3.1, 3.2, and 3.3)** was selected. The preferred scenario would be one that enables international compatibility and interoperability across borders, prevents technical barriers to trade, and increases market access by complying with established norms. Adopting regional or international standards, for example, reduces the burden and timeline associated with meeting various regulatory requirements.

If the gap analysis revealed that no standard exists:

- **Option 4** was selected. Due to the cost, time, and resource requirements of developing a new standard, this option should only be considered once it is confirmed that no other existing standards can be adopted or harmonized. Depending on the situation, other standards-based options (aside from an NSC) may be explored as an interim solution until a Canadian standard is developed or an international/regional standard is adopted. Flexible standards-based options offer a range of strategies that can be selected based on urgency, funding, and need for a consensus-based product and certification.[12]

REMINDER: DEVELOPING A NEW STANDARD IS A SIGNIFICANT UNDERTAKING

i. NSCs incorporate international best practices, necessitating thorough research, consultation, and adaptation to ensure alignment with global standards.

ii. NSCs are developed to meet local needs, safety requirements, and industry expectations.

iii. Timing is crucial, considering market readiness, technological advancements, and economic impact.

iv. Sufficient funding is essential for research, drafting, and review processes.

v. Technical committees must have balanced representation and require experts from relevant fields to collaborate.

vi. NSCs undergo rigorous reviews by stakeholders, industry representatives, and the public.

vii. Development can be national or involve adopting international standards, with the latter requiring careful consideration of the local context and balancing national needs with global harmonization.

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[11] A Canadian standard refers to a National Standard of Canada (NSC), which can only be developed by an SCC-accredited SDO.

[12] Standards Council of Canada (2021). *Flexible Standards-Based Strategies and Solutions*. Retrieved from https://scc-ccn.ca/resources/publications/flexible-standards-based-strategies-and-solutions

If the gap analysis revealed that a standard is under development:

- **Option 5** was selected. Stakeholders may either wait for the standard or develop an interim solution as described in Option 4.

If the gap analysis revealed that a Canadian standard is not yet required due to low technology maturity or deployment in Canada:

- **Option 6** was selected. This is applicable in cases of new technology (i.e., the element has a Technology Readiness Level (TRL) below 7) or where there is minimal activity or adoption in Canada.[13] It is recommended to wait until the technology is more mature or commercialized before pursuing standards-related action.

Standards as the Building Blocks for Codes

Standards are independent normative documents that provide guidelines, specifications, and best practices. They serve as reference points for various industries and applications.

Codes, on the other hand, are compilations of specific rules and regulations. They often incorporate relevant standards for a particular purpose. For instance, electrical, plumbing, building, and fire safety codes select and integrate relevant standards to ensure compliance.

The CHIC (i.e., CAN/BNQ 1784-000) does not follow the same definition for a code. It aligns more closely with a standard with the purpose of establishing guidelines and practices related to hydrogen installation.

Since codes rely on underlying standards, it is essential to address any gaps in standardization to facilitate code development. Further discussions are necessary to identify and bridge codes gaps effectively.

[13] Innovation, Science and Economic Development Canada (2018). *Technology readiness levels*. Retrieved from https://ised-isde.canada.ca/site/innovation-canada/en/technology-readiness-levels

Figure 4: Detailed Standards-Based Options Assigned to Elements

1. RELEVANT CANADIAN STANDARD(S) EXISTS FOR THE HYDROGEN ELEMENT

Options Include:
- No action
- Update/expand the existing standard as required periodically or for evolving hydrogen landscape

2. A CANADIAN STANDARD EXISTS FOR SIMILAR EQUIPMENT OR INDUSTRY BUT MAY NOT ADEQUATELY COVER THE HYDROGEN ELEMENT

Options Include:
- Use the similar standard as-is
- Update/expand the existing standard to cover hydrogen, which may include adopting regional or international standards

3. A CANADIAN STANDARD DOES NOT EXIST FOR THE HYDROGEN ELEMENT, BUT A REGIONAL OR INTERNATIONAL STANDARD EXISTS

3.1 RELEVANT UNITED STATES STANDARD(S) EXISTS

Options Include:
- Harmonize to create a bi-national standard (U.S./Canada)
- Develop a standards-based solution in accordance with SCC recommendations; U.S. standard can be used as a seed document
- Adopt the U.S. standard

3.2 RELEVANT REGIONAL (E.G., EU) STANDARD(S) EXISTS

Options Include:
- Adopt the regional standard with Canadian deviations
- Develop a standards-based solution in accordance with SCC recommendations; regional standard can be used as a seed document

3.3 RELEVANT INTERNATIONAL STANDARD(S) EXISTS

Options Include:
- Adopt the international standard with Canadian deviations
- Develop a standards-based solution in accordance with SCC recommendations; internatioinal standard can be used as a seed document

4. A CANADIAN, REGIONAL, OR INTERNATIONAL STANDARD DOES NOT EXIST

Options Include:
- Develop a new National Standard of Canada
- Develop other standards-based solution in accordance with SCC recommendations

5. A STANDARD IS UNDER DEVELOPMENT

Options Include:
- Wait for the standard to be developed
- Develop a standards-based solution in accordance with SCC recommendations depending on urgency and priority

6. STANDARDS MAY OR MAY NOT YET EXIST AS TECHNOLOGY IS EMERGING OR DEVELOPMENT IS NEW

Options Include:
- For technologies at a Technology Readiness Level (TRL) below 7: monitor the technology development and be ready to assess the priority of this element by the time the technology reaches a TRL of 7
- For technologies where there are no activities in Canada: monitor for new activities of these technologies in Canada at a TRL of 7 and be ready to assess the priority of this element (complete a gap analysis if new activities are observed in Canada at a TRL of 7)

2.5 Prioritizing the Gaps

2.5.1 Priority Criteria and Ratings

Given the considerable number of elements, prioritizing individual elements is required to develop an efficient plan (i.e., roadmap) to address standardization gaps. A Decision-Based Priority Matrix (DBPM) rating system was created to consider multiple variables to assess the weight of the gaps and their importance in removing barriers to safe hydrogen deployment. Various stakeholder groups, including members of the CSWG task forces, as well as external representatives from provincial governments and AHJs, were offered the opportunity to weigh in by completing the rating exercise. The ratings were based on criteria that represent current hydrogen deployment or enable successful future hydrogen deployment. They are based primarily on addressing codes and standards gaps and do not necessarily represent the economic priority of elements.

Initially, the rating exercise involved members of the CSWG's task forces, encompassing a diverse group of stakeholders. Task force members were asked to provide information, as well as their perspective, or enlist the expertise of their networks, on ratings based on criteria shown in ***Table 3*** for each element in their value chain segment.

Table 3: Criteria Used for Task Force Members and Experts to Rate Elements

Rating Criterion	Description
# of Canadian Companies	Number of companies that are actively operating and have products, projects, or research in a given element
Activity in the Sector	Relative size and influence (e.g., revenue) of active companies with products, projects, or research in a given element; larger and more influential companies indicate higher interest and commercialization, which increases an element's priority
Impact	Effect of having a relevant standard published; if the development or update of a standard would remove barriers and/or accelerate adoption of the technology, its priority is increased
Technology Readiness Level (TRL)	Maturity level for a given element (e.g., conceptual phase or commercially advanced/available)
Urgency	The degree to which timing of standards development affects its adoption; urgency is high if the demand for a certain technology is strong, but the lack of applicable standards is preventing its development or implementation

Subsequently, a distinct rating exercise was carried out with government representatives and regulatory authorities. This was done to gain a deeper insight into their priorities and to check for consistency with the outcomes identified in the initial exercise. Representatives from provincial governments and AHJs were asked to complete a rating exercise using the four criteria described in ***Table 4***, which complemented the data collected from the CSWG members. These criteria were adapted for hydrogen codes and standards based on the American National Standards Institute (ANSI) Electric Vehicles Standards Panel's report *Roadmap of Standards and Codes for Electric Vehicles at Scale*, which shared similar objectives as this Roadmap.[14] This Roadmap includes input from Alberta, British Columbia, Newfoundland and Labrador, Ontario, and Québec government representatives as well as AHJ representatives from British Columbia, Ontario, Québec, and Saskatchewan. Inputs from more provinces and the territories in subsequent prioritization exercises would increase the robustness of the results.

[14] American National Standards Association. *ANSI Electric Vehicles Standards Panel (EVSP)*. Retrieved from https://www.ansi.org/standards-coordination/collaboratives-activities/electric-vehicles

Table 4: Criteria Used for Provincial Government and AHJ Representatives to Rate Elements

Rating Criterion	Description
Achievability	Level of resources required to address gaps, while also considering competing priorities (i.e., in relation to other elements); projects that are already underway have a higher achievability, whereas projects not yet initiated have lower achievability given effort required
Criticality	Importance and urgency of having standards for a specific element; if the consequences (e.g., negative safety or quality implications) of not developing standards are significant, the criticality rating is high
Effect	Positive impact of addressing the standards gaps for an element; a high return on investment for closing the gap represents a higher priority
Scope	Level of investment required (e.g., time, effort, money) to develop knowledge and address the gap as well as the degree to which information, tools, and/or resources are currently available; if the investment required is relatively minimal, this yields a higher rating for scope

The weightings were then applied, per the DBPM methodology (see ***Appendix E*** for more details), to determine a final normalized rating out of 100. The closer the rating is to 100, the higher priority it is. For the remainder of this report, the term **"overall rating"** refers to this final rating.

2.5.2 Timelines for Action

Based on the priority ratings, the 72 elements were ranked from highest to lowest in terms of overall rating. The top 20 were then further analyzed and assigned a proposed timeline. The timeline options are defined as follows:

- **Short-term:** Gaps associated with these elements are the highest priority and necessary to address. This Roadmap recommends relevant codes and standards to be published within three years of this report's publication (i.e., before 2028). This aligns with typical standard development timelines in Canada of 18 to 36 months.
- **Medium-term:** Gaps are critical to fill, but do not need to be addressed immediately. This Roadmap recommends codes and standards to be published in the next three to six years (i.e., 2028–3030).
- **Long-term:** No gap exists or gaps are non-critical but potentially beneficial to address eventually. Codes and standards can be published in six years or more (i.e., 2031 and beyond).

To assign the timelines for elements with full or partial gaps, Urgency and Criticality scores (as listed in ***Table 3*** and ***Table 4***, respectively) were used, as they both align with stakeholders' views of the timeline in which gaps should be filled. Elements with a combined Urgency and Criticality score greater than 70 (out of 100) were assigned a short-term timeline, while scores less than 70 were assigned medium-term.

Elements that did not have gaps, either because a standard already exists or the gaps were unable to be validated, were assigned as a long-term timeline. However, timelines are expected to evolve as additional data becomes available and needs of the industry change. It is expected that some of the long-term priorities will move into short- and medium-term, and periodic updates of this Roadmap will capture these changes.


3

3. RESULTS OF THE GAP ANALYSIS

The results of the gap analysis are presented by element of the hydrogen value chain from production (***Section 3.1***) to delivery and storage (***Section 3.2***) and end-use applications (***Section 3.3***). Given the large number of elements within the Delivery and Storage and End-Use segments, the elements are further grouped for ease of comprehension. Some issues that cross-cut multiple value chain segments are discussed in ***Section 3.4***.

A full list of published codes, standards, and guidance documents identified during the environmental scan and gap analysis is available at *List of Codes, Standards, and Guidance Documents*.

Some elements were assessed together in the gap analysis due to similarities in technology or industry area, which allowed for concurrent standards review. Other elements were not assessed, either because the technology is still new and information is not yet available, or there was a lack of expertise at the time the gap analysis was conducted.

3.1 Production

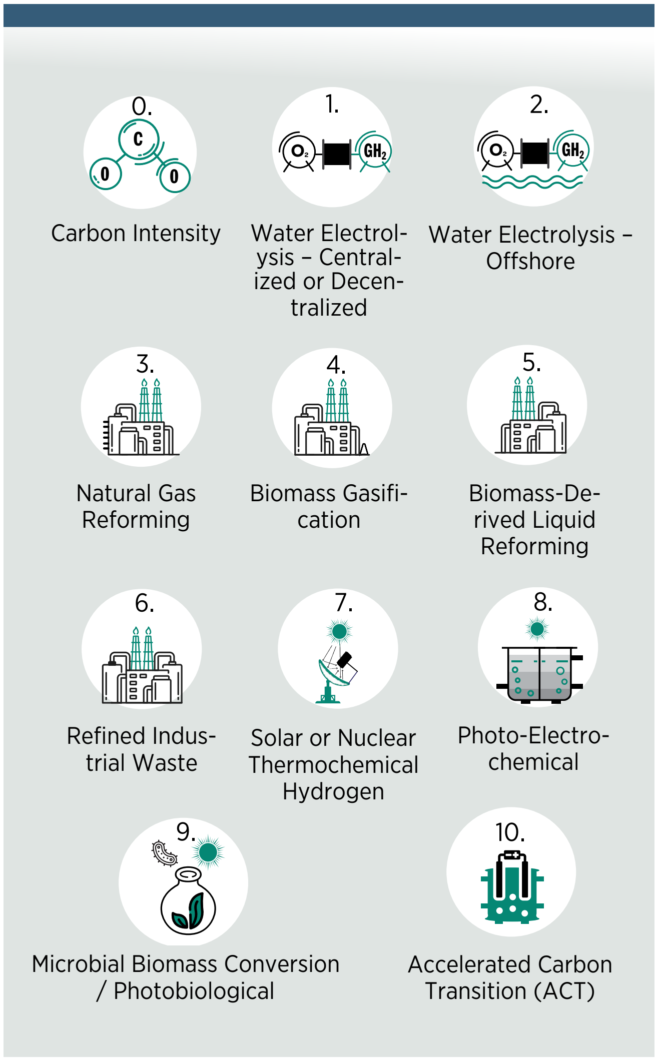
3.1.1 Scope

The Production value chain segment focuses on the various pathways for producing hydrogen from natural resources and primary energy. This includes Elements 0–10, which cover hydrogen CI associated with production and several production pathways.

The production of hydrogen includes many mature technologies and established commercial processes, such as water electrolysis and steam methane reforming (SMR). New technologies are continuously emerging, like thermochemical and biological conversions. Hydrogen can also be sourced as a byproduct from other industrial processes.

The task force members aimed to identify gaps and present suggestions that would rapidly increase hydrogen availability by 2030. They concentrated on production technologies rated at TRL 8 and above – specifically on Elements 1–6. Elements 7–10 are still emerging technologies (TRL 4 or less) so were not included in the gap analysis.

Presently, hydrogen is predominately produced at a large scale in centralized industrial locations. It is expected that some hydrogen may be produced at a smaller scale closer to end-use infrastructure, such as fueling stations, reducing delivery requirements. Small-scale or decentralized hydrogen could be produced using a variety of hydrogen production technologies, so the application of codes and standards should be integrated between hydrogen production and the associated end-use application.



Hydrogen has been produced at industrial scale for decades; however, low-carbon hydrogen is much less common. Low-carbon hydrogen in Canada means hydrogen that is expected to have an average life cycle CI of less than 4 kg of carbon dioxide equivalent per kg of hydrogen produced. It is necessary to have a standard mechanism to determine the CI of the various production pathways to support the development of low-carbon hydrogen. A certificate or comparable system could be created to distinguish between lower and higher CI production. This could support the global trade of hydrogen to further spur demand. Potential export markets (e.g., Europe) continue to develop and adopt requirements and specifications for what constitutes low-carbon hydrogen, which Canada will need to consider as it determines its hydrogen life cycle assessment (LCA) standard.[15]

THE PURITY OF PRODUCED HYDROGEN IS AN IMPORTANT FACTOR

The purity of hydrogen required may be dictated by several elements along the value chain (e.g., material compatibility, safety aspects, whether blending with other fuels). A minimum hydrogen quality specification and/or critical level of contaminants should be identified to ensure the hydrogen produced meets the requirements for further processing, delivery, and end-use application(s). Standards related to the quality or purity of hydrogen exist (e.g., ISO/DIS 14687 (Hydrogen Fuel Quality)).

Purification equipment is primarily designed to eliminate impurities such as non-hydrogen gas contaminants, oxygen, water, oil, and particulate matter from hydrogen gas streams. Hydrogen purification systems are typically co-located with hydrogen production facilities. These systems are commercially available, in operation, and mostly covered in existing standards. However, some aspects have standards gaps. For example, there are no dedicated standards for hydrogen gas drying equipment. Equipment to dry and purify hydrogen can be partly covered by CSA B22734 (Hydrogen Generators Using Water Electrolysis) and CSA B51 (Boiler, Pressure Vessel, and Pressure Piping Code), but there remains a need for a standard that defines the minimum construction and safety requirements for a hydrogen gas dryer.

[15] Life cycle assessment (LCA) is a common approach for determining the CI of a product with sources for the many emissions factors used in the analysis.

3.1.2 Gaps

Table 5 summarizes the status of the gaps in the hydrogen production value chain segment.

Table 5: Gaps in the Hydrogen Production Segment

Element #	Element Name	Gap	Standards-Based Option(s)
0	Carbon Intensity	●	5 – Wait for standard(s) under development to be published
1	Water Electrolysis – Centralized or Decentralized	◐	2 – Use as-is or update existing Canadian standard(s)
2	Water Electrolysis – Offshore	◐	2 – Use as-is or update existing Canadian standard(s)
3	Natural Gas Reforming	◐	3.1 – Reference or adopt existing U.S. standard(s)
4	Biomass Gasification	◐	3.1 – Reference or adopt existing U.S. standard(s)
5	Biomass-Derived Liquid Reforming	◐	6 – No immediate action; wait until technology is more mature or commercialized
6	Refined Industrial Waste	○	1 – No immediate action; periodically update existing Canadian standard(s)
7	Solar or Nuclear Thermochemical Hydrogen	X	
8	Photo-Electrochemical	X	
9	Microbial Biomass Conversion / Photobiological	X	
10	Accelerated Carbon Transition (ACT)	X	

○ No gap ◐ Partial gap ● Full gap X Not assessed

Elements 7–10 were not assessed due to low TRL, limited activity in Canada, and/or unavailable expertise for input to this Roadmap.

Carbon Intensity (Element 0) – *Full gap*

The CI of hydrogen production is an important consideration for end-use both locally and for export markets. Although LCA is an approach often used, there needs to be a common global method of accounting. Determining the CI of a product and/or process using an LCA approach typically uses ISO or jurisdictional greenhouse gas (GHG) protocol definitions and standards. It is important that standards developed for Canada are aligned with ISO standards at a minimum and consider a global context, with consideration given to Canada's target export markets.

Currently, work is underway to address this gap. The Bureau de normalisation du Québec (BNQ) and CSA Group (CSA) are developing a bi-national (U.S./Canada) standard that sets guidelines specifying criteria for assessing the CI of hydrogen production.[16] CSA published a research paper proposing guidance for designing a hydrogen classification system that would provide suppliers and consumers with greater clarity on hydrogen supplies.[17]

The IPHE also developed the *Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen*, which was released in July 2023.[18] Referred to as the "IPHE methodology," it served as the basis for the recently published ISO Technical Specification 19870:2023 (Methodology for Determining the Greenhouse Gas Emissions associated with the Production, Conditioning and Transport of Hydrogen to Consumption Gate).

Although a variety of work is being pursued in this area, an applicable standard is not yet published, so this element was given a full gap.

Water Electrolysis (Elements 1 and 2) – *Partial gaps*

Water electrolysis is a chemical process that uses electricity to separate water into hydrogen and oxygen. The primary difference between offshore and onshore electrolysis is related to the location and the jurisdictional/regulatory authority. Standards for existing offshore operations, such as wind turbines and oil and gas platforms, would likely provide the suitable standards guidance.

Although there are few types of water electrolysis technologies, there are standards that cover many of the typical technologies. For example, an update to the bi-national (U.S./Canada) standard CSA B22734 (Hydrogen Generators Using Water Electrolysis) has been published. This standard is an adoption of ISO 22734, with some deviations, to support harmonization with international standards and additional components of the electrolysers.

A noteworthy gap in standards is the interconnected nature of hydrogen production with other aspects of the value chain, such as delivery and storage. This relates to the integration of decentralized water electrolysis systems, or any decentralized small-scale hydrogen production onsite, with other components of hydrogen fueling infrastructure (e.g., compressors, storage tanks, dispensers), possibly in an urban and commercial setting.

There may also need to be updates to existing codes and standards for various means of electricity generation, such as combined cycle natural gas and nuclear to support hydrogen production at scale (e.g., assessing impacts of hazards imposed on nuclear power plants).[19] For these reasons, these elements were given a partial gap.

Natural Gas Reforming (Element 3) – *Partial gap*

Natural gas reforming, including SMR and ATR, is a process for producing a syngas that is a combination of hydrogen and carbon monoxide by reaction of hydrocarbons, typically natural gas, with water and/or oxygen. SMR has historically been the predominant pathway for large-scale hydrogen production, providing a significant portion of the world's hydrogen supply.

SMR and ATR are fully advanced and commercialized technologies with SMR having many operating facilities in Canada. Carbon capture and storage (CCS) or carbon capture, utilization, and storage (CCUS) is being added to existing SMR facilities to reduce the CI of the hydrogen produced, which may need to be considered as part of the standards landscape. All planned hydrogen production projects using ATR incorporate the use of carbon capture to lower the CI. CCS and CCUS systems are beyond the scope of this Roadmap, but the technical report ISO/TR 27912:2016 (Carbon Dioxide Capture — Carbon Dioxide Capture Systems, Technologies and Processes) provides more details on carbon capture systems, technologies, and processes.

Other hydrogen production technologies under development include partial oxidation and methane pyrolysis.

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16 Standards Council of Canada. *Carbon Intensity of Hydrogen*. Retrieved from https://scc-ccn.ca/standards/notices-of-intent/bureau-de-normalisation-du-quebec-bnq/carbon-intensity-hydrogen

17 Oliver, B., Davidson, A., Punia G.K. (2023). *Advanced Classification of Hydrogen: Life Cycle Assessment and Beyond*. Canadian Standards Association, Toronto, ON.

18 International Partnership for Hydrogen and Fuel Cells in the Economy (2021). *Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen*. Retrieved from https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021

19 Standards relevant to nuclear power plant safety include CSA N286:12 (Management System Requirements for Nuclear Facilities) and CSA N290.17 (Probabilistic Safety Assessment for Nuclear Power Plants).

Most standards for hydrogen production are international, with few Canadian standards specific to hydrogen production; only CSA B51:19 (Boiler, Pressure Vessel, and Pressure Piping Code) was deemed relevant for this element. Since standards do exist, a partial gap was assigned.

There may be an opportunity to consolidate and streamline standards to support hydrogen projects in areas such as best practices for process design, operational knowledge, and experience, without adding additional burden and costs for manufacturing, and to develop test methods to evaluate process performance. This could be applicable to all methods of hydrogen production.

Biomass Gasification and Biomass-Derived Liquid Reforming (Elements 4 and 5) – *Partial gaps*

Gasification is the thermochemical process for converting raw, solid carbonaceous materials into combustible or chemical feedstock gas. It involves biomass-based feedstock undergoing partial oxidation at temperatures typically greater than 800°C in the presence of an oxidizing agent (e.g., air, steam) to produce a mixture of carbon monoxide, hydrogen, carbon dioxide, water vapour, methane, and nitrogen, in addition to contaminants consisting of sulphur, tar, and ash. The hydrogen can then be recovered.

Biomass-based production of hydrogen represents an opportunity to utilize renewable feedstock, which is abundant in certain areas of Canada. Biomass-derived liquids can also be produced using various processes including gasification, pyrolysis, hydrothermal liquefaction, and fermentation. Subsequent reforming of such liquids into hydrogen can also be coupled with carbon capture and utilization to reduce the CI. The production of hydrogen from biomass should be actively monitored, given its potential to expand sources of low-carbon hydrogen, so that standards progress as the technologies and projects are developed.

There are several existing standards relevant to these elements, which contributed to them being assigned a partial gap. For Biomass Gasification (Element 4), it is recommended to:

- expand CAN/CGA-B105-M93 (Code for Digester Gas and Landfill Gas Installations) and CSA/ANSI B149.6:20 (Code for Digester Gas, Landfill Gas, and Biogas Generation and Utilization) to cover hydrogen generation aspects;
- make CSA/ANSI FC 5:21 (Hydrogen Generators Using Fuel Processing Technologies – Part 1: Safety) a U.S./Canada bi-national standard.

Standards in other areas, including biogas (e.g., ISO 20675:2018 (Biogas Production, Conditioning, Upgrading and Utilization)), could also be adapted.

Refined Industrial Waste (Element 6) – *No gap*

Hydrogen can be sourced as a byproduct from certain industrial processes, including petrochemical processes and electrochemical processes involved in the production of polyethylene and chloroalkyl compounds. During these processes, hydrogen is generated incidentally and not as the primary product.

At these facilities, hydrogen can be captured for use within the facility as fuel gas or purified and sold as a hydrogen product. The capture and purification technologies are commercially available with existing standards, so no specific standards gaps have been identified.

3.2 Delivery and Storage

3.2.1 Scope

The Delivery and Storage value chain segment includes hydrogen carriers, storage, liquefaction, delivery, and liberation (Elements 11–26). Hydrogen delivery and storage is required for domestic use as well as the import or export of hydrogen. For this Roadmap, the scope of delivery is contained within Canada's jurisdiction.[20]

Hydrogen's low volumetric energy density makes storage a challenge. The method of hydrogen storage is often based on the end-use requirement, including weight and volume available for energy storage.

Hydrogen can be delivered and stored in the following forms:

- Gaseous hydrogen (GH_2): Gaseous hydrogen can be stored in pressure vessels, solid-state storage, pipelines, and salt caverns. Some of these can also serve as delivery methods. ***Appendix F*** provides more information on each of these methods.
- Liquid hydrogen (LH_2): Liquid hydrogen is a denser energy carrier than gaseous hydrogen. Hydrogen liquefies at -253°C and requires electrical energy to cool the gas to its liquid state, approximately 10 kWh/kg-H_2, which is approximately 30% of the heating value of the hydrogen. Liquid hydrogen must be stored at cryogenic temperature in super-insulated storage tanks to reduce boil-off or evaporation, similar to how liquid natural gas is stored. For hydrogen delivery over longer distances in moderate amounts where dedicated hydrogen pipelines are not an option, liquid hydrogen can be a viable delivery method due to its significantly higher energy density.
- Hydrogen carriers: The three hydrogen carriers reviewed for this Roadmap are ammonia (NH_3), liquid organic hydrogen carriers (LOHCs), and methanol. More information on each carrier is included in ***Appendix F***. Other emerging hydrogen carriers were beyond the scope of this Roadmap but may be considered in future work.

[20] Future iterations of a gap analysis may warrant classifying export within the delivery segment and/or a comprehensive analysis of hydrogen export for delivery and related international standards.

The Delivery and Storage segment of the hydrogen value chain comprises 16 elements and has been organized into three groups as listed in ***Table 6***.

Table 6: Delivery and Storage Segment Groups and Elements

Group Description	Elements Covered
H_2 Carriers, Storage, Liquefaction at Production Site	11a. NH_3 for H_2 Delivery and Storage; 11b. Liquid Organic H_2 Carriers (LOHCs) for H_2 Delivery and Storage; 11c. Methanol for H_2 Delivery and Storage; 12a. LH_2 Storage at Production Site; 12b. GH_2 Storage; 13. H_2 Liquefaction Plant
H_2 Gas/Liquid Delivery	14a. NH_3 Delivery by Truck; 14b. LOHC Delivery by Truck; 15a. NH_3 Delivery by Ship; 15b. LOHC Delivery by Ship; 16a. NH_3 Delivery by Rail; 16b. LOHC Delivery by Rail; 17. GH_2 Delivery by Rail; 18. GH_2 Delivery by Truck; 19. and 20. H_2 Gas Pipeline Systems / GH_2 Pressure Reduction Stations; 21a. GH_2 Delivery by Ship; 21b. LH_2 Delivery by Ship; 22. LH_2 Delivery by Truck; 23. LH_2 Delivery by Rail
H_2 Storage, Conversion, Vapourization at End-Use Site	24a. NH_3 Cracking to Liberate GH_2; 24b. LOHC Dehydrogenation to Liberate H_2; 25. LH_2 Storage at End-Use Site; 26. LH_2 Vapourization at Distribution Site

3.2.2 Gaps

3.2.2.1 Hydrogen Carriers, Storage, Liquefaction at Production Site (Elements 11-13)

Table 7 summarizes the status of the gaps in hydrogen carriers, storage, and liquefaction at the production site.

Table 7: Gaps in Hydrogen Carriers, Storage, Liquefaction at Production Site

Element #	Element Name	Gap	Standards-Based Option(s)
11a	NH_3 for H_2 Delivery and Storage	Partial gap	4 – Develop new standard(s)
11b	Liquid Organic H_2 Carriers (LOHCs) for H_2 Delivery and Storage	Partial gap	6 – No immediate action; wait until technology is more mature or commercialized
11c	Methanol for H_2 Delivery and Storage	Partial gap	6 – No immediate action; wait until technology is more mature or commercialized
12a	LH_2 Storage at Production Site	Partial gap	2 – Use as-is or update existing Canadian standard(s)
12b	GH_2 Storage Includes: pressure vessels, solid-state storage, pipelines, including use as temporary storage, salt caverns/underground storage, and compression stations/compressors	Partial gap	2 – Use as-is or update existing Canadian standard(s)
13	H_2 Liquefaction Plant	Full gap	4 – Develop new standard(s)

○ No gap ● Partial gap ● Full gap **X** Not assessed

NH_3 for H_2 Delivery and Storage (Element 11a) – *Partial gap*

Ammonia is an emerging carrier for delivery and storage of hydrogen, and processes for its production are technologically and commercially mature. Interest in the use of ammonia as a hydrogen carrier stems from the fact that it can be used directly in several applications or cracked back into hydrogen at points of use.

The noted gaps for this element include pipelining, bulk transport via unit trains, storage in marine ports, and shipment from Canadian ports. No standards currently exist for these areas, and therefore a new standard or a new section of an existing standard would need to be developed. Furthermore, if volumes of ammonia that will be delivered within heavily populated areas increase significantly, a standards gap would exist. For these reasons, a partial gap was given.

Liquid Organic H_2 Carriers (LOHCs) for H_2 Delivery and Storage (Element 11b) – *Partial gap*

There are no codes and standards that specifically reference LOHCs. Nonetheless, the addition of LOHCs to existing codes and standards for flammable organics (e.g., dangerous goods manufacturing) and/or existing petrochemical processing regulations would largely cover this subject area. As such, a partial gap was assigned.

Methanol for H_2 Delivery and Storage (Element 11c) – *Partial gap*

Methanol is a widely traded alcohol that is used as a solvent, fuel, precursor to a broad range of chemicals, and more recently a carrier for the delivery and storage of hydrogen. Methanol can be derived from petroleum feedstock or emerging sustainable feedstock such as municipal solid waste, agricultural waste, and captured carbon dioxide.

Conventional methanol production is mature with large volumes traded globally. However, the market for e-methanol, a synthetic fuel generated from captured carbon dioxide or monoxide and hydrogen generated from sustainable sources, is anticipated to grow rapidly over the coming decade. Since e-methanol is chemically identical to conventional methanol that has long been widely used in a range of products, existing regulations, codes, and standards for its delivery, handling, and storage will be applicable. However, further review is required to determine if there is a gap specific to the large-scale production of e-methanol. Because of this, this element was given a partial gap.

Liquid Hydrogen (LH_2) Storage at Production Site (Element 12a) – *Partial gap*

Hydrogen is often liquefied to prepare it for delivery (e.g., via rail or trucks). Prior to delivery, the liquid hydrogen is sometimes stored on-site, co-located with its production process. Liquid hydrogen storage already exists at a commercial scale, with multiple storage equipment operating in Canada.

While several related standards exist, there is an opportunity for greater coverage. All CSA B3xx standards (e.g., CSA B339-18 (Cylinders, Spheres, and Tubes for the Transportation of Dangerous Goods)) are specific to goods delivery but could potentially be used for temporary storage on-site. Since liquid hydrogen storage requires hazardous area classification, the Canadian Electrical Code (CSA C22.1:21) should be reviewed and updated to have classification for liquid hydrogen. For these reasons, this element was assigned a partial gap.

Gaseous Hydrogen (GH_2) Storage (Element 12b) – *Partial gap*

Gaseous hydrogen storage methods include pressure vessels, solid-state storage, pipelines, including use as temporary storage, and salt caverns and underground storage. Standards gaps for each of these methods were reviewed for this element's gap analysis. While some aspects have no gap, others do have gaps, so the overall element was assigned a partial gap.

The associated compression stations and compressors are also important components of gaseous hydrogen storage. Since compression equipment is already readily used for other gases, and related standards exist, no critical compression-related gap was identified.

Pressure Vessels

Pressure vessels include small-scale and large-scale storage tanks and containers, used for mobile or stationary applications. Transport Canada regulates the transport of hydrogen and its derivatives through the Transportation of Dangerous Goods Regulations. Canadian standards for pressure vessels and tanks, such as CSA B51 (Boiler, Pressure Vessel, and Pressure Piping Code), are applicable and partially cover gaseous storage. However, they need to be revised and expanded to include hydrogen elements. A review of CSA B625:20 (Portable Tanks for the Transport of Dangerous Goods), for example, could be useful to assess whether it can equally be applied to long-term hydrogen storage. All CSA B3xx standards (e.g., CSA B339-18 (Cylinders, Spheres, and Tubes for the Transportation of Dangerous Goods)) are specific to goods delivery but could potentially be used for temporary storage on-site. Future revisions of CSA standards, which will include details for hydrogen and hydrogen blends and alignment with other standards, are currently underway.

Pipelines, Including Use as Temporary Storage

Depending on regulations, pipelines can be considered as either storage or delivery. CSA Z662:23 (Oil and Gas Pipeline Systems) addresses hydrogen storage in pipelines at a high level; Clause 17 on hydrogen requires the user to assess the impacts of hydrogen blends with respect to storage (e.g., duration of storage and impact of hydrogen sitting in one area for long periods of time and stratification of gases due to lack of movement). For the electrical requirements associated with compression, metering, and other storage facilities, the Canadian Electrical Code (CSA C22.1:21), which makes reference to combustible gases, has classifications for gaseous hydrogen along with NG-H_2 blend limits. There are standardization gaps regarding applicable maximum pipe hoop stress for hydrogen and hydrogen blend services (i.e., greater than 50% Specified Minimum Yield Strength (SMYS)). These gaps can be addressed by ensuring alignment with the proposed hydrogen requirements in ASME B31.3 (Process Piping) and ASME B31.8 (Gas Transmission and Distribution Piping Systems).

Solid-State Storage

There are gaps in standards for reversible hydride storage canisters and carbon material tanks filled with gaseous hydrogen, notably:

- filter types and filter sizes required to maintain the integrity of the hydrogen released and of the cylinder's pressure relief valve;
- degassing, life cycle, and maintenance requirements for nano material filled tanks;
- integrity of the container for solid-state materials under pressure;
- solid-state mobile storage (i.e., transport of tanks).

Salt Caverns and Underground Storage

There are several standards that either already exist or are under development related to underground hydrogen storage. A supplement to CSA Z341:22 (Storage of Hydrocarbons in Underground Formations) was published in 2023 and is applicable to hydrogen and hydrogen blends. It is recommended that the standard be updated accordingly to include hydrogen storage. Also, an update to CSA Z625:16 (Well Design for Petroleum and Natural Gas Industry Systems) is being developed. CSA W228 (Quantitative Risk Assessment of Underground Storage of Hydrogen) is under development for underground storage risk evaluations. For these reasons, it was considered that underground storage has no gap.

H_2 Liquefaction Plant (Element 13) – *Full gap*

Though the CHIC covers liquid applications of hydrogen, it does not cover cryogenic systems for liquefaction or liquefaction in petroleum refineries and chemical plants. To support the buildout of liquefaction at industrial sites, standardizing risk assessment procedures may address complexities and propose fundamental methods for safe design and operation. Therefore, a full gap exists.

3.2.2.2 Hydrogen Gas/Liquid Delivery (Elements 14-23)

Table 8 summarizes the status of the gaps in hydrogen gas/liquid delivery.

Table 8: Gaps in Hydrogen Gas/Liquid Delivery and Distribution

Element #	Element Name	Gap	Standards-Based Option(s)
14a	NH_3 Delivery by Truck	○	1 – No immediate action; periodically update existing Canadian standard(s)
14b	LOHC Delivery by Truck	X	
15a	NH_3 Delivery by Ship	○	1 – No immediate action; periodically update existing Canadian standard(s)
15b	LOHC Delivery by Ship	◐	2 – Use as-is or update existing Canadian standard(s)
16a	NH_3 Delivery by Rail	○	1 – No immediate action; periodically update existing Canadian standard(s)
16b	LOHC Delivery by Rail	○	1 – No immediate action; periodically update existing Canadian standard(s)
17	GH_2 Delivery by Rail	◐	2 – Use as-is or update existing Canadian standard(s)
18	GH_2 Delivery by Truck	◐	2 – Use as-is or update existing Canadian standard(s)
19 & 20	H_2 Gas Pipeline Systems / GH_2 Pressure Reduction Stations	◐	2 – Use as-is or update existing Canadian standard(s)
21a	GH_2 Delivery by Ship	●	6 – No immediate action; wait until technology is more mature or commercialized
21b	LH_2 Delivery by Ship	X	
22	LH_2 Delivery by Truck	X	
23	LH_2 Delivery by Rail	○	1 – No immediate action; periodically update existing Canadian standard(s)

○ No gap ◐ Partial gap ● Full gap X Not assessed

Elements 14b, 21b, and 22 were not assessed due to low TRL, limited activity in Canada, and/or unavailable expertise for input to this Roadmap.

NH_3 Delivery by Truck (Element 14a) – *No gap*

The use of ammonia in several applications is made possible at various locations by truck delivery. Ammonia delivery by truck is typically in pressurized liquid form, using insulated vessels with refrigeration systems to prevent vapourization. Currently, protocols for delivery exist within the Transportation of Dangerous Goods Regulations (SOR/2001-286) Appendix E: Schedule 2. Consequently, this element was assigned no gap.

NH_3 Delivery by Ship (Element 15a) – *No gap*

Since the regulation of current practices of delivering ammonia by ship is well established, no standards gap was assigned. However, new modes of delivery and storage for large amounts of hydrogen in the form of ammonia may be required to fulfill the future needs of the hydrogen industry, which may require new or updated standards.

LOHC Delivery by Ship (Element 15b) – *Partial gap*

While there are no standards gaps presently noted with respect to the use of ships for delivering LOHCs, gaps may be present in the design of systems at ports to accommodate LOHC delivery, especially where there are significant increases in volume. As such, a partial gap was assigned.

NH_3 Delivery by Rail (Element 16a) – *No gap*

Ammonia is currently delivered via rail, which is why no gap was assigned. However, should ammonia be used in the future as a hydrogen carrier for large-scale rail transport in densely populated or environmentally sensitive areas, the risk would need to be assessed and potentially mitigated through standards or regulations. Proposed large-scale ammonia production projects targeting exports in western Canada would require unit train deliveries of ammonia, which currently do not exist.

LOHC Delivery by Rail (Element 16b) – *No gap*

Given that the organic compounds that are employed as hydrogen carriers are already being delivered by rail, no gap was assigned. Periodic codes and standards updates should be expected to account for increased transportation volumes.

Gaseous Hydrogen (GH_2) Delivery by Rail (Element 17) – *Partial gap*

Though standards do exist for the transportation of dangerous goods, they may require a review to ensure that they properly cover gaseous hydrogen. For this reason, this element was given a partial gap.

Generally, standards should consider:

- the design of hydrogen tender cars;
- transport by ISO containers;
- existing liquefied natural gas rail cars design requirements for hydrogen transport.[21]

Gaseous Hydrogen (GH_2) Delivery by Truck (Element 18) – *Partial gap*

For gaseous hydrogen delivery by truck, various standards cover the transportation of dangerous goods and so the same conclusion is drawn as for GH_2 Delivery by Rail (Element 17). CSA performed research on gaps in hydrogen delivery by truck and published a high-level overview in 2023.[22]

H_2 Gas Pipeline Systems / Gaseous Hydrogen (GH_2) Pressure Reduction Stations (Elements 19 and 20 – *Partial gaps*

These elements cover gas delivery and transmission at high and low pressures through a dedicated pipeline. There is a partial gap for high-stress pipelines (i.e., greater than 50% SMYS), which is a safety issue. The 2023 edition of CSA Z662 (Oil and Gas Pipeline Systems) covers hydrogen but not to the extent that it could, and CSA is working on including more specific requirements.

[21] Kauling, D., Sage, G., Pinatton, M., Jeremic Nikolic, D. (2023). *Hydrogen Storage and Transport Beyond Pipelines: Regulations and Standardization*. Canadian Standards Association, Toronto, ON.

[22] Kauling, D., Sage, G., Pinatton, M., Jeremic Nikolic, D. (2023). *Hydrogen Storage and Transport Beyond Pipelines: Regulations and Standardization*. Canadian Standards Association, Toronto, ON

Gaseous Hydrogen (GH_2) Delivery by Ship (Element 21a) – *Full gap*

Currently, there is no established standard for ocean delivery of compressed hydrogen. While maritime shipping of hydrogen is anticipated to be crucial for Canadian producers to access global markets, liquid hydrogen or other hydrogen carriers including ammonia and methanol are the most explored for bulk hydrogen delivery. Delivery as a gas will result in less hydrogen being carried but avoids critical technical challenges, such as maintaining the cryogenic temperature required for liquid hydrogen and the associated energy penalties when liberating hydrogen from carriers (e.g., cracking ammonia). Although efforts are ongoing to develop marine vessels for hydrogen delivery, the lack of publicly available information hinders a comprehensive understanding of gaps in this area, which contributed to a full gap being assigned.

Liquid Hydrogen (LH_2) Delivery by Rail (Element 23) – *No gap*

Liquid hydrogen delivery by rail can be accomplished at significantly lower pressures compared to gaseous hydrogen delivery. Existing standards largely cover this element. As such, no gap was assigned.

However, transportation of dangerous goods standards may require a review to ensure that they properly cover liquid hydrogen delivery by rail. Generally, standards should consider:

- the design of cryogenic hydrogen tender cars;
- transport by ISO containers;
- existing liquefied natural gas rail cars design requirements for hydrogen transport.[23]

3.2.2.3 Hydrogen Storage, Conversion, Vapourization at End-Use Site (Elements 24-26)

Table 9 summarizes the status of the gaps in hydrogen storage, conversion, and vapourization at the end-use site.

Table 9: Gaps in Hydrogen Storage, Conversion, Vapourization at End-Use Site

Element #	Element Name	Gap	Standards-Based Option(s)
24a	NH_3 Cracking to Liberate GH_2	●	6 – No immediate action; wait until technology is more mature or commercialized
24b	LOHC Dehydrogenation to Liberate H_2	◐	2 – Use as-is or update existing Canadian standard(s)
25	LH_2 Storage at End-Use Site	○	1 – No immediate action; periodically update existing Canadian standard(s)
26	LH_2 Vapourization at Distribution Site	◐	2 – Use as-is or update existing Canadian standard(s)

○ No gap ◐ Partial gap ● Full gap X Not assessed

[23] Kauling, D., Sage, G., Pinatton, M., Jeremic Nikolic, D. (2023). *Hydrogen Storage and Transport Beyond Pipelines: Regulations and Standardization*. Canadian Standards Association, Toronto, ON.

NH_3 Cracking to Liberate GH_2 (Element 24a) – *Full gap*

Ammonia cracking is the process of converting ammonia into hydrogen and nitrogen. To release the hydrogen, a relatively large amount of energy is consumed compared to the regasification of liquid hydrogen. Currently, there are no known large-scale processes in operation globally (not to be confused with the established Haber-Bosch process for producing ammonia from hydrogen). Cracking technologies are under development with several existing pilot plants.

Consequently, no standard exists for ammonia cracking. While certain aspects might be covered by existing standards, such as those related to high pressures, material compatibility for hydrogen, area classification, and others, they will not fully encapsulate specific requirements for ammonia cracking technologies. This element is ascribed a full gap due to the absence of standards directly addressing its unique requirements.

LOHC Dehydrogenation to Liberate H_2 (Element 24b) – *Partial gap*

Currently, there are no codes and standards that specifically reference LOHCs. Nonetheless, the addition of LOHCs to existing codes and standards for flammable organics (e.g., dangerous goods manufacturing) and/or existing petrochemical processing regulations would largely cover this subject area, which is why a partial gap was assigned.

Liquid Hydrogen (LH_2) Storage at End-Use Site (Element 25) – *No gap*

Requirements for liquid hydrogen storage already exist, which is why no gap was assigned. However, periodic updates will be necessary as higher volumes become stored.

Liquid Hydrogen (LH_2) Vapourizer at Distribution Site (Element 26) – *Partial gap*

Most standard requirements are met for this element, including how to deploy liquid hydrogen vapourizers at gate stations. The Canadian Electrical Code (CSA C22.1:21), along with CSA Z662:23 (Oil and Gas Pipeline Systems), should be reviewed to verify that existing equipment and codes can be used when liquid hydrogen is vapourized to gaseous hydrogen before it is injected into natural gas distribution and transmission lines. For these reasons, a partial gap was assigned.

3.3 End-Use

3.3.1 Scope

Once hydrogen is produced and delivered to the end-user, it can be used in many ways. The End-Use value chain segment covers the utilization and dispensing of hydrogen in industrial, commercial, transportation, and residential applications (Elements 27–72). Dispensing is included in the End-Use segment because dispensing equipment will be located at the end-use site.[24] This segment comprises 49 elements and has been organized into eight groups as listed in ***Table 10***.

Table 10: End-Use Segment Groups and Elements

Group Description	Elements Covered
Power Production	27. Portable & Micro Fuel Cell Power Systems 28. Stationary Fuel Cell Power Systems 29a. H_2 Gas Turbines 29b. H_2 Gas Internal Combustion Engines (ICEs)
Hydrogen Gas-Burning Appliances	30. GH_2 Boilers & Water Heaters 31. GH_2 Furnaces & Burners 32. GH_2 Cooking Appliances
Natural Gas-Hydrogen (NG-H_2) Blending, Burning Appliances, Power Production, and Export	33. GH_2 Injection into Natural Gas Pipeline Systems 34a. NG-H_2 Water Heaters 34b. NG-H_2 Furnaces & Burners 34c. NG-H_2 Cooking Appliances 35. NG-H_2 Gas Turbines 36. NG-H_2 Delivery by Ship
Vehicles Fueled by Hydrogen, NG-H_2 Blends, or Diesel-H_2 Blends	37. NG-H_2 Dispensers for Light-Duty Vehicles 38. NG-H_2 Dispensers for Heavy-Duty Vehicles 39. NG-H_2-Powered Materials Handling 40. NG-H_2-Powered Light-Duty Vehicles 41. NG-H_2-Powered Heavy-Duty Vehicles – Buses 42. NG-H_2-Powered Heavy-Duty Vehicles – Trucks 46. H_2 Light-Duty Vehicles 47. H_2 Materials Handling 48. H_2 Heavy-Duty Vehicles – Buses 49. H_2 Heavy-Duty Vehicles – Trucks

[24] Future work by the CSWG, or future Roadmap iterations, may warrant adjustments and optimization to how elements are classified and organized in the hydrogen value chain.

Group Description	Elements Covered
Vehicles Fueled by Hydrogen, NG-H_2 Blends, or Diesel-H_2 Blends (cont.)	50. Hydrail (H_2 Rail) 55. H_2-Powered Ships 56. H_2-Powered Aircraft 57. H_2-Powered Unmanned Aerial Vehicles (UAVs) 58. H_2 Airport Vehicles 72. Diesel-H_2 Trucks
Hydrogen Dispensing	43. H_2 Dispensers for Light-Duty Vehicles 44. H_2 Dispensers for Heavy-Duty Vehicles 45. H_2 Dispensers for Rail 51. H_2 Dispensers for Ships 52. H_2 Dispensers for Aircraft 53. H_2 Dispensers for UAVs 54. H_2 Dispensers for Airport Vehicles
Mining Operations and Industrial Use Elements 27-32 are also implicated in this group	59. H_2 Dispensers for Surface Mining Vehicles 60. GH_2 Dispensers for Underground Mining Vehicles 61. H_2 Heavy-Duty Surface Mining Equipment 62. H_2 Heavy-Duty Underground Mining Equipment 63. H_2 Heating & Ventilation Systems for Underground Mining 64. Chemical Production 65. Fertilizers 66. Synthetic Fuels 67. Steel Production 68. Cement Plants
Items Common to All Applications and Common Installation Items	69. Items Common to All Applications 70. Common Installation Items
Oil and Gas	71. Oil & Gas

3.3.2 Gaps

3.3.2.1 Power Production (Elements 27-29)

Hydrogen serves as a versatile fuel for power generation through two main methods:

- combustion in turbines
- electrochemical conversion in stationary portable fuel cell power plants

Its applications include load management, long-term energy storage, backup power, and facilitating the integration of intermittent renewables into the energy market. Standard coverage in power production is partial, as seen in ***Table 11***, given that existing standards can be expanded or adopted.

Table 11: Gaps in Power Production

Element #	Element Name	Gap	Standards-Based Option(s)
27	Portable & Micro Fuel Cell Power Systems	Partial gap	3.1 – Reference or adopt existing U.S. standard(s)
28	Stationary Fuel Cell Power Systems	No gap	1 – No immediate action; periodically update existing Canadian standard(s)
29a	H_2 Gas Turbines	Partial gap	2 – Use as-is or update existing Canadian standard(s)
29b	H_2 Gas Internal Combustion Engines (ICEs)	Partial gap	2 – Use as-is or update existing Canadian standard(s)

○ No gap   ● Partial gap   ● Full gap   X Not assessed

Portable & Micro Fuel Cell Power Systems (Element 27) – *Partial gap*

For this element, a CSA technical information letter (TIL) for certification, a provisional standard, has been used as guidance in the absence of a Canadian standard. However, the TIL will be withdrawn in favour of adopting a relevant IEC standard harmonized with the United States, as is the case with Stationary Fuel Cell Power Systems (Element 28). As such, a partial gap was assigned.

Stationary Fuel Cell Power Systems (Element 28) – *No gap*

This element has bi-national standard CSA/ANSI FC 1:21/CSA C22.2 NO. 62282-3-100:21 (Fuel Cell Technologies — Part 3-100: Stationary Fuel Cell Power Systems — Safety), which adopted IEC 62282-3-100:2019, second edition, 2019-02, with Canadian and United States deviations. Therefore, there is no gap.

H_2 Gas Turbines and Internal Combustion Engines (ICEs) (Elements 29a and 29b) – *Partial gaps*

Several standards exist for gas turbines and reciprocating ICE-driven generators, but the coverage will need to be extended to include hydrogen. So, a partial gap was given.

3.3.2.2 Hydrogen Gas-Burning Appliances (Elements 30-32)

Pure hydrogen gas-burning appliances, including direct fired heating, will need separate requirements from natural gas-burning appliances to operate safely and efficiently. The same is true for retrofitting natural gas appliances to hydrogen. This group of elements covers the same appliances as in ***Section 3.3.2.3***, but with pure hydrogen gas fuel instead of blended fuel. ***Table 12*** summarizes the status of the gaps in hydrogen gas-burning appliances.

Table 12: Gaps in Hydrogen Gas-Burning Appliances

Element #	Element Name	Gap	Standards-Based Option(s)
30	GH_2 Boilers & Water Heaters	Partial gap	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.2 – Reference or adopt existing regional standard(s)
31	GH_2 Furnaces & Burners	Partial gap	2 – Use as-is or update existing Canadian standard(s) 5 – Wait for standard(s) under development to be published
32	GH_2 Cooking Appliances	Partial gap	2 – Use as-is or update existing Canadian standard(s) 5 – Wait for standard(s) under development to be published

○ No gap ● Partial gap ● Full gap X Not assessed

Gaseous Hydrogen (GH_2) Boilers, Water Heaters[25], Furnaces, Burners, and Cooking Appliances (Elements 30-32) – *Partial gaps*

Various manufacturers are developing hydrogen-compatible appliances for different product types, such as boilers, water heaters, furnaces, burners, and cooking appliances. There are no Canadian standards that specifically include hydrogen gas for these appliances, but related North American and international standards are available and applicable, which is why a partial gap was given. Many appliance types will require standards for conformity assessment when the fuel gas supply infrastructure is in place.

Requirements for appliances and equipment using pure hydrogen will need to be assessed, considering both safety and energy efficiency performance. It is recommended to update existing natural gas appliance standards to include up to 100% hydrogen or develop new standards specific to hydrogen appliances. This includes maintaining harmonization with the United States (in terms of bi-national standards) and continuing to monitor progress at the ISO and other international standards developers.

There are over 100 standards that affect natural gas appliances, components (e.g., gas controls, connectors), and their installation (some listed in ***Section 3.3.2.7***). They will all need to be assessed and most, if not all, will need to be modified.

For new equipment, certification will be necessary to indicate the appliance meets appropriate standards. Certifications could include hydrogen blends, hydrogen-ready (conversion compatible), or 100% hydrogen.

[25] Water heaters include hot water tank heaters, instantaneous tankless water heaters, pool heaters, boilers, and industrial water heaters.

3.3.2.3 Natural Gas-Hydrogen (NG-H_2) Blending, Burning Appliances, Power Production, and Export (Elements 33-36)

Hydrogen blending may play a crucial role in the transition to a sustainable and low-carbon energy future by leveraging existing infrastructure, reducing emissions, and facilitating the integration of renewable energy sources. Also, it acts as a stepping stone helping industry stimulate demand before 100% hydrogen systems are ready. Hydrogen blending at concentrations less than 5% by volume is still classified as natural gas. Currently, there are no standards for blending above this percentage.[26]

This group includes hydrogen injection into natural gas pipelines as well as NG-H_2 mixture appliances and potential export by ship, and ***Table 13*** summarizes the associated gaps.

For this Roadmap, the export of hydrogen or hydrogen blends fell under the End-Use segment of the hydrogen value chain because the vessels will cross international borders and not be subject to Canadian authorities. As such, evaluating import and export regulations was considered out of scope. Future iterations of this Roadmap may warrant different value chain classification and/or an analysis of international standards for hydrogen export.

Table 13: Gaps in NG-H_2 Blending, Burning Appliances, Power Production, and Export

Element #	Element Name	Gap	Standards-Based Option(s)
33	GH_2 Injection into Natural Gas Pipeline Systems	● (Partial gap)	2 – Use as-is or update existing Canadian standard(s) 3.2 – Reference or adopt existing regional standard(s) 3.3 – Reference or adopt existing international standard(s)
34a	NG-H_2 Water Heaters	● (Partial gap)	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.2 – Reference or adopt existing regional standard(s)
34b	NG-H_2 Furnaces & Burners	● (Partial gap)	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.2 – Reference or adopt existing regional standard(s)
34c	NG-H_2 Cooking Appliances	● (Partial gap)	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.2 – Reference or adopt existing regional standard(s)
35	NG-H_2 Gas Turbines	● (Partial gap)	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s)
36	NG-H_2 Delivery by Ship	X	

○ No gap ● Partial gap ● Full gap X Not assessed

Element 36 was not assessed because evaluating import and export regulations was considered out of scope.

[26] Suchovsky, C.J., Ericksen, L., Williams, T.A., Nikolic, D.J. (2021). *Appliance and Equipment Performance with Hydrogen-Enriched Natural Gases*. Canadian Standards Association, Toronto, ON.

Gaseous Hydrogen (GH_2) Injection into Natural Gas Pipeline Systems (Element 33) – *Partial gap*

International codes and standards exist for blending hydrogen into natural gas pipelines (not to be confused with H_2 Gas Pipeline Systems (Element 19), which is 100% hydrogen), covering high-pressure transmission, intermediate-pressure distribution, and low-pressure distribution (e.g., community) networks. However, there is often disagreement among global codes and standards regarding the precise definitions of “high-pressure” and “low-pressure” systems.

Most codes and standards for pipeline systems do not address hydrogen blending in natural gas, but a few have been identified. There are standards for natural gas pipeline systems, such as ASME B31.8 (Gas Transmission & Distribution Piping Systems) and the new edition of CSA Z662:23 (Oil and Gas Pipeline Systems), which include consideration for hydrogen blending in natural gas. Codes and standards such as ASME B31.12 (Hydrogen Piping and Pipelines) and IGEM/H1 (Reference Standard for Low Pressure Hydrogen Utilisation) are relevant, but only cover pure hydrogen pipeline systems. Additionally, supplementary documents have been created for United Kingdom standards to address hydrogen blending.

The industry could benefit from having codes and standards that consider the impact of hydrogen’s partial pressure on pipelines and component integrity for designing new high-pressure, intermediate-pressure, and low-pressure distribution pipeline systems and for modifying existing pipeline systems for blended gas service. The IEC 60079 (Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres) does address hazardous area classification changes that would be relevant for NG-H_2 blend facilities and covers compressor stations, gate stations, pressure reduction stations, and other components. CSA has recently published a research paper assessing the gaps in natural gas pipeline materials for hydrogen service, highlighting this to be a crucial step for accelerating the hydrogen economy rollout.[27]

The transition from natural gas to hydrogen behaviour in NG-H_2 blends is influenced by the hydrogen concentration, with increasing hydrogen content leading to combustion properties more similar to pure hydrogen.

The Canadian Electrical Code (CSA C22.1:21) should be updated to have classification for NG-H_2 blends. It can either be prescribed by a fixed percentage or by an interchangeability analysis based on a fixed worst-case where a treatment needs to be determined. Current electrical code requirements, along with CSA Z662:23 (Oil and Gas Pipeline Systems), should allow existing equipment and codes to be implemented when liquid hydrogen is vapourized to gaseous hydrogen before it is injected into the natural gas distribution and transmission sites.

No specific codes or standards were found covering upgrade considerations for the equipment and systems specifically for injecting and blending hydrogen. The new edition of CSA Z662:23 (Oil and Gas Pipeline Systems), which applies to natural gas transmission and distribution pipeline systems, includes provisions for the design, materials, construction, operation, and maintenance of hydrogen and hydrogen blend pipeline systems.

The AS/NZA 4645 series (Gas Distribution Networks) does not apply to gas mixtures with hydrogen content exceeding 15 vol%. This is likely based on global research indicating minimal impacts on pipeline systems from hydrogen blending in low pressure systems, at least up to this level. For example, a study by Hodges et al. (2015) claims that blending hydrogen into the natural gas lines up to 20% by volume in low-pressure distribution gas networks and appliances was unlikely to increase the risk to end-users.[28] Similarly, this series does not address end-use equipment, which is generally considered the limiting factor for blending into low-pressure distribution networks. Certification for existing natural gas meters for blended hydrogen is another potential gap that should be considered.

[27] Dinata, R., Janzen, T., Miller, T., Korolnek, R., Finneran, S. Lee, K., Gajonera, D. (2024). *Assessment of Natural Gas Pipeline Materials for Hydrogen Service*. Canadian Standards Association, Toronto, ON.

[28] Hodges, J., Geary W., Graham S., Hooker P., and Goff R. (2015). Injecting *Hydrogen into the Gas Network–a Literature Search*. Health and Safety Laboratory, Buxton.

When it comes to transitioning NG-H_2 pipelines to 100% hydrogen pipelines, new or updated standards would be required to convert existing natural gas pipelines to hydrogen-only pipelines. For example, specifications such as the use of odorants, decontamination of existing natural gas pipelines, relining of existing pipes, material joint and component compatibility, and alternative leak detection systems need to be considered.

RELEVANT CODES AND STANDARDS FOR HYDROGEN BLENDING INTO NATURAL GAS

i. Based on a Request for Interpretation (RFI) submitted to CSA, the relevant Technical Committees agreed that NG-H_2 blends up to 5% by volume are covered by current testing for natural gas for a specific suite of gas appliances. However, this is not applicable for the entire hydrogen blend value chain.

ii. CSA Z662:23 (Oil and Gas Pipeline Systems) includes provisions for the design, materials, construction, operation, and maintenance of hydrogen and hydrogen blend pipeline systems.

iii. The Australian standard for low-pressure natural gas distribution systems (up to 1050 kPa / 152 psi), AS/NZA 4645 series (2018) (Gas Distribution Networks) covers the design, construction, operations, and maintenance of gas distribution systems and is inclusive of natural gas mixtures with up to 15 vol% hydrogen.

iv. The international standard IEC 60079-10-1:2020 (Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres), which the Canadian Electrical Code refers to, includes consideration of hazardous area classification change with hydrogen blending in natural gas.

v. The British codes governing natural gas transmission and distribution systems are being supplemented by documents to address the conveyance of blended gas mixtures and the conversion of natural gas assets to blended gas mixtures as follows:

- IGEM/TD/1 (Steel Pipelines for High Pressure Gas Transmission) covers high-pressure piping (7 bar to 100 bar) and is being supplemented by IGEM/TD/1 Edition 6 Supplement 2 to address 10 vol% hydrogen blends and higher. The standard considers anything below 10 vol% to be low risk, but this is a gap that would need to be addressed.
- IGEM/TD/3 (Steel and PE Pipelines for Gas Distribution) covers low-pressure piping (lower than 7 bar) and is being supplemented with IGEM/TD/3 Edition 5 Supplement 1 to address up to 20 vol% hydrogen blends.
- IGEM/TD/13 (Pressure Regulating Pipeline Installations Exceeding 7 Bar) covers pressure regulation installations for distribution and transmission systems and is being supplemented with IGEM/TD/13 Edition 2 Supplement 2 to address up to 20 vol% hydrogen blends with maximum operating pressures not exceeding 7 bar.

NG-H_2 Water Heaters, Furnaces & Burners, and Cooking Appliances (Elements 34a, 34b, and 34c) – *Partial gaps*

These elements include NG-H_2 blend water heaters, furnaces, and cooking appliances (e.g., residential, commercial, and industrial).[29] Though no Canadian standards exist for NG-H_2 blends (only for natural gas), North American and international standards are applicable to the general appliance case and installation requirements, which contributed to a partial gap being assigned. Existing natural gas standards may be adapted for NG-H_2 blends, and there are North American and international standards currently in development that will address these needs.

Many similar appliances for use by residential, commercial, and industrial users will need certification standards while the blended gas supply infrastructure is being established. It would be essential to assess the requirements necessary for new and existing appliances and equipment using hydrogen blends of varying percentages, considering both safety and energy efficiency performance. In terms of standardization, this would mean:

- updating existing natural gas appliance standards to include hydrogen blends or developing new standards specific to hydrogen appliances;
- maintaining efforts to harmonize with the United States and continuing to monitor progress at the international level (e.g., ISO);
- updating relevant installation codes to include coverage for hydrogen blends.

There is also a need to develop and publish a national maximum hydrogen blend threshold for existing in-service appliances. For existing in-field appliances, field approvals may be required for equipment not included within the hydrogen blend threshold. Blending is further discussed in ***Section 3.4.5***.

NG-H_2 Gas Turbines (Element 35) – *Partial gap*

Hydrogen gas turbines (Element 29a) were already covered in ***Section 3.3.2.1***, and the blended version has the same challenges. A partial gap still exists because although there are gas turbine standards, they currently do not cover hydrogen.

[29] Since there are different safety conditions associated with residential, commercial, and industrial applications, these elements may be separated and/or re-organized for future Roadmap iterations.

3.3.2.4 Vehicles Fueled by Hydrogen, NG-H_2 Blends, or Diesel-H_2 Blends (Elements 37-42, 46-50, 55-58, 72)

This section addresses various vehicles fueled by pure hydrogen or hydrogen blends and is further subdivided by on-road and off-road vehicles.

On-Road Vehicles

On-road vehicles refer to vehicles that are designed and licensed for use on public roads and highways. These include automobiles and motorcycles (i.e., light-duty vehicles) and buses and trucks (i.e., heavy-duty vehicles). ***Table 14*** summarizes the status of the gaps in on-road vehicles fueled by hydrogen, NG-H_2 blends, or diesel-H_2 blends.

Table 14: Gaps in On-Road Vehicles Fueled by Hydrogen, NG-H_2 Blends, or Diesel-H_2 Blends

Element #	Element Name	Gap	Standards-Based Option(s)
37	NG-H_2 Dispensers for Light-Duty Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)
38	NG-H_2 Dispensers for Heavy-Duty Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)
39	NG-H_2-Powered Materials Handling	Partial gap	3.3 – Reference or adopt existing international standard(s)
40	NG-H_2-Powered Light-Duty Vehicles	Partial gap	3.3 – Reference or adopt existing international standard(s)
41	NG-H_2-Powered Heavy-Duty Vehicles – Buses	Partial gap	3.3 – Reference or adopt existing international standard(s)
42	NG-H_2-Powered Heavy-Duty Vehicles – Trucks	Partial gap	3.3 – Reference or adopt existing international standard(s)
46	H_2 Light-Duty Vehicles	Partial gap	3.1 – Reference or adopt existing U.S. standard(s)
48	H_2 Heavy-Duty Vehicles – Buses	Partial gap	2 – Use as-is or update existing Canadian standard(s) (for GH_2) 6 – No immediate action; wait until technology is more mature or commercialized (for LH_2)
49	H_2 Heavy-Duty Vehicles – Trucks	Partial gap	2 – Use as-is or update existing Canadian standard(s) (for GH_2) 6 – No immediate action; wait until technology is more mature or commercialized (for LH_2)

No gap   Partial gap   Full gap   X Not assessed

Dispensers and Vehicles Using NG-H_2 Blends (Elements 37-42) – *Partial gaps*

Standards exist for natural gas-fueled vehicles and hydrogen-fueled vehicles (e.g., CSA/ANSI HGV 4.1 (Hydrogen-Dispensing Systems), CSA/ANSI NGV 4.1 (Natural Gas Vehicle Dispensing Systems), CSA/ANSI NGV 3.1 (Fuel System Components for Compressed Natural Gas Powered Vehicles), CSA/ANSI HGV 3.1 (Fuel System Components for Compressed Hydrogen Gas Powered Vehicles), CSA/ANSI HGV 2 (Compressed Hydrogen Gas Vehicle Fuel Containers), CSA/ANSI NGV 2 (Compressed Natural Gas Vehicle Fuel Containers), CSA/ANSI HPRD 1 (Thermally Activated Pressure Relief Devices for Compressed Hydrogen Vehicle (HGV) Fuel Containers), CSA/ANSI PRD 1 (Pressure Relief Devices For Natural Gas Vehicle (NGV) Fuel Containers)). However, there exists a partial gap in that there are no standards for vehicles operating on NG-H_2 blended fuel. If percentages of hydrogen in the NG-H_2 blends are lower, they may be included in the NGV standards.

In the near term, NG-H_2 blends are likely to be used in natural gas vehicles. Therefore, additional coverage relative to blends in standards such as CSA/ANSI NGV 4.1 (Natural Gas Vehicle Dispensing Systems) and CSA/ANSI NGV 3.1 (Fuel System Components for Compressed Natural Gas Powered Vehicles) should be considered.

For the transportation elements utilizing NG-H_2 blend fuels, it is recommended to:

- update existing natural gas vehicle codes and standards to include hydrogen blends based on assessment data from vehicles and refueling stations using NG-H_2 blends of varying percentages;
- maintain harmonization with the United States and continue to monitor progress at the ISO.

H_2 Light-Duty Vehicles (Element 46) – *Partial gap*

Canadian and United States bi-national standards do exist; however, they are not fully aligned with relevant ISO standards. Therefore, a partial gap exists, and continued harmonization is required.

H_2 Heavy-Duty Vehicles - Buses (Element 48) and Trucks (Element 49) – *Partial gaps*

Buses and trucks were grouped together for the gap analysis based on the definition of heavy-duty vehicles as having a gross vehicle weight rating (GVWR) greater than 3,856 kg and spanning several GVWR classes (i.e., 6, 7, and 8).

Gaseous Hydrogen

Though several North American (including U.S./Canada bi-national) and international standards exist for gaseous hydrogen buses and trucks, there is a partial gap as existing standards for hydrogen vehicles only cover the basic requirements.

CSA has created a Heavy-Duty Hydrogen Transportation Task Force to identify technical considerations for heavy-duty applications, and SAE is working on a heavy-duty fueling protocol for gaseous hydrogen. Fuel cell vehicles also use batteries to start the vehicle (low voltage) and to store regenerated energy and provide supplemental power to electric traction motor (high voltage).

There is still uncertainty as to whether hybrid gaseous hydrogen fuel cell and battery vehicles (i.e., using a battery as the main energy source and a hydrogen fuel cell to extend the range) should be treated similarly to battery electric vehicles. This needs to be clarified by standards.

In addition, larger battery packs in battery-dominant hybrids may affect standards related to fire suppression in hydrogen vehicle storage facilities, requiring different considerations from those recommended for battery electric vehicles. Currently, CSA is proceeding to update the B401 series of standards to cover fire suppression of batteries in vehicle storage/maintenance facilities (more details are discussed in Items Common to All Applications (Element 69) and Common Installation Items (Element 70)).

Liquid Hydrogen

As for liquid hydrogen vehicles, there are no Canadian standards currently available. Only two international standards are applicable: ISO 13984 (Liquid Hydrogen – Land Vehicle Fueling System Interface) and ISO 13985 (Liquid Hydrogen – Land Vehicle Fuel Tanks). These two ISO standards are currently being updated. There is also some work being done at the ISO for cryogenic applications, which would eventually include liquid hydrogen truck applications, including fueling.

Therefore, a partial gap exists when it comes to liquid hydrogen buses and trucks. As the two ISO standards for liquid hydrogen vehicles are under revision, they are not yet ready for adoption. When published, they will still need to be thoroughly assessed for suitability. Additionally, the limited sector activity related to liquid hydrogen buses and trucks in Canada suggests that it would be prudent to wait until the standards are finalized and the technology has matured further.

Recommendations for the on-road vehicle elements (e.g., all elements listed in ***Table 14***) include:

- continue to update the portfolio of hydrogen vehicle and station standards, such as CSA/ANSI HGV 3.1 (Fuel System Components for Compressed Hydrogen Gas Powered Vehicles) and CSA/ANSI HGV 2 (Compressed Hydrogen Gas Vehicle Fuel Containers) to incorporate new technologies, including vehicle maintenance facilities;
- update medium- and heavy-duty vehicle design standards for hydrogen readiness;
- continue to update the CHIC for fueling stations and dispensing equipment to keep up with emerging technologies.

Off-Road Vehicles

Off-road vehicles refer to the use of vehicles on surfaces other than traditional paved roads and highways. These vehicles are designed to navigate and operate in rough or unpaved terrain, and they are not typically intended for use on public roads. These would include material handling vehicles, air, and water transport, as well as rail. ***Table 15*** summarizes the status of the gaps in off-road vehicles fueled by hydrogen, NG-H_2 blends, or diesel-H_2 blends.

Table 15: Gaps in Off-Road Vehicles Fueled by Hydrogen, NG-H_2 Blends, or Diesel-H_2 Blends

Element #	Element Name	Gap	Standards-Based Option(s)
47	H_2 Materials Handling	Partial gap	3.1 – Reference or adopt existing U.S. standard(s)
50	Hydrail (H_2 Rail)	Partial gap	3.3 – Reference or adopt existing international standard(s)
55	H_2-Powered Ships	Partial gap	3.3 – Reference or adopt existing international standard(s)
56	H_2-Powered Aircraft	Partial gap	3.1 – Reference or adopt existing U.S. standard(s)
57	H_2-Powered Unmanned Aerial Vehicles (UAVs)	Full gap	5 – Wait for standard(s) under development to be published
58	H_2 Airport Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.3 – Reference or adopt existing international standard(s)
72	Diesel-H_2 Trucks	Partial gap	2 – Use as-is or update existing Canadian standard(s)

○ No gap ● Partial gap ● Full gap X Not assessed

H_2 Materials Handling (Element 47) and Airport Vehicles (Element 58) – *Partial gaps*

These elements cover hydrogen-fueled vehicles that handle materials for retail, storage, or ports (e.g., forklifts), as well as hydrogen-fueled vehicles at airports (e.g., airplane tugs, airplane ground power units, airport baggage handling trucks). They were grouped together due to similar size and function. There are partial gaps because although CSA has published relevant standards (e.g., HPIT 1 (Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components) and HPIT 2 (Dispensing Systems and Components for Fuelling Hydrogen Powered Industrial Trucks)), they are not NSCs.

Alignment with UL 2267 (Standard for Fuel Cell Power Systems for Installation in Industrial Electric Trucks) is recommended, along with potentially adopting IEC 62282-4-101 (Fuel Cell Technologies – Part 4-101: Fuel Cell Power Systems for Electrically Powered Industrial Trucks – Safety). CSA should also consider updating HPIT 1 (Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components) and HPIT 2 (Dispensing Systems and Components for Fuelling Hydrogen Powered Industrial Trucks) to become an NSC.

For airport vessels specifically, recommendations include:

- use heavy- and medium-duty vehicle standards for aircraft tugs, trucks, buses, and luggage handlers;
- use both heavy-duty and materials handling standards for equipment such as forklifts;
- develop standards that leverage portable power plants (e.g., ANSI/CSA FC3 (Portable Fuel Cell Power Systems) or IEC 62282-5-100 (Fuel cell technologies – Part 5-100: Portable Fuel Cell Power Systems – Safety)) as per Portable & Micro Fuel Cell Power Systems (Element 27) for ground power units.

Hydrail (H_2 Rail) (Element 50) – *Partial gap*

Hydrogen rail activities in Canada are on the rise, including demonstration projects by Alstom and by the University of British Columbia as well as Canadian Pacific's (CPKC) Hydrogen Locomotive Program.[30,31,32]

There is currently a partial gap in Canadian standards that cover all aspects of liquid hydrogen, gaseous hydrogen, passenger, and freight trains, including switcher locomotives. To address this, IEC 63341-1 (Railway Applications – Rolling Stock – Fuel Cell Systems for Propulsion – Part 1: Fuel Cell Power System), IEC 63341-2 (Railway Applications – Rolling Stock – Fuel Cell Systems for Propulsion – Part 2), and IEC 63341-3 (Railway Applications – Rolling Stock – Part 3 – Fuel Cells for Propulsion – Performance Test Methods) should be adopted once they are ready. Since developing standards can be time-consuming, CSA has published technical specification CSA TS-602 (Railway Applications – Rolling Stock – Onboard Lithium-ion Traction Batteries) and is working on technical specification CSA SPE-601 (Hydrogen Fuel Cell Power Systems for Locomotives) as interim solutions to bridge this gap.

As for liquid hydrogen trains specifically, standards need to be developed for the liquid hydrogen storage and vapourizer aspects of rail. Parts of the standards for similar liquid hydrogen equipment were identified and may be used or referenced.

Additional recommendations for hydrogen rail include:

- address gaps on risk assessment of hydrogen and battery power in locomotives identified in Transport Canada's report *Risk Assessment of Hydrogen and Battery Power in Locomotives – Part 3 – Codes and Standards Review*;[33]
- address gaps identified in CSA's research titled *Advancing the Use of Hydrogen and Electrification in the Rail Industry*, which identifies standards gaps related to hydrogen fuel cell and battery

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[30] Alstom (2023). *Alstom concludes the successful demonstration of the first commercial service hydrogen-powered train in North America*. Retrieved from https://www.alstom.com/press-releases-news/2023/10/alstom-concludes-successful-demonstration-first-commercial-service-hydrogen-powered-train-north-america

[31] The University of British Columbia. *Sustainable & Zero-Emission Rail Technology*. Retrieved from https://sustainablecommunities.ok.ubc.ca/research/sustainable-zero-emissionrail-technology/

[32] CPKC (2021). *Canadian Pacific expands Hydrogen Locomotive Program to include additional locomotives, fueling stations with Emissions Reduction Alberta grant*. Retrieved from https://investor.cpkcr.com/news/press-release-details/2021/Canadian-Pacific-expands-Hydrogen-Locomotive-Program-to-include-additional-locomotives-fueling-stations-with-Emissions-Reduction-Alberta-grant/default.aspx

[33] Transport Canada. *Risk Assessment of Hydrogen and Battery Power in Locomotives – Part 3 – Codes and Standards Review.* Retrieved from https://tc.canada.ca/en/innovation-centre/priority-reports/risk-assessment-hydrogen-battery-power-locomotives-part-3-codes-standards-review

rolling stock technology implementation and related fueling and charging considerations;[34]

- continue to develop requirements for rolling stock propulsion and associated refueling and recharging infrastructure, based on current CSA activities;
- monitor ISO TC 197 SC 1/IEC TC 9 activities for possible adoptions.

H_2 Powered Ships (Element 55) – *Partial gap*

There is a partial gap because relevant international standards exist. Lloyd's Register issued the first rules for hydrogen for use as a fuel on vessels, and Bureau Veritas has rules for hydrogen-fueled ships.[35] It is also recommended to evaluate the applicability of standards from similar industries to marine applications, particularly refueling infrastructure and applications that do not operate in international waters.

H_2-Powered Aircraft (Element 56) – *Partial gap* and Unmanned Aerial Vehicles (UAVs) (Element 57) – *Full gap*

For hydrogen-powered aircraft, standards from similar industries to aviation applications (e.g., airport support equipment and small conventional aircraft) may be applicable. However, further evaluation is required. This contributed to a partial gap being assigned.

For UAVs, also known as drones, ASTM WK60937 (Design of Fuel Cells for Use in Unmanned Aircraft Systems) is currently in development, which outlines specifications for the use of fuel cell power generating systems for application in UAVs. However, this standard will likely need additional safety requirements for the aerospace industry. As such, a full gap was assigned.

Standards to consider for aircraft and UAV applicability include CSA/ANSI HGV 3.1 (Fuel System Components for Compressed Hydrogen Gas Powered Vehicles), CSA/ANSI HGV 2 (Compressed Hydrogen Gas Vehicle Fuel Containers), and CSA HPIT 1 (Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components). For both manned and unmanned aerial vehicles, current Federal Aviation Administration safety directives are likely to be consulted for hydrogen codes and standards.

Diesel-H_2 Trucks (Element 72) – *Partial gap*

Diesel-H_2 mix trucks are vehicles (both on and off-road) that use a blend of diesel and hydrogen as fuel for ICEs. This dual-fuel technology is typically retrofit onto an existing vehicle, with the aim of reducing GHG emissions and fuel consumption, while maintaining the performance and reliability of conventional diesel trucks.

This technology has major gaps in codes and standards. No Canadian codes and standards address the design, installation, inspection, and repair requirements for these vehicles, though existing CSA hydrogen standards largely cover the component requirements, which contributed to the partial gap assigned. There is also ambiguity surrounding the approval process among AHJs in Canada, who may lack expertise in hydrogen mobility applications.

The recommended course of action is to develop a new standard modeled off the existing Canadian natural gas vehicle standards CSA B109 (Compressed Natural Gas Vehicle Installation Code) and CSA/ANSI NGV 6.1 (Compressed Natural Gas (CNG) Fuel Storage and Delivery Systems for Road Vehicles).

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[34] Hegazi, M., Wong, D., Aitken, H., Hoffrichter, A. (2024). *Advancing the Use of Hydrogen and Electrification in the Rail Industry.* Canadian Standards Association, Toronto, ON.

[35] Hydrogen Central (2023). *Lloyd's Register Issues World's First Rules For Hydrogen Fuel.* Retrieved from https://hydrogen-central.com/lloyds-register-issues-worlds-first-rules-hydrogen-fuel/

3.3.2.5 Hydrogen Dispensing (Elements 43-45, 51-54)

Hydrogen dispensing refers to the process of providing hydrogen fuel to vehicles that use hydrogen as a source of energy. This typically involves specialized infrastructure and equipment designed to store, deliver, and dispense hydrogen to end-users. ***Table 16*** summarizes the status of the gaps in hydrogen dispensing.

Table 16: Gaps in Hydrogen Dispensing

Element #	Element Name	Gap	Standards-Based Option(s)
43	H_2 Dispensers for Light-Duty Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)
44	H_2 Dispensers for Heavy-Duty Vehicles	Partial gap	3.1 – Reference or adopt existing U.S. standard(s) 5 – Wait for standard(s) under development to be published
45	H_2 Dispensers for Rail	Partial gap	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 5 – Wait for standard(s) under development to be published
51	H_2 Dispensers for Ships	Partial gap	2 – Use as-is or update existing Canadian standard(s)
52	H_2 Dispensers for Aircraft	Partial gap	2 – Use as-is or update existing Canadian standard(s)
53	H_2 Dispensers for UAVs	Partial gap	2 – Use as-is or update existing Canadian standard(s)
54	H_2 Dispensers for Airport Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)

○ No gap ● Partial gap ● Full gap **X** Not assessed

H_2 Dispensers for Light-Duty Vehicles (Element 43) – *Partial gap*

Though there is a general codes and standards framework for dispensing, additional guidance may be needed with respect to safety management of hydrogen fueling stations in public areas. Standardization in this area would be helpful for a national installation process.

As an example, the CHIC mandates that certain components are designed to withstand ambient temperatures as low as -40°C. However, in United States/international standards (e.g., NFPA 2 (Hydrogen Technologies Code)), the temperature design condition is only -20°C. This results in difficulties for non-Canadian vendors, who adhere to the United States/European standards, in supplying their equipment to Canadian projects since their products may not meet Canadian design requirements. It can also cause an economic disadvantage for Canadian producers since production costs will be higher to meet the more stringent design requirement, even if their consumer base is predominantly outside Canada. Having the option for a consistent design condition could be one way to allow vendors to streamline equipment importation and reduce costs.

Additionally, considering the regional variations in Canada, it may be necessary to consider allowing more flexibility in the ambient temperature prerequisite without compromising safety. To achieve this, conducting an engineering assessment in a case-by-case basis would provide better guidance on acceptable ambient temperatures for different regions. Therefore, there is a partial gap regarding this element because the CHIC may need revision.

H_2 Dispensers for Heavy-Duty Vehicle (Element 44) – *Partial gap*

Heavy-duty dispensing is not adequately covered by Canadian standards. There is a lack of Canadian standards that address higher hydrogen flows required for timely refueling of medium- and heavy-duty vehicles. Though not an NSC, SAE J2601-5 (High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles), which was published in February 2023, is applicable. CSA will be developing a bi-national standard to test systems to the SAE standard, as it is expected that it will be used in Canada.

It is recommended that North American liquid hydrogen dispensing standards be developed and harmonized with ISO/WD 13984 (Liquid Hydrogen Land Vehicle Fueling Protocol), which is currently under development. Mobile fueling will be covered by CSA/ANSI HGV 5.3 (Mobile and Portable Refueling Units), which is currently under development.[36] As such, a partial gap was given.

H_2 Dispensers for Rail, Ships, and Aircraft (Elements 45, 51, and 52) – *Partial gaps*

The gaps described for H_2 Dispensers for Heavy-Duty Vehicles (Element 44) extend to rail, ships, and aircraft because they also require high flow rates. For ships and aircraft, the existing North American dispensing (or upcoming ISO) standards should be modified or used as a basis to develop standards for hydrogen dispensing. So, there is a partial gap.

H_2 Dispensers for UAVs (Element 53) – *Partial gap*

There is a need to further assess the applicability of existing standards for UAV dispensing. There is a partial gap because even though there are many related standards on dispenser components and fueling protocols, none are specific to dispensing hydrogen to hydrogen-powered UAVs. The size variation in UAVs requires different on-board fuel storage requirements, which in turn affect the fuel dispensing specifications. Depending on dispensing needs, CSA HPIT 2 (Dispensing Systems and Components for Fuelling Hydrogen Powered Industrial Trucks) or CSA/ANSI HGV 4.1 (Hydrogen-Dispensing Systems), which mostly refers to light-duty currently, might be applicable. An update to existing standards, in this case, CSA/ANSI HGV 4.1, could help fill the standards gap for this element.

H_2 Dispensers for Airport Vehicles (Element 54) – *Partial gap*

Similar to UAVs, airport vehicles can vary by size, which means there may be different fuel dispensing requirements. It is unclear how relevant existing dispensing standards (e.g., CSA HPIT 2 (Dispensing Systems and Components for Fuelling Hydrogen Powered Industrial Trucks) and CSA/ANSI HGV 4.1 (Hydrogen-Dispensing Systems)) would apply, and therefore a partial gap exists. There is a larger gap for liquid hydrogen because dispensing standards are not currently available.

[36] Standards Council of Canada. *Transportable hydrogen refuelling units.* Retrieved from https://scc-ccn.ca/standards/notices-of-intent/csa-group/mobile-and-portable-hydrogen-refuelling-units-mruh-pruh

3.3.2.6 Mining Operations and Industrial Use (Elements 59-68)

Hydrogen offers a chance to significantly lower emissions in mining and industrial operations.

Mining Operations

Table 17 summarizes the status of the gaps in mining operations. Elements 27–32 also have implications within mining operations (refer to ***Section 3.3.2.1*** and ***Section 3.3.2.2***).

Table 17: Gaps in Mining Operations

Element #	Element Name	Gap	Standards-Based Option(s)
59	H_2 Dispensers for Surface Mining Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)
60	GH_2 Dispensers for Underground Mining Vehicles	Partial gap	2 – Use as-is or update existing Canadian standard(s)
61	H_2 Heavy-Duty Surface Mining Equipment	Partial gap	2 – Use as-is or update existing Canadian standard(s)
62	H_2 Heavy-Duty Underground Mining Equipment	Partial gap	2 – Use as-is or update existing Canadian standard(s)
63	H_2 Heating & Ventilation Systems for Underground Mining	Partial gap	2 – Use as-is or update existing Canadian standard(s)

○ No gap ● Partial gap ● Full gap X Not assessed

H_2 Dispensers for Surface Mining Vehicles (Element 59) and GH_2 Dispensers for Underground Mining Vehicles (Element 60) – *Partial gaps*

Fuel dispensing systems in mining operations differ between surface and underground. Codes and standards of hydrogen dispensing systems for surface mining operations follows all other industries to fuel heavy-duty equipment. However, dispensing systems in underground mining operations have unique hazards that are not currently addressed by existing codes and standards (e.g., confined space).

Many codes and standards are available on a component level for dispensing systems of light-duty equipment in Canada (largely the CSA HGV series), the United States, Germany, and internationally. But there are also standards gaps, which contributed to the element being assigned a partial gap.

Specific gaps in dispensing include:

- a fast, high-pressure fueling system for large on-board tanks in heavy-duty mobile equipment;
- a built-in system to manage heat efficiently during rapid fueling, reducing the time for refueling;
- a unique sealant system and design for all mechanical connections in the dispenser to prevent continuous small hydrogen leaks in underground applications;
- ventilation system requirements to address hydrogen leaks;
- safe hydrogen distribution from surface to underground.

The existing Canadian standards (largely the CSA's HGV series of standards) currently cover on-road vehicles but could be modified or used as a basis to develop standards for hydrogen dispensing systems for heavy-duty and off-road vehicles. The same applies for relevant ISO standards.

It is recommended to evaluate the applicability of standards from similar industries to mining applications. For underground dispensing, an expansion on existing codes and standards is needed, or standards from similar industries need to be assessed to better understand their applicability to the mining operations, with an emphasis on dispensing in a confined environment (i.e., underground).

IMPACT OF DISPENSING SYSTEM ON OPERATIONAL EFFICIENCY

Heavy-duty mobile mining equipment requires a significant amount of hydrogen gas for operation. The dispensing system's impact on mining productivity is crucial, with a need for short refueling times to prevent equipment unavailability. Current technology allows for a fueling rate of 1 to 8 kg per minute, but this is insufficient for quickly filling large hydrogen tanks. Special dispensing systems for off-road heavy-duty mobile equipment refueling stations are not urgently needed, as technology for light-duty equipment is already available. The priority is the development and adoption of hydrogen-driven mobile equipment in mining operations, which has codes and standards implications.

H_2 Heavy-Duty Surface and Underground Mining Equipment (Elements 61 and 62) – *Partial gaps*

Codes and standards for designing hydrogen powered off-road and heavy-duty mobile equipment align with those of similar manufacturing industries. In underground mining, safety challenges arise from hydrogen use in confined spaces, compounded by limited vehicle space for gas storage. Liquid hydrogen fuel is a potential solution, but its feasibility, especially in underground mining, requires further assessment.

Standards for designing hydrogen vehicle components are available in Canada and globally. As fuel cell electric vehicles (FCEVs) are designed in a hybrid format, incorporating both fuel cells and a significant battery, relevant codes and standards from battery electric vehicles apply.

MINING VEHICLES: CURRENT STATE OF THE ART

The use of hydrogen-powered heavy-duty mobile equipment in mining is being studied, considering its suitability for surface or underground mining. Mining production vehicles are major sources of GHG emissions in mining operations. Comparisons between fuel FCEVs and hydrogen ICE vehicles reveal pros and cons for mining activities. These vehicles must operate autonomously during shifts and handle peaks in power demand. While a 350-ton FCEV truck is at the demonstration level, hydrogen ICE is still in development. On-road heavy-duty vehicles have been successfully demonstrated, providing insights for potential off-road and mining applications.

Gaps for surface and underground mining vehicles (ICE or fuel cell) include:

- a lack of standards addressing risk of using liquid hydrogen, requiring further investigation with respect to mining activities and environment;
- a lack of standards for hydrogen ICEs for off-road and heavy-duty vehicles;
- the development and assessment of emission control and ventilation requirements for hydrogen-driven mining vehicles, along with the establishment of a certification procedure.

Standards need to be developed for the liquid hydrogen storage and vapourizer aspects for on-board vehicle storage. Parts of the standards for similar liquid hydrogen equipment may be used or referenced. Codes and standards related to hydrogen ICE on mobile equipment should be developed.

H_2 Heating & Ventilation Systems for Underground Mining (Element 63) – *Partial gap*

For underground mine ventilation in cold seasons, it is essential to heat the intake air slightly above freezing to prevent freezing and ice formation in the mine's infrastructure. Traditionally, the underground mining industry has used natural gas, propane, or diesel for indirect heating of the intake air. While there are relevant codes and standards for similar applications, they do not cover mining ventilation heating systems fueled by hydrogen or NG-H_2 blends, which is why a partial gap was assigned.

The impact of NG-H_2 blending on existing equipment installations and infrastructure in underground mining is high, and mining operations must have proper understanding of the implications.

The ventilation heating system's burner releases emissions into the underground air as it is in-line with the air flow. Burning an NG-H_2 blend introduces additional nitrogen oxides into the underground air.

Gaps related to ventilation systems in underground mining include:

- confirming the safety and performance of current burners when using a NG-H_2 blend;
- defining required ventilation flow rates, particularly when the hydrogen blend exceeds 20% (e.g., up to 100%);
- defining emissions control limits for mining activities.

Relevant parts of standards for heating technologies using a NG-H_2 blend apply. Further study, testing, and demonstrations are needed for the development of related standards.

Industrial Use

Industry sectors reviewed as part of this Roadmap include chemical production, fertilizers, synthetic fuels, steel, and cement. ***Table 18*** summarizes the status of the gaps in industrial. Hydrogen gas-burning appliances (Elements 30–32) also have implications within this group (refer to ***Section 3.3.2.2***) as large size boilers or burners may be used for industrial applications as well.

Table 18: Gaps in Industrial Use

Element #	Element Name	Gap	Standards-Based Option(s)
64	Chemical Production	Partial gap	2 – Use as-is or update existing Canadian standard(s)
65	Fertilizers	No gap	1 – No immediate action; periodically update existing Canadian standard(s)
66	Synthetic Fuels	Partial gap	2 – Use as-is or update existing Canadian standard(s) 5 – Wait for standard(s) under development to be published
67	Steel Production	Partial gap	2 – Use as-is or update existing Canadian standard(s) 3.1 – Reference or adopt existing U.S. standard(s) 3.2 – Reference or adopt existing regional standard(s)
68	Cement Plants	Partial gap	2 – Use as-is or update existing Canadian standard(s)

No gap   Partial gap   Full gap   X Not assessed

Chemical Production (Element 64) – *Partial gap* and Fertilizers (Element 65) – *No gap*

Hydrogen is currently used as a feedstock to produce chemicals (e.g., methanol). Syngas, which is a combination of hydrogen and carbon monoxide, may also be used in various industrial processes to produce amines, cycloalkanes, hydrogen peroxide, higher alcohols, and aldehydes. However, the chemical production industry can start using hydrogen as a fuel source to lower their GHG emissions. A partial gap was assigned because relevant Canadian standards exist, but they may need to be modified.

Fertilizer production also relies heavily on hydrogen as a feedstock or precursor. No gap was assigned because the industry is well established and existing codes and standards are in place and adequate.[37] However, it is recommended that the AHJs continue to monitor and issue addenda if gaps are identified.

Synthetic Fuels (Element 66) – *Partial gap*

Synthetic fuels (e.g., synthetic gasoline or diesel) can be made by capturing carbon dioxide and combining it with hydrogen. Canadian standards do exist for this element but may require some updates, which contributed to the assignment of a partial gap. For example, they do not cover formic acid technology, which may be required in the future. CSA Z21.106 (Hydrogen-Fueled Appliances and Related Accessories) is in development and may become relevant for hydrogen use in synthetic fuel plants in the future.

[37] Due to its maturity, fertilizer production was out of scope of the environmental scan.

Steel Production (Element 67) – *Partial gap*

Steel is made from iron ore and other raw materials through the following steps:

- Make iron from iron ore.
- Produce the steel, either by basic oxygen steelmaking or electric arc furnace methods.
- Cast, form, and finish.

There are steel production plants in Canada in operation and being developed. Some of the steel processes, which require hydrogen, have existed for almost a century and are mature. Canadian standards cover some aspects, but the burners are covered by NFPA standards.

Direct reduction of iron (DRI) is a process that removes oxygen from the iron ore to make iron. This process uses hydrogen and carbon monoxide. A DRI production facility has been safely operating in Canada for 50 years, suggesting that necessary codes and standards under which it is operating are sufficient and in place. However, existing DRI facilities use natural gas which is reformed to produce hydrogen and carbon monoxide to complete the DRI. Future developments will seek to feed hydrogen directly into the DRI and will require modification to the process, which may require codes and standards development. When hydrogen is used to produce steel, it must be ensured that the steel complies with the quality standard.

Hydrogen can offer a dual benefit for steel production and can serve as both a viable zero-emission fuel source for electric arc furnaces, as well as a substitute for coal in the reduction reaction. The codes and standards for building and operating such systems are proven and well understood by both regulators and industry. No new codes or standards are required. The processes to modify natural gas heaters (for some steel making processes) to hydrogen is well understood and the equipment necessary is widely used in oil refineries and commercially available. The codes and standards necessary to switch to hydrogen-based combustion already exist and are well understood.

For these reasons, a partial gap was given. Recommendations for steel production include:

- adopt United States standards governing the DRI equipment;
- examine the regulations that govern operating DRI facilities to see if they can be adapted to other applications;
- address approvals for hydrogen-air and hydrogen-oxygen burner retrofits;
- adopt NFPA 86C (Industrial Furnaces Using a Special Processing Atmosphere) and NFPA 86D (Industrial Furnaces Using Vacuum as an Atmosphere) as Canadian standards.

Cement Plants (Element 68) – *Partial gap*

Although relevant Canadian standards exist for fuel used in industrial plants, none address the blending or direct use of hydrogen in cement plant operations, which is why this element has a partial gap. A study conducted in the UK in 2019 explored the challenges and gaps associated with NG-H_2 blending in cement kiln operations to reduce emissions.[38] Since most GHG emissions are not from fuel use, using hydrogen, either as a blend or as direct use, will have limited GHG reduction benefits.

Common safety and technical concerns in industrial NG-H_2 blending or hydrogen direct use applications, such as flame properties control, burner systems, and leak/hazard detection, are relevant to cement facilities.

[38] Mineral Products Association, Cinar Ltd, VDZ gGmbH (2019). *Options for switching UK cement production sites to near zero CO_2 emission fuel: Technical and financial feasibility.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866365/Phase_2_-_MPA_-_Cement_Production_Fuel_Switching.pdf

3.3.2.7 Items Common to All Applications and Common Installation Items (Elements 69, 70)

Items common to all applications are necessary to address risks unique to hydrogen, such as low-emission energy and hydrogen leakage. Common installation items refer to codes that provide the framework to safely install equipment such as natural gas, electrical, plumbing – and most notably, hydrogen.

Due to the scope and detailed nature of these elements, which would require a separate inquiry, they were not assessed, as shown in ***Table 19***. Nonetheless, existing standards for hydrogen equipment do encompass most of these items. End-use applications and technologies are developing rapidly in the hydrogen space, and therefore continued stakeholder engagement is required to keep pace with industry and ensure that standardization addresses market needs.

For these elements, a few observations are shared for consideration.

Element 69: Items Common to All Applications

i. General hydrogen standards
ii. Static electricity
iii. Hydrogen quality
iv. Hydrogen material compatibility
v. Components (e.g., sensors, enclosures, air compressors, hydrogen compressors, gas valve trains, control equipment)
vi. Functional safety
vii. Programmable controls
viii. Electromagnetic compatibility
ix. Material properties and fire ratings
x. Risk assessments
xi. Personnel qualification and training
xii. Refurbishment, disposal, and recycling

Element 70: Common Installation Items

i. Installation codes
ii. Area classification and equipment standards for use in classified areas
iii. Hydrogen venting
iv. Fire alarm systems
v. Protection against lightning
vi. Emergency response

Table 19: Gaps in Items Common to All Applications and Common Installation Items

Element #	Element Name	Gap	Standards-Based Option(s)
69	Items Common to All Applications	X	
70	Common Installation Items	X	

○ No gap ● Partial gap ● Full gap X Not assessed

Items Common to All Applications (Element 69) – *Not assessed*

Area Classification: Minimizing the Risk of Installation Errors

The area classification section of the CHIC refers to IEC 60079-10-1 (Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres), which deals with classifying areas where there may be flammable gas or vapour hazards, including hybrid mixtures and flammable mists. IEC 60079-10-1 applies when there is a risk of ignition due to the presence of flammable hazards and provides guidelines for designing, constructing, operating, and maintaining equipment in such areas. IEC 60079-10-1 uses a complex methodology, which may lead to unsafe installations if not calculated properly.

Installation error risk could be diminished by enhancing the CHIC with more prescriptive guidance in the area classification methodology, and therefore reducing reliance on the complex IEC 60079-10-1 method. The IEC 60079-10-1 standard can still be used to complement the CHIC in situations where the CHIC's prescriptive method is not applicable or not practical.

Static Electricity

NFPA 77 (Recommended Practice on Static Electricity) is being used in Canada, and it addresses the hazard of static electricity.

Common Installation Items (Element 70) – *Not assessed*

Hydrogen Dispensing Proximity to Other Fuel Sources and Residential Areas

Knowledge gaps exist in relation to hydrogen dispensing near other fuel dispensers in public gas stations. Additionally, safety distances between hydrogen refueling stations and residential zones are still unclear. This is an area where multiple standards from various sectors may need to be harmonized.

Maintenance Facilities for Hybrid Vehicles

Currently, CSA is updating the B401 series of standards to include hydrogen vehicle and battery electric and hybrid facilities. CSA is proceeding to develop CSA B401.3 (Hydrogen Vehicle and Trailer Maintenance Facilities Code) as an NSC.[39] This standard aims to offer Canadian code guidelines for sections within a vehicle maintenance facility dedicated to the maintenance, repair, or storage of hydrogen-fueled vehicles, hydrogen tube trailers, and tenders. Additionally, it addresses ancillary areas and systems.

Similarly, CSA is proceeding to develop CSA B401.4 (Battery Electric Vehicle Maintenance Facility Code) as an NSC.[40] This code will outline the necessary requirements and suggestions for maintenance facilities for battery electric and hybrid vehicles, encompassing depot and support facilities. These facilities are used for parking, maintaining, repairing, or storing battery electric and hybrid fleet vehicles, and include related systems and areas. CSA B401.4 will address aspects such as electric shock/arc flash control, facility fire detection and suppression, deflagration, and emergency response. It will also make references to existing standards concerning fire suppression and battery storage/handling.

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[39] Standards Council of Canada. *Hydrogen vehicle and trailer maintenance facilities code.* Retrieved from https://scc-ccn.ca/standards/notices-of-intent/csa-group/hydrogen-vehicle-and-trailer-maintenance-facilities-code

[40] Standards Council of Canada. *Battery Electric Vehicle Maintenance Facility Code.* Retrieved from https://scc-ccn.ca/standards/notices-of-intent/csa-group/battery-electric-vehicle-maintenance-facility-code

In the meantime, the CHIC has provisions for repair garages and maintenance facilities for compressed hydrogen-fueled light-duty vehicles. It also references CSA B401.1 (Natural Gas Vehicle (NGV) Maintenance Facilities Code) for vehicles that store more than 1 kg of hydrogen. CSA B401.1 is effectively being used for motor vehicle maintenance facilities where natural gas vehicles are maintained, repaired, or stored. Some of these requirements could also be adapted for hydrogen buses maintenance facilities, while considering that there would be larger quantities of stored hydrogen.

Building Codes for Vehicle Facilities

Building codes pertaining to vehicle storage facilities, particularly those handling gaseous and liquid hydrogen, present uncertainties in two key aspects:

- Mixing of vehicle types: There is ambiguity regarding the acceptability of mixing various vehicle types (e.g., diesel, compressed natural gas (CNG), battery electric, hydrogen fuel cell) within the same area. The codes do not provide clear guidance on whether these vehicles can coexist in shared spaces or if they should be placed in separate areas or buildings.
- Limitations on vehicle numbers: The lack of clarity extends to limitations on the number of vehicles allowed in the same storage area, and whether there should be limits on the number of vehicles within a given space.

These uncertainties highlight the need for clearer guidelines in building and fire codes for effective and safe management of vehicle storage facilities dealing with gaseous and liquid hydrogen.

Fire Wall Standards for Vehicle Facilities

There is uncertainty regarding the adequacy of current building fire wall standards for new hydrogen vehicles, including those with very large batteries. Clarity on facility requirements in the Canadian Fire Code as well as the International Fire Code (IFC) is required for the following:

- Differences between major versus minor repairs
  - Unlike the National Fire Protection Association (NFPA), the IFC lacks clarity on major and minor facility requirements, which leads to ambiguity on defueling requirements for minor service activities (e.g., fluid checks and top-ups) in storage facilities.
  - There is also a lack of national adoption for the CHIC, with similar contradictions as the IFC, which leads to uncertainty on issues such as major versus minor repair garages.
- Potential conflicts or misalignment between building and fire codes

3.3.2.8 Oil and Gas (Element 71)

Table 20 summarizes that hydrogen use in the oil and gas industry has a partial standardization gap. Since the oil and gas industry can employ hydrogen in a variety of ways, several other elements are implicated. Examples include the following:

- Heavy-duty trucks, which relates to
  - H_2 Heavy-Duty Surface Mining Equipment (Element 61)
- Local power generation, which relates to
  - Portable & Micro Fuel Cell Power Systems (Element 27)
  - Stationary Fuel Cell Power Systems (Element 28)
  - H_2 Gas ICEs (Element 29b)
- Gas-burning appliances for steam creation, which relates to[41]
  - GH_2 Boilers & Water Heaters (Element 30)
  - GH_2 Furnaces & Burners (Element 31)
- Mining, which relates to[42]
  - H_2 Dispensers for Surface Mining Vehicles (Element 59)
  - GH_2 Dispensers for Underground Mining Vehicles (Element 60)
  - H_2 Heavy-Duty Surface Mining Equipment (Element 61)
  - H_2 Heavy-Duty Underground Mining Equipment (Element 62)

Table 20: Gaps in Oil and Gas

Element #	Element Name	Gap	Standards-Based Option(s)
71	Oil & Gas	● (Partial gap)	3.1 – Reference or adopt existing U.S. standard(s)

○ No gap ● Partial gap ● Full gap X Not assessed

Oil & Gas (Element 71) – *Partial gap*

There are no Canadian standards for this element. However, several United States standards may be applicable (e.g., CSA/ANSI FC 5:21 (Hydrogen Generators Using Fuel Processing Technologies – Part 1: Safety), CGA H-10 (Combustion Safety for Steam Reformer Operation), CGA H-11 (Safe Startup and Shutdown Practices for Steam Reformers), CGA H-12 (Mechanical Integrity of Syngas Outlet Systems)). International standards also exist for similar industries (e.g., ISO 16110-1 (Hydrogen Generators Using Fuel Processing Technologies – Part 1: Safety), ISO 16110-2 (Hydrogen Generators Using Fuel Processing Technologies – Part 2: Test Methods for Performance), ISO 26142 (Hydrogen Detection Apparatus – Stationary Applications), ICS Code 75.200 Standards (Petroleum Products and Natural Gas Handling Equipment)). Therefore, a partial gap was assigned. The suggestion is to align with a United States standard or create a bi-national standard (U.S./Canada).

[41] Conventional production can use hydrogen to replace natural gas, particularly in generating steam to heat the oil (i.e., lowering its viscosity) so that it can be more easily transported.

[42] Ex-situ oil sands mining includes the removal and transportation of sand by heavy-duty trucks, whereas in-situ mining uses steam-assisted gravity drainage (SAGD).

As hydrogen codes and standards work continues in the oil and gas industry, it may be useful to further delineate specific sub-sectors and/or sub-elements to account for unique circumstances across this diverse and large industry. For example, there are differences between onshore and offshore oil and gas production due to space constraints, differences between marine and terrestrial environments, and delivery considerations (e.g., third-party services provided by marine vessels and trucks).

3.4 Cross-Cutting Issues

Throughout the gap analysis, several issues were raised by the CSWG members that affect multiple, if not all, of the 72 elements in the hydrogen value chain. As these issues cut across the value chain segments, they were explored at a high level. While they are discussed broadly, they remain significant. It is recommended that these issues are integrated in subsequent gap analysis and prioritization exercises.

3.4.1 Collaboration and Harmonization

Regardless of the area of the value chain or industry, a significant opportunity to support rapid deployment of hydrogen is the harmonization of standards across Canada, with the United States for bi-national standards, and internationally by leveraging trade agreements. For example, water electrolysis equipment may be sourced from outside Canada, so it is important that there is a unified approach to testing and certification of imported equipment, which may include methods to estimate its performance and efficiency. The import and export of hydrogen itself represents another example, where the alignment of standards (e.g., the definition of an empty tank) will reduce economic and technical barriers when crossing borders.

Using existing standards, where possible, is also critical to accelerate the timeline to have standards in place. This means using standards developed for other industries and regions. Within Canada, SDOs are well placed to lead this effort in collaboration with industry and regulatory bodies.

3.4.2 Safety, Awareness, and Public Acceptance

Regardless of the application area or technology, safety needs must be entrenched in regulations, codes, standards, guidelines, and permits. It is an important aspect that is common to all elements in the hydrogen value chain. Furthermore, safety concerns have been identified as one of the highest obstacles to wide-scale adoption of hydrogen in our economy, especially in handling hydrogen, mostly due to inexperience. One of the approaches to prevent incidents is the use of modelling to generate data that can be employed in codes and standards development. Best practices from successful deployment cases can also be replicated.

It is important to bring together government, industry associations, utility companies, equipment manufacturers, and regulators to harmonize the development and understanding of the gaps in the hydrogen safety standards.

Safety is also linked to public awareness of the risks associated with hydrogen and mitigation approaches. The public should be reassured that:

- every aspect related to the production, delivery, and use of hydrogen is thoroughly tested prior to deployment;
- operations are within acceptable safety limits.

Hydrogen is a different fuel than what people are used to, but with the proper safety precautions, its safe use can be ensured. With increased awareness comes public acceptance.

Pan-Canadian codes and standards harmonization should be supported through multi-stakeholder engagement initiatives. These activities will promote consistent safety processes implemented in all jurisdictions and allow the public to become familiar with the handling and use of hydrogen and hydrogen systems.

3.4.3 Education and Training

The success of hydrogen deployment hinges on preparing the workforce and bridging skill gaps.

Preparing the Workforce

Closely linked to public safety, an imminent challenge is the need to prepare a skilled workforce with the knowledge and training to produce, handle, and use hydrogen safely and effectively. Many of the core technical occupations and capabilities required by the hydrogen economy are already found within Canada's labour market, notably expertise in the following:

- Water electrolysis to produce clean hydrogen and derivatives (i.e., ammonia)
- CCUS, which is required to produce low-carbon hydrogen from fossil fuels

Canada also has a thriving fuel cell development and manufacturing sub-sector.

Bridging Skill Gaps

Pan-Canadian organization Transition Accelerator has contributed a workforce assessment tool identifying the core occupations, capabilities, and potential risks associated with expansion of the hydrogen economy's labour market.[43] Skilled labour shortages are anticipated for occupations including engineering and geoscience professionals, technicians, and inspectors trained to work with fuel cell vehicles, and for jobs in sectors using hydrogen as an industrial feedstock. All these fields would require knowledge and application of regulations, codes, and standards.

Emerging skills gaps and re-skilling needs can be effectively addressed using innovative approaches such as micro-credentials, bootcamps, and work-integrated learning. All these can incorporate specialized training on codes and standards.

LACK OF RECOGNIZED HYDROGEN SAFETY COURSES AND SPECIAL CERTIFICATES

Example from a CSWG member: Staff working on hydrogen appliances need to have taken a hydrogen safety course, need to be experienced working with hydrogen, and need to have gas fitter certification. However, most staff with years of experience working with high-pressure compressed natural gas (CNG) are not necessarily certified to work with CNG. Despite CNG experience, they would not be qualified to assemble and work on hydrogen equipment. Companies must hire a certified gas fitter to oversee the assembly and work, but most gas fitters are not experienced with hydrogen. There is also currently no mechanism for experienced high-pressure CNG technicians to be issued a special certificate to work on hydrogen appliances. A similar hydrogen safety course recognized by a regulatory agency is needed, and a special certificate that can be issued to experienced CNG workers to work on hydrogen appliances should be created. Other courses on standards related to hydrogen must be prioritized to assist staff in achieving the necessary qualification to safely operate and inspect hydrogen systems and infrastructure.

Stakeholders, including governments, industry, and academia, will need to collaborate to provide accessible training and safety certifications tailored to specific skills requirements. Harmonizing guidance with international standards is crucial. Canadian educational institutions play a vital role in raising awareness and recruiting young workers for hydrogen deployment hubs. Collaboration with equipment manufacturers and SDOs creates new training opportunities. These efforts aim to address risks from uneven standards implementation and the shortage of diverse, qualified talent.

[43] The Transition Accelerator (2022). *Workforce Requirements for Advancing a Hydrogen Economy.* Retrieved from https://transitionaccelerator.ca/wp-content/uploads/2023/05/TA_H2-Workforce-Requirements-Assessment-Tool_FINAL-1.pdf

3.4.4 Carbon Intensity and Certification

Clean hydrogen has the potential to play a key role in helping Canada achieve its net-zero carbon goals. The COP28 pact highlights the need to accelerate the deployment of low-carbon hydrogen alongside renewables and carbon capture to meet global commitments for limiting climate change.[44] Hydrogen's CI, which is a measure of the GHG emissions associated with the production of a unit of hydrogen, is the generally accepted indicator for environmental sustainability. The CI is frequently expressed in terms of kilogram of carbon dioxide equivalent per kilogram of hydrogen (kg $CO_{2\text{-eq}}$/kg H_2) or gram of carbon dioxide per megajoule (g $CO_{2\text{-eq}}$/MJ). Although the CI may correspond to the Production segment of the value chain, a cradle-to-grave scope, which covers delivery and extends to the end-use of hydrogen, may also be considered.

Determining Carbon Intensity

Several guidance documents and methodologies can be leveraged for CI determination, including LCAs, environmental sustainability standards, carbon footprint assessments, and measurement and reporting of GHGs associated with various processes or product. There is a need for a CI standard that is adapted to the realities of hydrogen production in Canada and draws from international standardization efforts.

Certification as a Means to Guarantee Low-Carbon Hydrogen

Certification schemes, which are separate from product testing and certification, involve issuing a transferable or guarantee statement by an independent accredited organization. This statement confirms that a specified unit of an energy vector, like hydrogen, meets defined sustainability criteria throughout its value chain. Certification is crucial for establishing the commercial value of low-carbon hydrogen, driving trade, and defining target markets for which CI is a critical input.

STEPS TOWARDS A CARBON INTENSITY STANDARD

Standards and other references that exist or are in development include:

i. Environment and Climate Change Canada (ECCC) Fuel LCA Model
ii. ISO/TS 19870:2023 (Methodology for Determining the Greenhouse Gas Emissions Associated with the Production, Conditioning and Transport of Hydrogen to Consumption Gate)
iii. ISO 14040, ISO 14044, and ISO 14067 (LCA and carbon accounting standards)
iv. GHG Protocol Life Cycle Database System
v. CSA/ANSI R124/BNQ 1789-200 (A Harmonized Methodology for Reporting the Production Pathway and Carbon Intensity of Hydrogen) (in development)
vi. CSA's Advanced Classification of Hydrogen (research paper)

[44] United Nations Climate Change. *UN Climate Change Conference – United Arab Emirates*. Retrieved from https://unfccc.int/cop28

Establishing credible systems to determine and certify the sustainability of produced and imported hydrogen and hydrogen carriers (e.g., ammonia, methanol) is paramount, especially as hydrogen from different sources and technologies may be blended in supply chains. A guarantee of origin is also crucial for hydrogen exports from Canada to have access to target markets including the European Union.

Consumers seeking low-carbon options will require reliable information about the hydrogen's origin. This necessitates the development of credible chain of custody systems, including intermediary delivery and storage, as well as mass balance systems or guarantees of origin. Additional jurisdiction-specific sustainability criteria include water consumption, land use, social acceptability, and impact on Indigenous communities. Canada participated in the COP28 *Declaration of Intent on Mutual Recognition of Certification Schemes for Renewable and Low-Carbon Hydrogen and Hydrogen Derivatives* and is involved the IPHE Task Force working towards this goal.

Within the Canadian context, certification will serve to confirm if hydrogen and hydrogen carriers have been produced, stored, and/or delivered with specific sustainability criteria. Certification can be:

- a building block for policy measures linked to emissions reduction such as tax credits;
- a means of incorporating other sustainability measures;
- a tool for creating transparency for end-users of hydrogen;
- a basis for establishing trust between Canadian hydrogen producers and target domestic and export markets with clearly defined and verifiable credentials for hydrogen.

3.4.5 Blending from a Market Demand Standpoint

Hydrogen blending with natural gas offers an avenue to reduce emissions from fuels so long as the CI of the hydrogen is significantly lower than that of the natural gas with which it is blended. Currently, the use of gaseous fuels across different sectors of the economy is primarily enabled by a natural gas dominated pipeline network, with increasing renewable natural gas content.

Hydrogen blending standards are essential from a market demand standpoint because introducing hydrogen to existing fuel delivery systems acts as a stepping stone to help the industry get started. Ensuring blended hydrogen can be delivered safely and efficiently will enable the development and use of other elements such as hydrogen gas-burning appliances and power production by combustion of hydrogen. Blending will play a role in the short, medium, and long term by allowing natural gas appliances to work with NG-H_2 blends and to increase the hydrogen concentration until 100% hydrogen readiness is achieved.

Since the existing natural gas transmission and distribution networks were not designed for hydrogen, several technical challenges will need to be addressed. An overview of existing regulatory limits for hydrogen tolerance in existing natural gas infrastructure and end-use for Europe is available.[45] This provides a methodical approach for gap analysis in the Canadian context.

Focus areas of investigation need to span the impact of hydrogen in both industrial and built environment applications and specifically consider the impact on pipelines, gas properties and safety systems, metering equipment, and end-use equipment and appliances.

[45] ENTSOG, GIE, Hydrogen Europe. *How to Transport and Store Hydrogen – Facts and Figures.* Retrieved from https://www.gie.eu/h2-report-facts-and-figures/

There are published and ongoing research activities, including within CSA, on hydrogen impacts for pipeline materials and components (in development) and end-use appliances (published and in development).[46] Hydrogen blending trial projects have also been carried out across different provinces, as outlined below, to inform the future deployment of hydrogen and the ongoing development of codes and standards:

- Alberta – Fort Saskatchewan Hydrogen Blending Project by ATCO[47]
- Québec – Green hydrogen injection pilot project by Énergir[48]
- Ontario – Hydrogen Blending by Enbridge Gas[49]

Only natural gas containing up to and including 5% by volume of hydrogen is currently considered covered by existing tests and certification in Canada. Standards covering hydrogen blending greater than 5% by volume are required for both the Delivery and Storage and End-Use segments of the hydrogen value chain. This includes developing criteria that help determine whether existing infrastructure is suitable to switch to a hydrogen-blended or 100% hydrogen fuel.

3.4.6 Hydrogen Leakage and Environmental Consequences

Hydrogen leakage at any point in the value chain can cause detrimental environmental effects that have not been widely studied yet.[50] Although not a GHG itself, hydrogen can cause indirect global warming effects by extending the lifetime of GHGs such as methane in the atmosphere. As the scale of hydrogen production, delivery, and use increases, so could the volume of leaked hydrogen.

Within the context of hydrogen delivery via pipelines, existing natural gas pipelines have demonstrated structural integrity coupled with risk modelling. However, the quantification of the interaction of hydrogen with pipeline materials is important to ensure embrittlement can be contained.

HYDROGEN LEAKAGE IS A GROWING TOPIC OF INDUSTRY FOR BOTH PUBLIC AND PRIVATE COMPANIES

One example of a company involved in hydrogen leakage research is C-FER Technologies (C-FER). C-FER works alongside the industry to evaluate and implement novel technologies for the widespread deployment of hydrogen. Research at C-FER generates data for developing and updating industry. Areas of work include pipeline integrity, safety, and underground storage.

Hydrogen detection is important to resolve leak instances. Sensors, detectors, and tracers serve as critical safety infrastructure that can trigger alarms, activate ventilation systems in closed environments, and shut down hydrogen systems.

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[46] Suchovsky, C.J., Ericksen, L., Williams, T.A., Nikolic, D.J. (2021). *Appliance and Equipment Performance with Hydrogen-Enriched Natural Gases*. Canadian Standards Association, Toronto, ON.

[47] ATCO (2020). *Fort Saskatchewan Hydrogen Blending.* Retrieved from https://gas.atco.com/en-ca/community/projects/fort-saskatchewan-hydrogen-blending-project.html

[48] Energir. *Green hydrogen injection pilot project.* Retrieved from https://energir.com/en/about/the-company/major-works/hydrogene-vert

[49] Enbridge (2022). *Clean hydrogen enters the Markham energy mix.* Retrieved from https://www.enbridge.com/stories/2022/january/hydrogen-blending-project-enbridge-gas-cummins-operational-markham-ontario

[50] Leakage differs from permeation. However, in this section, the term ‘leakage’ is used to encompass both leakage and permeation.

More research should be conducted in this area to better understand potential future leakage rates as well as effective methods to detect, measure, and reduce leaks. Reliable sensing technologies will be crucial to providing accurate flow and loss results when used to measure and meter hydrogen based on its chemical and physical properties. Sensing technologies and systems must also be calibrated with metrological references to ensure traceability and proper validation. Measurement solutions for quality assurance and assessment, leak detection, energy content, storage, or flow metering of hydrogen in gaseous or liquified form and in hydrogen carriers (e.g., LOHCs) are not metrologically validated and standardized yet and therefore cannot be widely adopted in the hydrogen value chain. Codes and standards will ultimately play a role in mitigating leaks by stipulating technical requirements and providing methods for estimating, detecting, measuring, and reducing leakage for varying equipment and processes.

Standards development will need to address the following:

- Level of precision
- Response time
- Measuring range
- Selectivity
- Stability
- Useful life
- Odorants

3.4.7 Prototypes

Another barrier that affects all segments of the value chain is a lack of reasonable regulations to cover hydrogen equipment/appliance prototypes. This is contrasted by available standards for natural gas appliance prototypes, which can be inspected by using CSA B149.3 (Code for the Field Approval of Fuel-Burning Appliances and Equipment), as well as electrical appliance prototypes that can be inspected by using the SPE 1000 (Field Evaluation Code). Hydrogen blends and pure hydrogen have been proposed for inclusion in the 2025 edition of CSA B149.3. Currently, AHJs require full certification for hydrogen appliance prototypes, which can limit end-use trials. Some CSWG members have identified that it would be helpful to special inspections for limited numbers of prototypes. This remains a topic for further discussions.


4

4. RESULTS OF THE PRIORITIZATION EXERCISE AND ROADMAP FORWARD

Based on the priority ratings that were collected, the elements were ranked from highest to lowest in terms of overall priority ratings.[51] The top 20 elements were then assigned a timeline for action based on Urgency and Criticality ratings received from CSWG members, provincial governments, and AHJs. The timelines for action are defined as short-term (before 2028), medium-term (2028–2030), and long-term (after 2030).

Out of the top 20 ranked elements, this resulted in 12 short-term priority elements, as shown in ***Table 21***. More than half of the short-term priority elements fall within the End-Use segment of the hydrogen value chain. For a complete list of the elements' gaps and prioritization timelines, refer to ***Appendix G***.

Although ***Table 21*** provides an accurate representation of the prioritization exercise results, the noted priorities should be regarded in a relative sense. Rankings are not absolute, and there are interdependency factors that were not analyzed for this Roadmap. For example, H_2 Dispensers for Light-Duty Vehicles (Element 43) is a short-term priority, whereas H_2 Light-Duty Vehicles (Element 46) is a medium-term priority. In reality, the timelines and successful deployment of these two elements would be closely linked to one another as the availability of fueling stations and dispensers will enable the adoption of hydrogen vehicles. This type of interdependency was not analyzed during the rating exercise; however, this additional level of review could be considered in subsequent iterations of this Roadmap or prioritization exercises.

Figure 5 demonstrates a potential timeline for addressing gaps for short-term and medium-term elements listed in ***Table 21***. The elements have been listed in order of overall rating, while respecting short-term and medium-term timelines as described above. Actual timelines of work will be subject to SDO(s) forming technical committee(s) for standards development and/or updates for the specific element. Recognizing a typical standard development timeline in Canada is 18–36 months, actions related to short-term elements should begin immediately.

EVOLVING HYDROGEN LANDSCAPE

Priority elements and assigned timelines are expected to evolve as additional data become available and needs of the industry and AHJs evolve. Some of the long-term priorities will move into short- and medium-term, and periodic updates of this Roadmap will capture these changes.

[51] Overall rating refers to the final rating (out of a score of 100) based on all nine of the criteria described in ***Section 2.5.1***: number of Canadian companies, activity in the sector, impact, TRL, urgency, achievability, criticality, effect, and scope.

Table 21: Top 20 Ranked Elements per Overall Rating

Timeline for Action	Overall Rating Rank	Element Name and #	Segment	Gap	Standards-Based Option(s)
Short-Term	1	H_2 Dispensers for Light-Duty Vehicles (Element 43)	End-Use		Use as-is or update existing Canadian standard(s) (Option 2)
	2	Water Electrolysis — Centralized or Decentralized (Element 1)	Production		Use as-is or update existing Canadian standard(s) (Option 2)
	3	Carbon Intensity (Element 0)	Production		Wait for standard(s) under development to be published (Option 5)
	4	GH_2 Injection into Natural Gas Pipeline Systems (Element 33)	End-Use		Use as-is or update existing Canadian standard(s) (Option 2) Reference or adopt existing regional standard(s) (Option 3.2) and/or Reference or adopt existing international standard(s) (Option 3.3)
	5	GH_2 Storage (Element 12b) [A]	Delivery and Storage		Use as-is or update existing Canadian standard(s) (Option 2)
	6	GH_2 Cooking Appliances (Element 32)	End-Use		Use as-is or update existing Canadian standard(s) (Option 2) and/or Wait for standard(s) under development to be published (Option 5)
	7	GH_2 Furnaces & Burners (Element 31)	End-Use		Use as-is or update existing Canadian standard(s) (Option 2) and/or Wait for standard(s) under development to be published (Option 5)
	8	H_2 Heavy-Duty Vehicles — Buses (Element 48) [B]	End-Use		For GH_2: Use as-is or update existing Canadian standard(s) (Option 2) For LH_2: No immediate action; wait until technology is more mature or commercialized (Option 6)
	9	H_2 Heavy-Duty Vehicles — Trucks (Element 49) [C]	End-Use		For GH_2: Use as-is or update existing Canadian standard(s) (Option 2) For LH_2: No immediate action; wait until technology is more mature or commercialized (Option 6)
	10	GH_2 Delivery by Truck (Element 18)	Delivery and Storage		Use as-is or update existing Canadian standard(s) (Option 2)
	15	Steel Production (Element 67)	End-Use		Reference or adopt existing U.S. standard(s) (Option 3.1) and/or Reference or adopt existing regional standard(s) (Option 3.2)
	17	NH_3 for H_2 Delivery and Storage (Element 11a)	Delivery and Storage		Develop new standard(s) (Option 4)

Timeline for Action	Overall Rating Rank	Element Name and #	Segment	Gap	Standards-Based Option(s)
Medium-Term	11	H_2 Light-Duty Vehicles (Element 46)	End-Use	Partial gap	Reference or adopt existing U.S. standard(s) (Option 3.1)
	12	LH_2 Storage at Production Site (Element 12a)	Delivery and Storage	Partial gap	Use as-is or update existing Canadian standard(s) (Option 2)
	14	H_2 Dispensers for Heavy-Duty Vehicles (Element 44)	End-Use	Partial gap	Reference or adopt existing U.S. standard(s) (Option 3.1) Wait for standard(s) under development to be published (Option 5)
	16	Portable & Micro Fuel Cell Power Systems (Element 27)	End-Use	Partial gap	Reference or adopt existing U.S. standard(s) (Option 3.1)
	18	H_2 Materials Handling (Element 47)	End-Use	Partial gap	Reference or adopt existing U.S. standard(s) (Option 3.1)
	19	Water Electrolysis — Offshore (Element 2)	Production	Partial gap	Use as-is or update existing Canadian standard(s) (Option 2)
	20	NH_3 Cracking to Liberate GH_2 (Element 24a)	Delivery and Storage	Full gap	No immediate action; wait until technology is more mature or commercialized (Option 6)
Long-Term [D]	13	NH_3 Delivery by Ship (Element 15a)	Delivery and Storage	No gap	No immediate action; periodically update existing Canadian standard(s) (Option 1)

No gap | Partial gap | Full gap

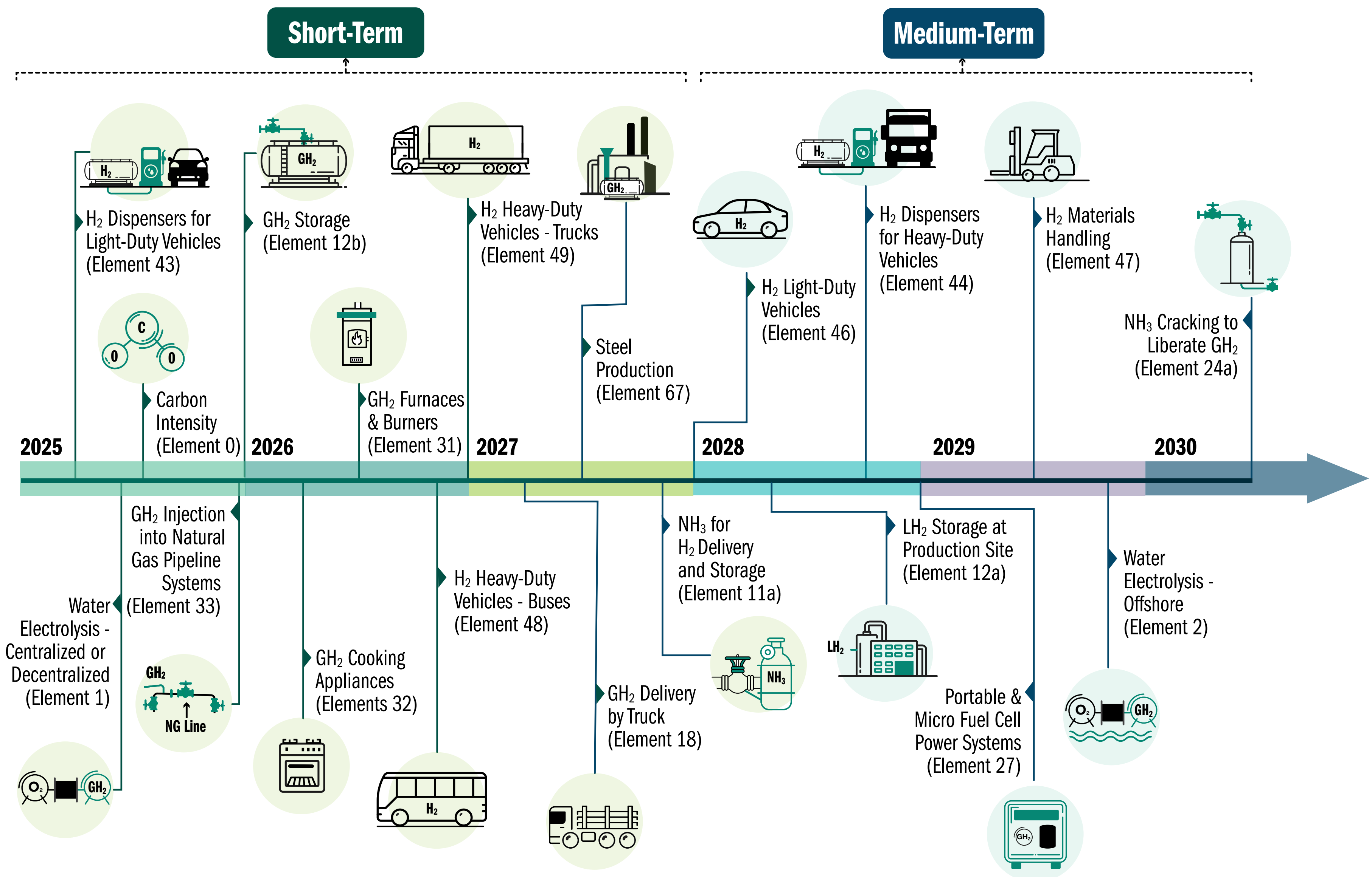
[A] GH_2 Storage (Element 12b) includes a variety of gaseous hydrogen storage equipment/methods, whose priority rankings vary. The ranking shown is an overall representation. For more precise ratings in future prioritization exercises, this element may be separated to better represent each specific storage equipment/method.

[B] Although H_2 Heavy-Duty Vehicles – Buses (Element 48) included both gaseous and liquid hydrogen fuels, the prioritization exercise found that only gaseous hydrogen is a short-term priority.

[C] Although H_2 Heavy-Duty Vehicles – Trucks (Element 49) included both gaseous and liquid hydrogen fuels, the prioritization exercise found that only gaseous hydrogen is a short-term priority.

[D] As a reminder, long-term and "no gap" elements may still have an associated action because existing standards will undergo regular periodic reviews.

Figure 5: Proposed Roadmap for Actioning Prioritized Standards Gaps



5

5. STAKEHOLDER CALL TO ACTION

Codes and standards represent an important and consistent framework for a hydrogen economy with long-term impacts. Their development ranks highly alongside increased supply, infrastructure build-out, and demand-side support. Beyond technical considerations, codes and standards offer an opportunity to align policy and regulatory considerations. For example, a standard on CI might support regulations that require CI for climate-related objectives and/or tax credits. Furthermore, standards could help increase the "social licence" for the hydrogen economy by generating trust and confidence.

For effective use in policy, regulations, and the hydrogen economy, codes and standards should enhance safety, lower trade barriers, allow for geographical differences and priorities, be periodically updated, and support conformity assessments. It is also important to distinguish between emerging areas and mature industrial sectors that have been operating to the highest safety level for decades. Efforts should prioritize new areas with standards gaps and avoid adding undue burden to industries with long-standing expertise.

This Roadmap has systematically identified critical gaps across the hydrogen value chain, with broad stakeholder participation, for the first time within the Canadian context. Based on results from the gap analysis and prioritization exercise, a roadmap of codes and standards development was created (***Figure 5***).

Standards-based options, such as those recommended within this Roadmap, could provide guidance in how to address these gaps while ensuring Canada's public policy and regulatory objectives, industry needs, as well as the health and safety of Canadians are upheld.

Some of the gaps will require research that will lead to innovation. Subsequently, as the codes and standards are developed, they could lead to improved market access as compliance costs for hydrogen related technologies will be lower. They will also facilitate investment decision making for technology options because best practices and technical guidance will be widely available.

Recommended actions and desired outcomes, categorized broadly into six groups, are included in ***Table 22***. Stakeholders including governments, regulatory authorities, industry associations, hydrogen producers and technology developers, and end-users will all have roles to play to accelerate the much-needed development of codes and standards. Collaboration between stakeholders will be especially vital for filling identified gaps. Furthermore, as the hydrogen landscape is rapidly evolving, flexibility will be required to reduce barriers faced by emerging priorities, technologies, processes, and projects. Periodic exercises should be designed to capture changes in order to provide timely advice.

Table 22: Recommended Actions and Desired Outcomes Grouped by Pillars

Recommended Action(s)	Desired Outcome(s)
Governance	
i. Continue CSWG activities, which may include recruiting additional expertise to address evolving or emerging elements or priorities. ii. Establish a hydrogen codes and standards coordination platform to play a key role in bringing together governments, industry, SDOs that are active in the hydrogen space, as well as stakeholders to ensure Roadmap priorities are implemented. iii. Initiate a process to complete periodic updates to this Roadmap. iv. Coordinate between governments and AHJs on priority setting to address obstacles to hydrogen codes, standards, and certification.	i. Leverage broad and diverse expertise for codes and standards priority and goal setting through a forum for engagement with stakeholders. ii. Alignment with technical working groups/forums to support the hydrogen value chain and leverage best practices. iii. Measurement of progress on actions, including addressing gaps of listed priority elements, and identifying emerging gaps requiring standardization activities. iv. Synergies found between government and regulators covering budgeting, planning, and shared priorities leading to credentials for industry practitioners to ensure the safe use of hydrogen technologies and applications in Canada.
Policy Measures & Regulatory Action	
i. Create dedicated government policy programs to support the adoption of codes and standards for hydrogen. ii. Support SDOs to work on addressing codes and standards gaps aligned with priorities listed in this Roadmap, as well as federal and provincial hydrogen strategies. iii. Ensure that hydrogen support mechanisms (e.g., targeted programing, strategic finance, research and development support) require a consideration of codes and standards gaps. iv. Address regulatory barriers resulting from an absence of codes and standards for projects across the hydrogen value chain, with focus on applications that stimulate demand.	i. Sustained funding and support available for codes and standards development and their use in regulations. ii. Continuity in the priorities that have been identified in this Roadmap. iii. Additional emphasis on scans of codes and standards in activities that involve direct government funding or investment aimed at generating innovative approaches across the hydrogen value chain. iv. Support for opportunities to create demand for hydrogen and related technologies in Canada even without relevant Canadian codes and standards.
International Cooperation	
i. Maintain alignment with the United States and the European Union and continue to contribute at the ISO level to support international harmonization.	i. Enhanced bilateral and multilateral international initiatives on codes and standards, including new and hydrogen specific workplans for the U.S.-Canada Regulatory Cooperation Council and the Canada–European Union Regulatory Cooperation Forum.

Recommended Action(s)	Desired Outcome(s)
Innovation & Capacity Building	
i. Fund federal laboratories and other institutions to do research and development activities to support the development of codes and standards. ii. Identify skills and training requirements for hydrogen related codes and standards. iii. Make support available for the harmonization of successful qualification programs and requirements by AHJs. iv. Continue to ensure emerging technologies are flagged and prioritized for codes and standards development ahead of commercial deployment.	i. Knowledge disseminated and critical data required for codes and standards development made publicly available. ii. Bridges created between hydrogen skills gaps, particularly the use of codes and standards. iii. Increased efficiency by avoiding multiplication of efforts across multiple Canadian jurisdictions. iv. Awareness created across the hydrogen value chain to enable technology developers provide a signal on the codes and standards implications of emerging hydrogen related technologies.
Information Technology & Access	
i. Create a means (e.g., accessible portal) for stakeholders that have identified standardization gaps critical for the deployment of hydrogen and related technologies to submit requests or communicate needs to SDOs and AHJs. ii. Require public disclosure of environmentally related information, generally by industry to consumers, which could include: a. labelling programs. b. rating and certification systems. v. Provide the public with access to codes and standards that were developed with Government of Canada funding.	i. Improved communication between stakeholders and SDOs and AHJs. ii. Improved public access to hydrogen-related information including indicators such as standardized CI methodologies, models, and metrics. iii. Relevant codes and standards being made available at no cost to the end-users, especially those developed with support by governments.
Communication & Harmonization	
i. Broadly disseminate this Roadmap to stakeholders across Canada through technical forums and SDOs, and encourage participation of technical experts in the codes and standards process. ii. Map and disseminate the link between standards and equipment and management systems certification. iii. Develop novel approaches to sharing information and data, especially in cases where engineering assessments are used in the absence of codes and standards.	i. Hydrogen use enabled while promoting its associated decarbonization benefits and recognizing that increased demand for hydrogen will drive development of codes and standards. ii. Harmonization of codes and standards that are applicable in multiple industrial sectors and applications (i.e., inter-relate and interconnect the requirements across multiple codes and standards). iii. Domestic harmonization and trade between Canadian jurisdictions facilitated.

APPENDIX A: CSWG AND ROADMAP CONTRIBUTOR'S LIST

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APPENDIX B: ROLE OF AUTHORITIES HAVING JURISDICTION TO SUPPORT A HYDROGEN ECONOMY

The term “Authority Having Jurisdiction” (AHJ) refers to a government or regulatory authority at the federal, provincial, or territorial level responsible for enforcing and interpreting the laws and regulations related to a particular area. AHJs are responsible for various regulatory activities to ensure the welfare of the public in terms of health, safety, and the environment in their respective jurisdictions. These activities may include:

- rulemaking through the development or adoption and enforcement of codes and standards referenced in provincial and territorial law;
- participating in developing codes and standards through SDOs’ technical committees;
- issuing permits, which may include device permits, facility licenses, registrations for contractors, and certificates for technicians, to verify that work meets safety standards;
- conducting inspections and audits to ensure compliance with adopted codes and approved plans;
- delivering education programs and skills certification;
- executing public awareness campaigns such as education on building codes, safety measures, and regulations to increase compliance.

AHJs have statutory authority to adopt any code or to reference standards, in whole or in part, as part of applicable regulation, which may then be amended for province-specific requirements.

Challenges exist in that Canadian legislative frameworks were not enacted with hydrogen as an energy source in mind. Currently, the only code specific to hydrogen gas is the Canadian Hydrogen Installation Code (i.e., CAN/BNQ 1784-000). However, the gas industry is regulated through three primary groups of codes, which did not consider hydrogen during their inception:

- gas installation: CSA B149 series
- boiler and pressure vessel: CSA B51 series
- oil and gas pipelines: CSA Z662

To successfully and safely deploy hydrogen, several technical factors must be considered in the process of codes and standards development or adoption, and the regulations to which they may be incorporated, namely:

- adaptability to accommodate rapidly evolving technologies;
- robust safety precautions to address the flammable nature of hydrogen and need for specialized handling and storage for hydrogen as well as its various derivatives and carriers (e.g., ammonia and liquid organic hydrogen carriers);
- opportunities to harmonize, when feasible, internationally and nationally to promote interoperability and trade;
- the feasibility of repurposing existing infrastructure compared to developing new infrastructure.

APPENDIX C: SCC-ACCREDITED SDOS WORKING IN THE HYDROGEN SPACE

A number of SDOs accredited by SCC are currently involved or have planned activities for codes and standards development in the hydrogen space. Please note that this list is not exhaustive.

Bureau de normalisation du Québec (BNQ)	The BNQ developed the Canadian Hydrogen Installation Code which is common to all elements across the hydrogen value chain. They are also currently working on developing a bi-national carbon intensity standard with the CSA Group and the American National Standards Institute (ANSI).
Compressed Gas Association (CGA)	The CGA creates safety guidelines for producing, storing, transporting, and using hydrogen in the fuel cell electric vehicle industry. The Safe Hydrogen Project by the CGA involves developing safety standards for secure operations in hydrogen applications, increasing awareness through marketing and communication efforts, and reaching out to stakeholders interested in this field.
Canadian Standards Association (CSA Group)	The CSA Group is actively engaged in hydrogen-related standardization efforts, developing standards and guidelines for hydrogen technologies and application across various aspects of the hydrogen value chain, including hydrogen production, storage, transportation, infrastructure, end-use, and safety.
International Code Council (ICC)	The ICC's work in the hydrogen industry focuses on current proposals to address NG-H_2 blending in the International Fuel Gas Code and future revisions to the Building and Fire Codes which may be necessary to support the industry and to recognize advanced safety features of current hydrogen technology.
Underwriters Laboratories of Canada (UL)	UL plays a role in ensuring that that products, systems, and facilities related to hydrogen technologies meet specific safety and performance standards through testing and certification. This includes areas such as hydrogen fuel cells, hydrogen production, storage, and delivery systems.

APPENDIX D: CANADA'S INTERNATIONAL PARTICIPATION IN HYDROGEN CODES AND STANDARDS ACTIVITIES

Canada is working collaboratively with international partners on the role that hydrogen can play in achieving a net-zero future. Please note that this list is not exhaustive.

Asia-Pacific Economic Cooperation (APEC)	Canada is a member of APEC, a regional forum that promotes economic cooperation and free trade among its member economies from the Asia-Pacific region. Canada contributed to a workshop on the Low-Carbon Hydrogen International Standard project. The post-workshop report covers existing standards, approaches to development, and features of an international standard, and provides insight into the next steps for implementation in the APEC region.[52]
Canada-Germany Hydrogen Alliance	In 2022, Canada signed a Joint Declaration of Intent with the Government of the Federal Republic of Germany on establishing a Canada–Germany Hydrogen Alliance.[53] The Hydrogen Alliance aims to kickstart the hydrogen economy of both countries, and initiatives are understood to include alignment of codes, standards, and regulation, pertaining to the production, distribution, trade, and use of hydrogen and its derivatives. Supporting the development of a common methodology for the determination of carbon intensity of hydrogen has also been identified as a topic to be explored. In March 2024, Canada and Germany signed a Memorandum of Understanding to advance the Hydrogen Alliance by taking the first step to create a transatlantic hydrogen trade corridor via the development of a dedicated bilateral Canada window under Germany's H2Global Foundation to address the "green premium" gap with regards to the cost of hydrogen and its derivatives.
Canada-United States Regulatory Cooperation Council (RCC)	Canada participates in the Canada–United States RCC, a mechanism for the Canadian government to discuss regulatory priorities with our closest trade partner and, when warranted, align regulatory and standardization priorities. The goal of the RCC is to promote economic growth, job creation, and increased transparency and coordination. Because regulations reference codes and standards, the work plans developed by the RCC are directly linked to the work plans for priority codes and standards.
International Organization for Standardization (ISO)	ISO/TC 197 (Hydrogen Technologies) brings together experts and stakeholders from around the world to collaborate on the development of international standards in the field of systems and devices for the production, storage, transport, measurement, and use of hydrogen. SCC represents Canada as the secretariat of the Hydrogen Technologies technical committee TC 197.

[52] Asia-Pacific Economic Cooperation (2022). *Low-Carbon Hydrogen International Standard – Post-Workshop Report*. Retrieved from https://www.apec.org/publications/2022/07/low-carbon-hydrogen-international-standard-post-workshop-report

[53] Natural Resources Canada (2022). *Joint declaration of intent between the Government of Canada and the Government of the Federal Republic of Germany on establishing a Canada-Germany Hydrogen Alliance.* Retrieved from https://natural-resources.canada.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/the-hydrogen-strategy/joint-declaration-intent-between-the-government-canada-and-the-government-the-federal/24607

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)	Canada is a member of the IPHE, a collaboration whose aim is to support and expedite the clean energy economy using hydrogen and fuel cell technologies. Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen was published in July 2023. This served as the seed document for the ISO/TS 19870:2023. Canada is also actively involved in Regulations, Codes, Standards, and Safety task forces for Maritimes as well as the bulk storage of hydrogen and its derivatives. Ongoing work also covers hydrogen certification mechanisms.
International Renewable Energy Agency (IRENA)	As a member of IRENA's Collaborative Framework on Green Hydrogen, Canada engages in dialogue, cooperation, and coordinated action to accelerate the development and deployment of green hydrogen and its derivatives, as well as alignment on common codes, standards, and certification that will be necessary to enable international trade and environmental integrity along the value chain. The Collaborative Framework leverages the Agency's work on green hydrogen, the wealth of knowledge and expertise that exists within IRENA's membership, and the benefits that may be reaped through wider global cooperation with other entities, such as the World Economic Forum and the World Trade Organization.
Mission Innovation	Canada is a founding and active member of Mission Innovation, a global initiative that convenes governments from 23 countries and the European Commission through private-public coalitions called "Missions." Canada is a core member of the Clean Hydrogen Mission, which focuses on integrating production to end-use applications and preparing for scale-up of the hydrogen economy. One of the Mission's pillars of action is to convene stakeholders to exchange knowledge on creating better enabling conditions for scaling clean hydrogen. Canada is also a core member of the Net-Zero Industries and support member of the Zero-Emission Shipping Mission advancing research and innovation priorities for decarbonization pathways, such as the adoption of zero-emission fuels. For all three of these Missions, Canada is active in the activities supporting the development of policy frameworks, standards, and regulation.
Regulatory Cooperation Forum (RCF)	To support the efforts under the Canada–European Union Comprehensive Economic and Trade Agreement's (CETA) RCF, Canada has engaged with CEN-CENELEC to exchange progress on standardization initiatives related to hydrogen technologies.
Standards Council of Canada (SCC)	Canada, through SCC, is involved in international standardization efforts in organizations such as the ISO through the Hydrogen Technologies technical committee TC 197. These organizations develop global standards that are relevant to the hydrogen industry. SCC is Canada's national accreditation body. A list of the SDOs accredited by SCC can be found on the webpage titled Accredited Organizations.

APPENDIX E: RATING METHODOLOGY SUPPLEMENTAL INFORMATION

The rating methodology appears in ***Section 2.5.1***.

Decision-Based Priority Matrix (DBPM)

To address gaps, individual elements were prioritized based on multiple variables. Given the considerable number of variables, a systematic approach was necessary. The University of British Columbia provided the CSWG with a decision matrix, which is a model also used by the University of Florida. This matrix was adapted to create the Decision-Based Priority Matrix (DBPM), designed for situations where decisions must consider multiple variables to rank the priority of all elements. The criteria encompass the number of Canadian companies, sector activities, urgency, impact, and Technology Readiness Level (TRL) for each element. The matrix also integrates input from provincial government and AHJs, considering aspects such as scope, criticality, achievability, and effect.

The DBPM normalizes all variables on a scale out of 10 to ensure consistent impact. For instance, the TRL, originally ranging from 1 to 9, was divided by 9 and multiplied by 10, placing it on a scale out of 10. Similarly, the number of Canadian companies for each element was normalized by dividing it by the largest number of companies for any element (i.e., 38 companies for Water Electrolysis - Centralized or Decentralized (Element 1)) and then by multiplying the resulting number by 10.

Ratings for the number of Canadian companies, activity in the sector, impact, TRL, and urgency were provided by members of the CSWG task forces and their networks. Ratings for achievability criticality, effect, and scope were supplied by provincial governments and AHJs.

Rating Criteria	Original Scale Range	Normalized Scale	Overall Weighting
CSWG Task Force Members Input			
# of Canadian Companies **	0-38	Out of 10	5
Activity in the Sector **	0-10	Out of 10	5
Impact	0-10	Out of 10	10
Technology Readiness Level (TRL)	1-9	Out of 10	10
Urgency	0-10	Out of 10	10
		Total Weighting	**40**
Provincial Government Input			
Achievability	0-3	Out of 10	2.5
Criticality	0-3	Out of 10	2.5
Effect	0-3	Out of 10	2.5
Scope	0-3	Out of 10	2.5
		Total Weighting	**10**
AHJ Input			
Achievability	0-3	Out of 10	2.5
Criticality	0-3	Out of 10	2.5
Effect	0-3	Out of 10	2.5
Scope	0-3	Out of 10	2.5
		Total Weighting	**10**

** The number of Canadian companies and activity in the sector may have some overlapping impact, which is why the weighting is decreased. However, both are used because we intended to capture different aspects of priority. For example, the number of Canadian companies is one measure but may not reflect the whole picture if there are:

- few companies that are very active (e.g., two companies at a high TRL with $100+ million sales activity per year) and have a big impact on the Canadian economy; or,
- many companies that are less active (e.g., 10 companies at a lower TRL performing research and development and only $5 million activity per year) and that could have a small impact.

Examples of having few but very active companies are Water Electrolysis – Offshore (Element 2), Natural Gas Reforming (Element 3), and NH_3 Delivery by Rail (Element 16).

The number of companies also affects the creation of standards. More active companies will enable the formation of a balanced committee to create the standards. Furthermore, number of companies is an objective measure as opposed to activity in the sector being subjective, so including both is more balanced.

Technology Readiness Levels (TRLs)

TRLs range from 1, which means a technology is furthest away from deployment, to 9, which means a technology is completely ready to be deployed in the marketplace and commercialized.[54]

Level 1	Basic principles of concept observed and reported. This lowest level includes scientific research activities that need to be developed. Such activities include basic technology conceptual paper studies.
Level 2	Technology concept and/or application formulated. Level 2 consists of assessing basic characteristics of the technology and its practical applications through analytical studies.
Level 3	Analytical and experimental critical function and/or proof of concept. This level consists of research and development (it may be analytical in nature but could include lab research).
Level 4	Component and/or validation in a laboratory environment. At this level, components may be put together and tested to see if they work as intended. The hardware used at this stage may not be intended to be used in the final product but just used for testing purposes.
Level 5	Component and/or validation in a simulated environment. At this stage, the components are assembled for lab testing in a replicated environment.
Level 6	System/subsystem model or prototype demonstration in a simulated environment. At this level, a prototype close to the end product configuration is developed and tested in a laboratory or simulated environment.
Level 7	Prototype ready for demonstration in an appropriate operational environment. At this level, the prototype is ready to be field tested and demonstrated in a real environment.
Level 8	Actual technology completed and qualified through tests and demonstrations. At this level, the technology has been fully developed (it is in its final form) and has been confirmed to work as intended in the field.
Level 9	Actual technology proven through successful deployment in an operational setting. This is the final level at which the technology is ready and proven in real-life conditions.

[54] Innovation, Science and Economic Development Canada (2018). *Technology readiness levels.* Retrieved from https://ised-isde.canada.ca/site/innovation-canada/en/technology-readiness-levels

APPENDIX F: HYDROGEN DELIVERY AND STORAGE SUPPLEMENTAL INFORMATION

Types of Gaseous Hydrogen (GH_2) Delivery and Storage Methods

Pressure Vessels

- Hydrogen is delivered in tube trailer trucks at pressures of up to 250 bar (180 to 200 bar being more typical).
- Steel tube trailers are used for gaseous delivery, but weight regulations limit how much can be delivered by each truck.
- Many companies are developing 450 bar and even 700 bar hydrogen storage/delivery systems using composite materials to increase the amount of hydrogen delivered by each truck, thereby reducing costs and delivery emissions.

Solid-State Storage

- Hydrogen can be stored by adsorbing the gas on powders or other solid-state material to form hydrides or other hydrogen-adsorbent material.
- Through the development of codes and standards, the safety aspect of these substances would be evaluated through testing.
- The amount of energy required to adsorb (i.e., bind) the hydrogen to the powder is typically less than required to form chemical bonds, such as with LOHCs.
- It is possible to store relatively high densities of hydrogen, comparable to compressed gases, at lower pressures.

Pipelines, Including Use as Temporary Storage

- A component of increasing hydrogen's presence in Canada is the ability to use existing or new natural gas pipeline infrastructure.
- Existing natural gas infrastructure could potentially be repurposed to delivery pure hydrogen or a mixture of blended natural gas and hydrogen.
- Delivery of any amount of hydrogen in pipelines comes with challenges and uncertainties.
- By raising and lowering pressures, specific portions of a pipeline can be used to gain additional storage capacity for high-demand periods.
- Atomic hydrogen can permeate solid metals and render pipeline steel susceptible to cracking.
- Hydrogen's low energy per unit volume means the pipeline's pressure and flow must increase, raising questions over the consequences, compliance with safety protocols, and associated costs.

Salt Caverns and Underground Storage

- GH_2 can be stored effectively in underground salt caverns, as has been demonstrated in projects in the United Kingdom, United States, and in parts of Europe.
- Salt caverns are utilized for natural gas storage in salt rock formations in many provinces in Canada.
- The compact structure and composition of salt rock formations make the structures inherently gas tight, and the cavern's only surface access is the borehole, which is lined and capped to prevent leakage.
- Dried and compressed hydrogen can be injected through the borehole and effectively stored in the cavern indefinitely.
- Depleted gas wells are also being considered for bulk storage of hydrogen in Canada.
- Important safety considerations for underground hydrogen storage include integrity of materials, potential leakages, and hydrogen interaction with storage media.

Types of Hydrogen Carriers

Ammonia (NH_3)

- Ammonia is a promising hydrogen carrier candidate due to its high hydrogen density and high flexibility in its use.
- Due to its stability for long-term delivery and storage, ammonia can fulfill the demand to store energy in time (i.e., stationary energy storage) and in space (i.e., energy export and import).
- Ammonia is currently used in several industrial processes (e.g., fertilizers, chemicals) and the infrastructure to produce, deliver, store, and use ammonia has been globally established.
- Regulations and procedures for ammonia handling have been well established.
- Liquid ammonia has a relatively high volumetric energy density compared to liquid and compressed hydrogen.
- If high-purity hydrogen is required, hydrogen separation must follow the decomposition of ammonia.

Liquid Organic Hydrogen Carriers (LOHCs)

- LOHCs are an emerging technology for the large-scale delivery of hydrogen.
- LOHCs are organic compounds, such as methylcyclohexane, toluene, dibenzyl toluene, and benzyl toluene, in which hydrogen can be stored for delivery and subsequently recovered as GH_2 at the destination.
- Hydrogen is chemically bound to the LOHC, which can undergo many hydrogenation and dehydrogenation cycles.
- Key advantages include high boiling points compared to LH_2, high energy density compared to GH_2, non-flammability, low toxicity in some cases, and commercial availability of the compounds.

Methanol

- Methanol is liquid at ambient temperature and pressure, thereby enabling delivery and storage with existing infrastructure without the need for intensive capital investments.
- It has higher energy density than ammonia; however, it has lower gravimetric and volumetric hydrogen contents than ammonia.
- The adoption of methanol to store hydrogen may lead to environmental problems in the end-use site because of the release of carbon dioxide if methanol is directly combusted or decomposed, unless it is used in a closed-loop source.

APPENDIX G: SUMMARY OF THE GAP ANALYSIS AND PRIORITIZATION

Refer to ***Section 2*** for descriptions of gaps (***2.3.2***), standards-based options (***2.4***), and timelines for action (***2.5.2***). Some elements include several sub-elements and therefore multiple standards-based options may be suggested.

○ No gap
● Partial gap
● Full gap
X Not assessed

S Short-term
M Medium-term
L Long-term

Production Segment (Elements 0-10)

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
0	Carbon Intensity	Full gap	3							X		S
1	Water Electrolysis - Centralized or Decentralized	Partial gap	2		X							S
2	Water Electrolysis - Offshore	Partial gap	19		X							M
3	Natural Gas Reforming	Partial gap	31			X						M
4	Biomass Gasification	Partial gap	49			X						M
5	Biomass-Derived Liquid Reforming	Partial gap	52								X	M
6	Refined Industrial Waste	No gap	46	X								L
7	Solar or Nuclear Thermochemical Hydrogen	**X**										M*
8	Photo-Electrochemical	**X**										M*
9	Microbial Biomass Conversion / Photobiological	**X**										M*
10	Accelerated Carbon Transition (ACT)	**X**										M*

* Elements 7-10 were not assessed during the gap analysis but were assigned priority ratings based on criteria described in ***Section 2.5.1***, and as such, a timeline for action was assigned.

Delivery and Storage Segment (Elements 11–26)

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
11a	NH_3 for H_2 Delivery and Storage	●	17						X			S
11b	Liquid Organic H_2 Carriers (LOHCs) for H_2 Delivery and Storage	●	44								X	M
11c	Methanol for H_2 Delivery and Storage	●	24								X	M
12a	LH_2 Storage at Production Site	●	12		X							M
12b	GH_2 Storage (Includes: pressure vessels, solid-state storage, pipelines, including use as temporary storage, salt caverns/underground storage, and compression stations/compressors)	●	5		X							S
13	H_2 Liquefaction Plant	●	65						X			M
14a	NH_3 Delivery by Truck	○	27	X								L
14b	LOHC Delivery by Truck	X										
15a	NH_3 Delivery by Ship	○	13	X								L
15b	LOHC Delivery by Ship	●	37		X							M
16a	NH_3 Delivery by Rail	○	26	X								L
16b	LOHC Delivery by Rail	○	38	X								L
17	GH_2 Delivery by Rail	●	45		X							M
18	GH_2 Delivery by Truck	●	10		X							S
19 and 20	H_2 Gas Pipeline Systems / GH_2 Pressure Reduction Stations	●	32		X							M
21a	GH_2 Delivery by Ship	●	70								X	M
21b	LH_2 Delivery by Ship	X										
22	LH_2 Delivery by Truck	X										
23	LH_2 Delivery by Rail	○	54	X								L
24a	NH_3 Cracking to Liberate GH_2	●	20								X	M
24b	LOHC Dehydrogenation to Liberate H_2	●	41		X							M
25	LH_2 Storage at End-Use Site	○	67	X								L
26	LH_2 Vapourization at Distribution Site (Includes: piping, distribution stations, pressure vessels, heat exchangers, filling stations)	●	68		X							M

End-Use Segment (Elements 27–72)

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
27	Portable & Micro Fuel Cell Power Systems	●	16			X						M
28	Stationary Fuel Cell Power Systems (Includes: methanol fuel cell power plants, stationary indoor UPS systems)	○	66	X								L
29a	H_2 Gas Turbines	●	48		X							M
29b	H_2 Gas Internal Combustion Engines (ICEs)	●	30		X							M
30	GH_2 Boilers & Water Heaters (Includes: hot water tank heaters, instantaneous tankless water heaters, pool heaters, boilers, industrial water heaters)	●	34		X	X	X					S
31	GH_2 Furnaces & Burners	●	7		X					X		S
32	GH_2 Cooking Appliances	●	6		X					X		S
33	GH_2 Injection into Natural Gas Pipeline Systems	●	4		X		X	X				S
34a	NG-H_2 Water Heaters	●	39		X	X	X					S
34b	NG-H_2 Furnaces & Burners	●	21		X	X		X				M
34c	NG-H_2 Cooking Appliances	●	43		X	X	X					S
35	NG-H_2 Gas Turbines	●	69		X	X						M
36	NG-H_2 Delivery by Ship	X										
37	NG-H_2 Dispensers for Light-Duty Vehicles (for cars)	●	59		X							M
38	NG-H_2 Dispensers for Heavy-Duty Vehicles (for buses and trucks)	●	60		X							M
39	NG-H_2-Powered Materials Handling (Includes: forklifts)	●	64					X				M
40	NG-H2-Powered Light-Duty Vehicles (Includes: cars, SUVs, utility vehicles, off-road vehicles, ice resurfacers)	●	63					X				M

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
41	NG-H_2-Powered Heavy-Duty Vehicles – Buses	●	62					X				M
42	NG-H_2-Powered Heavy-Duty Vehicles – Trucks	●	61					X				M
43	H_2 Dispensers for Light-Duty Vehicles (for cars and lift trucks) (Includes: permanently installed dispensers, portable dispensers, high-pressure and low-pressure dispensing)	●	1		X							S
44	H_2 Dispensers for Heavy-Duty Vehicles (for trucks and buses) (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)	●	14			X				X		M
45	H_2 Dispensers for Rail (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)	●	36		X	X				X		M
46	H_2 Light-Duty Vehicles (Includes: cars, SUVs, utility vehicles, off-road vehicles, ice resurfacers)	●	11			X						M
47	H_2 Materials Handling (Includes: forklifts, vehicles for retail, storage, ports, airports)	●	18			X						M
48	H_2 Heavy-Duty Vehicles – Buses (Includes: GH_2 buses, LH_2 buses)	●	8		X						X	S
49	H_2 Heavy-Duty Vehicles – Trucks (Includes: GH_2 trucks, LH_2 trucks)	●	9		X						X	S
50	Hydrail (H_2 Rail) (Includes: LH_2/GH_2 trains, passenger/freight trains, switcher locomotives)	●	25					X				M

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
51	H_2 Dispensers for Ships (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)		42		X							M
52	H_2 Dispensers for Aircraft (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)		57		X							M
53	H_2 Dispensers for UAVs (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)		56		X							M
54	H_2 Dispensers for Airport Vehi-cles (Includes: permanently installed dispensers, portable dispensers, LH_2/GH_2 high-pressure and low-pressure dispensers)		71		X							M
55	H_2-Powered Ships (Includes: LH_2 marine, GH_2 marine, ships, tugboats, boats, submarines, unmanned marine vehicles)		72					X				M
56	H_2-Powered Aircraft (Includes: LH_2 airplanes, GH_2 airplanes, rigid blimps, dirigi-bles, helicopters)		58			X						M
57	H_2-Powered Unmanned Aerial Vehicles (UAVs) (Includes: LH_2 and GH_2 drones)		22							X		M
58	H_2 Airport Vehicles (Includes: LH_2/GH_2 vehicles, airplane tugs, ground power units (GPUs), airport trucks, baggage handling trucks)		55		X	X		X				M

Element #	Element Name	Gap	Overall Rating Rank	CDN Standard Exists		No CDN Standard Exists			No Standard Exists		Wait until technology has matured or commercialized	Timeline for Action
				For H_2: No immediate action; periodic review	For similar equipment: Use as-is or update	Reference or adopt existing U.S. standard(s)	Reference or adopt existing regional standard(s)	Reference or adopt existing international standard(s)	Develop new standard(s)	Wait for standard(s) under development		
59	H_2 Dispensers for Surface Mining Vehicles (Includes: LH_2/GH_2 surface vehicle dispensers, high-pressure and low-pressure dispensers)	●	23		X							M
60	GH_2 Dispensers for Underground Mining Vehicles (Includes: high-pressure and low-pressure dispensers)	●	40		X							M
61	H_2 Heavy-Duty Surface Mining Equipment (Includes: trucks, loaders, dozers, graters)	●	50		X							M
62	H_2 Heavy-Duty Underground Mining Equipment (Incudes: underground trucks and locomotives)	●	51		X							M
63	H_2 Heating & Ventilation Systems for Underground Mining	●	53		X							M
64	Chemical Production	●	35		X							M
65	Fertilizers	○	33	X								L
66	Synthetic Fuels	●	28		X					X		M
67	Steel Production	●	15		X	X	X					S
68	Cement Plants	●	47		X							M
69	Items Common to all Applications (See table below for list of items)	X										
70	Common Installation Items (Includes: installation codes, building codes, fire codes, gas metering)	X										
71	Oil & Gas	●	29			X						M
72	Diesel-H_2 Trucks	●	73		X							M

Element 69 – Items Common to All Applications

Air compressors	Fire alarm systems	Material compatibility
Area classification	Flame sensors	Personnel qualification and training
Component testing (e.g., fuel cells, material properties, fire ratings)	Fuel cell stack	Pressure regulating equipment
Compressors	Fuel cells	Pressure relief devices
Control equipment	Functional safety	Pressure vessels
Disposal	Gas valve train	Recycling
Electrical equipment	Hydrogen quality	Refurbishment
Electromagnetic compatibility	Hydrogen sensors, including leak detection	Risk assessment
Emergency response	Hydrogen venting	Static electricity
Enclosures	Lightning protection	