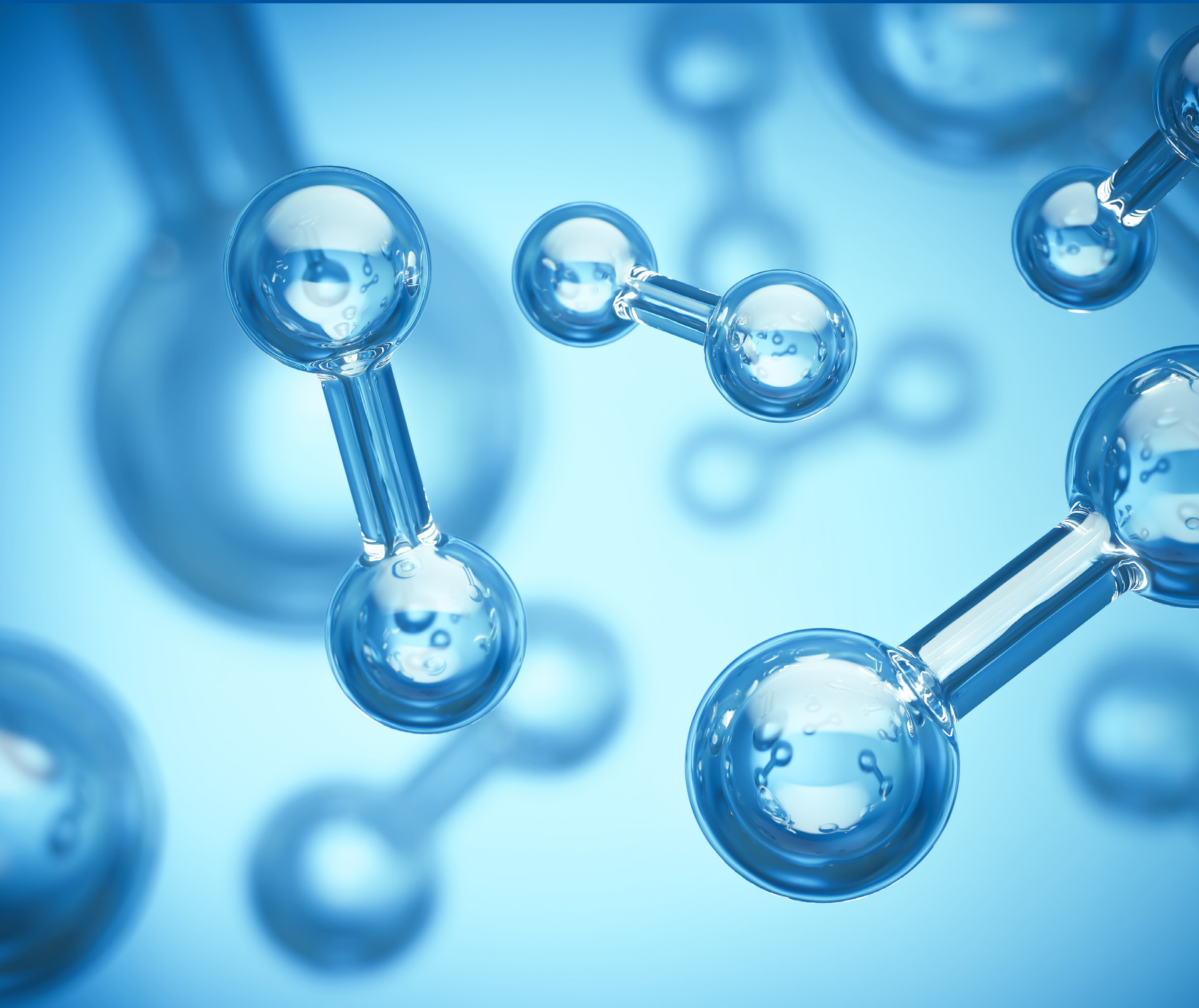
TGP-1 GUIDELINES TO ASME STANDARDS IN

HYDROGEN VALUE CHAINS



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Date of Issuance: June 29, 2023
This publication was prepared by ASME Standards Technology, LLC ("ASME ST-LLC") and sponsored by The American Society of Mechanical Engineers ("ASME"), New Product Development.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
Two Park Avenue, New York, NY 10016-5990

ISBN No. 978-0-7918-7630-5

ASME TGP-1-2023: GUIDELINES TO STANDARDS IN HYDROGEN VALUE CHAINS

CONTENTS

LIST OF TABLES

FOREWORD

Development of hydrogen infrastructure, either newly built or retrofitting existing infrastructure has been one of the major challenges the industry is facing toward reaching the zero carbon goals. The need for assessment and alignment of industry standards in hydrogen value chains (production, transportation, storage, and end use) is well recognized. This guidance document has been developed to summarize the existing hydrogen-related standards (ASME and non-ASME).

The authors acknowledge, with deep appreciation, the activities of ASME volunteers and staff who have provided valuable technical input, advice, and assistance with reviewing of, commenting on, and editing of, this document.

Established in 1880, ASME is a professional not-for-profit organization with more than 100,000 members and volunteers promoting the art, science, and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit https://www.asme.org/ for more information.

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Learn more about the ASME Hydrogen Solutions Portfolio

ABSTRACT

The repurposing of the existing infrastructure requires intensive evaluation. There are numerous programs worldwide that have been completed or are ongoing that address issues with such a transition. Although there is considerable data and information on the effects of hydrogen introduction into a natural gas network, it is recognized that the industry knowledge related to the assessment of materials, components, and equipment compatibility with hydrogen service, under various conditions is still continuously developing as knowledge is gained through ongoing laboratory research and testing programs, pilot studies, and early hydrogen deployment efforts.

Revisions to existing standards and guidelines, or an overall unified guideline is beneficial to support various practitioners in understanding the aspects required to ensure the safety of such networks and components. It is recognized that much of the existing hydrogen guidance was developed for new design, focused in many cases on pure hydrogen service. However, these standards and existing guidance may not address all considerations necessary for the conversion of existing infrastructure, for example considering blending of hydrogen in existing natural gas systems in lower concentrations.

The primary objective of this report is to provide a guidance document to be used by practitioners to better understand the standards and publications issued by ASME relevant to hydrogen service.

The scope of work summarized in this report includes identifying a list of documents ASME provides in relation to its Hydrogen Portfolio. For each product identified, the report provides a review to assess and characterize:

- Where the document lies on the hydrogen landscape.
- The audience the document is addressing, e.g., manufacturers, designers.
- Usability of the documents within the hydrogen industry landscape (high-level).
- Areas of confusion (if any) concerning the use of the documents.

1. PURPOSE AND USE

The intent of this guidance document is to:

- summarize the existing standards in hydrogen value chains
- identify relevant standards for specific hydrogen applications

The intent is to enable users to quickly identify the relevant Codes and Standards for their various applications. This guidance document is intended to provide high-level insights on the existing standards to various practitioners in hydrogen value chains such as engineers, managers, owners, system operators, manufacturers, the public, inspection parties, regulators, and other stakeholders. Standards published by other organizations such as API, ISO, AMPP (Formally NACE), and CGA are also discussed and included where relevant.

2. RELEVANT STANDARDS FOR HYDROGEN APPLICATIONS

This section discusses relevant standards for hydrogen applications, which include ASME documents and standards published by other organizations. Section 2.1 provides a general discussion of ASME documents in hydrogen value chains while Section 2.2 provides a list of relevant standards based on hydrogen applications (productions, transportation, storage, and end use), which includes both documents issued by ASME and other organizations. High-level commentary and key considerations for the standards and applications are also provided. Further detailed discussions for the specific applications can be found in the specific standards.

2.1 RELEVANT ASME DOCUMENTS

This section identifies a list of ASME documents in relation to its hydrogen portfolio listed in Table 1. Additional ASME technical conference papers (e.g., through Pressure Vessels & Piping Conference [PVP]), while relevant to hydrogen application, are listed in Appendix A.

Table 1: ASME Standards & Publications Relevant to Hydrogen Value Chains
B31.12 Hydrogen Piping and Pipelines
B31.3 Process Piping
B31.4 Pipeline Transportation Systems for Liquids and Slurries
B31.8 Gas Transmission and Distribution Piping Systems
B31.8S Managing System Integrity of Gas Pipelines
BPVC Section VIII, Division 1
BPVC Section VIII, Division 2
BPVC Section VIII, Division 3
BPVC Section X Fiber-Reinforced Plastic Pressure Vessels
BPVC Section XII Rules for Construction and Continued Service of Transport Tanks
STP-PT-003 Hydrogen Standardization Interim Report for Tanks, Piping, and Pipelines
STP-PT-005 Design Factor Guidelines for High-Pressure Composite Hydrogen Tanks
STP-PT-006 Design Guidelines for Hydrogen Piping and Pipelines
STP-PT-014 Data Supporting Composite Tank Standards Development for Hydrogen Infrastructure Applications
STP-PT-017 Properties for Composite Materials in Hydrogen Science
STP-PT-021 Nondestructive Testing and Evaluation Methods for Composite Hydrogen Tanks
STP-PT-023 Guidelines for In-Service Inspection of Composite Pressure Vessels
STP-PT-043 Flawed Cylinder Testing
STP-PT-064 Evaluation of Fracture Properties Test Methods for Hydrogen Service
Code Case 2938 – Hydrogen Crack Growth Rate Constants, Thresholds Stress Intensity Factor KIH, and Critical Crack Size Requirements for SA-372 and SA-723 Steels
Code Case 2949 – Composite Pressure Vessel Consisting of Inner Steel Layered Shell and Outer Reinforced and Prestressed Concrete Shell for Hydrogen Service for Class 2
B31G – Manual for Determining the Remaining Strength of Corroded Pipelines
PTC 50 – Performance Test Code for Fuel Cell Power Systems Performance

A commentary for each ASME reference listed in Table 1 can be found below:

(a) The B31.12 code is currently the standard for new construction of hydrogen piping and pipelines utilized by the project owner and designer. ASME B31.12 also provides considerations for repurposing pipelines for hydrogen service.

(b) The B31.12 code, particularly Part IP – Industrial Piping, refers to B31.3 for technical information for some items.

(c) Comparison between B31.4 and B31.12 is necessary when converting a liquid pipeline to hydrogen service.

(d) Comparison between B31.8 and B31.12 is necessary when converting a natural gas pipeline to hydrogen service as well as hydrogen-natural gas blending applications.

(e) Integrity management adjustment by conducting a thorough review of B31.8S and B31.12 is necessary when injecting hydrogen into a natural gas network for hydrogen-natural gas blending applications.

(f) Currently, hydrogen pressure vessels typically meet ASME BPVC Section VIII Division 1 although hydrogen service is not specifically addressed.

(g) Pressure Vessels and Storage Tanks designed for hydrogen meeting ASME BPVC Section VIII Division 2 are available in the market although hydrogen service is not specifically addressed.

(h) Article KD-10 provides special requirements for high-pressure vessels (exceeding 6,000 psi, and up to 15,000 psi) in hydrogen service – fatigue life evaluation using fracture mechanics.

(i) ASME BPVC Section X provides requirements for Class I, II, and III fiber-reinforced plastic (FRP) pressure vessels. The specifications in Mandatory Appendix 8 address specific considerations for high pressure Class III hydrogen storage vessels in stationary service.

(j) ASME BPVC Section XII addresses requirements for transport tanks for liquid and gaseous hydrogen. Though, some transport tanks are still under ASME BPVC Section VIII, Division 2 that have not been incorporated in ASME BPVC Section XII.

(k) The scope of STP-PT-003 includes addressing standardization issues related to storage tanks, transportation tanks, portable tanks, and piping and pipelines in hydrogen service.

(l) STP-PT-005 provides recommendations to the ASME Hydrogen Project Team for design factors for composite hydrogen tanks. The scope of this study included stationary (e.g., storage) and transport tanks; it does not include vehicle fuel tanks.

(m) STP-PT-006 provides recommendations and guidance to the B31.12 Committee. This includes all common metallic piping and pipeline materials used in the construction of piping and pipeline systems of seamless and welded construction, composite reinforced welded or seamless metallic lined piping and pipelines, and composite reinforced plastic-lined piping and pipelines. Practitioners designing, constructing, and operating hydrogen piping and pipelines are encouraged to review this document in addition to B31.12.

(n) STP-PT-014 provides data to support recommendations for composite cylinders by providing a review of the history of the use of composite cylinders in aerospace/defense, commercial and vehicle applications. This includes review of applications, materials of construction, standards used, and field service issues.

(o) STP-PT-017 provides discussions on studies conducted to address specific questions related to the use of composite-reinforced pressure vessels for the transportation of compressed hydrogen at pressures up to 103 MPa (15,000 psi).

(p) STP-PT-021 includes a study of various nondestructive evaluation (NDE) techniques for composite overwrapped pressure vessels intended for gaseous hydrogen infrastructure applications.

(q) STP-PT-023 describes the procedures and recommendations for in-service inspection of high pressure composite tanks made to ASME code requirements and used for the shipping or storage of hydrogen.

(r) STP-PT-043 provides a discussion of the effect of flaws with and without cyclic loading that were investigated on a composite overwrapped pressure vessel with a non-load sharing polymer liner.

(s) STP-PT-064 evaluates testing methods on the measurement of fracture properties for the design of ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 (ASME BPVC VIII-3) pressure vessels for hydrogen service.

(t) Code Case 2938 provides simplified relationships for fatigue crack growth rates in hydrogen and accounting for load ratio (R) and also includes Master Curves – design-based methods for pressure vessels as well as KIH values for design.

(u) Code Case 2949 covers the design, construction, and stamping of a composite vessel consisting of an inner layered vessel and an outer reinforced and prestressed concrete vessel used for pressurized hydrogen gas storage service. Construction is in accordance with ASME BPVC Section VIII, Division 2, Class 2.

(v) B31G is a supplement to the ASME B31 code for pressure piping. Potential use of this document includes assessing the remaining strength of corroded pipelines to be converted into hydrogen service.

(w) PTC 50 provides performance requirements for fuel cells for electricity and thermal energy generation.

2.2 RELEVANT DOCUMENTS FOR HYDROGEN APPLICATIONS

The ASME documents listed in Table 1, together with documents provided by other parties (e.g., API, CGA, EIGA, and ISO), relevant to specific applications in the hydrogen value chain are identified and listed in this section. These specific applications include hydrogen production, transportation, storage, and end use.

2.2.1 HYDROGEN PRODUCTION

Hydrogen can be produced through various processes such as thermochemical (e.g., SMR, gasification, ATR, and pyrolysis), electrolysis, microbial, and photoelectrical synthesis. Table 2 shows the list of relevant documents for hydrogen production published by ASME while Table 3 shows relevant documents issued by other organizations. Examples of potential users of these documents are listed in Table 4.

Table 2: ASME Relevant Documents for Hydrogen Production

Document Type	Document No.	Title
Code	ASME BPVC Section VIII – Div. 1, 2, and 3	Boiler and Pressure Vessel Code (BPVC) Section VIII
Code	ASME B31.12	Hydrogen Piping and Pipelines
Code	ASME B31.3	Process Piping

Table 3: Other Relevant Documents for Hydrogen Production

Document Type	Document No.	Title
Standard	ISO 22734	Hydrogen Generators Using Water Electrolysis — Industrial, Commercial, and Residential Applications
Standard	ISO 26142	Hydrogen Detection Apparatus - Stationary Applications
Standard	ISO/TR 15916	Basic Considerations for The Safety of Hydrogen Systems
Standard	ISO 14687	Hydrogen Fuel Quality — Product Specification
Outline	UL 2264A	Outline of Investigation for Water Electrolysis Type Hydrogen Generators
Outline	UL 2264B	Hydrogen Generators Using Water Reaction
Outline	UL 2264D	Portable Water Electrolysis Type Hydrogen Generators
Code	NFPA 2	Hydrogen Technologies Code
Standard	NFPA 855	Standard for the Installation of Stationary Energy Storage Systems
Standard	NFPA 68	Standard on Explosion Protection by Deflagration Venting
Standard	NFPA 69	Standard on Explosion Prevention Systems
Code	NFPA 55	Compressed Gases and Cryogenic Fluids Code
Code	NFPA 70	National Electrical Code
Standard	NFPA 221	Standard for High Challenge Fire Walls, Fire Walls, and Fire Barrier Walls
Standard	IFGC – Chapter 7	Gaseous Hydrogen Systems
Code	IFC	International Fire Code
Standard	CGA G-5.5	Standard For Hydrogen Vent Systems
Standard	AIGA 033 EIGA (IGC 121) CGA G-5.6	Hydrogen Pipeline Systems (Harmonized Documents)
Standard	EIGA (IGC 155/09/E)	Best available techniques for hydrogen production by steam methane reforming
Standard	EIGA Doc 183	Best Available Techniques for the co-production of hydrogen, carbon monoxide, and their mixtures by steam reforming
Standard	EIGA (IGC 122/04)	Environmental impacts of hydrogen plants
Standard	ISO 16110-1	Hydrogen generators using fuel processing technologies — Part 1: Safety
Standard	ISO 16110-2	Hydrogen generators using fuel processing technologies — Part 2: Test methods for performance
Standard	ISO/TS 19883	Safety of pressure swing adsorption system for hydrogen separation and purification
Standard	CSA FC4 / CSA C22.2 No. 22734	Hydrogen Generators using Water Electrolysis — Industrial, Commercial and Residential Applications

Document Type	Document No.	Title
Standard	CGA H-10	Combustion Safety for Steam Reformer Operation
Standard	CGA H-11	Safe Startup and Shutdown Practices for Steam Reformers
Standard	CGA H-12	Mechanical Integrity of Syngas Outlet Systems
Standard	CGA H-13	Hydrogen Pressure Swing Adsorber (PSA) Mechanical Integrity Requirements
Standard	CGA H-14	HYCO Plant Gas Leak Detection and Response Practices
Standard	CGA H-15	Safe Catalyst Handling in HYCO Plants

Table 4: Potential Users of the Documents

Applications	Examples of Document Users
Hydrogen generation via electrolysis	• Electrolyzer manufacturers • Project owner and designer • Pipe / vessel / equipment suppliers • Engineering, procurement, and construction firms • Consulting firms • Regulators (e.g., DOT) • System operator
Hydrogen generation via thermochemical (e.g., SMR, ATR. and coal gasification)	• Project owner and designer • Pipe / vessel / equipment suppliers • Engineering, procurement, and construction firms • Consulting firms • Regulators (e.g., DOT) • System operator / plant owner
Hydrogen generation via microbial and others	• Researchers • Academia • Consulting firms

Table 5 provides examples of relevant documents for applications pertaining to hydrogen production via electrolysis.

Table 5: Relevant Documents for Hydrogen Production through Electrolysis Processes	
Applications	**Relevant Documents**
Hydrogen generation via electrolysis	• ISO 22734 • ISO 26142 • ISO/TR 15916 • ISO 14687 • UL 2264A • UL 2264B • UL 2264D • NFPA 2 • NFPA 855 • NFPA 68 • NFPA 69 • NFPA 55 • NFPA 70 • NFPA 221 • IFGC – Chapter 7 • IFC • CSA FC4 / CSA C22.2 No. 22734 • AIGA 033 • EIGA (IGC 121) • CGA S-1.1 • CGA G-5.5 • CGA G-5.6 • ASME B31.12 • ASME BPVC Section VIII

Commentaries regarding some of the references listed in Table 5 can be found below:

(a) ISO 22734 first edition cancels and replaces ISO 22734-1:2008 and ISO 22734-2:2011, which have been combined and technically revised.

(b) CSA Group is working with the Compressed Gas Association (CGA) regarding the adoption of ISO 22734 with US deviations.

(c) UL 2264A is only an outline at this point and is expected to be superseded by CSA/ANSI 22734.

(d) CAN/BNQ 1784-000/2022 refers to ISO 22734 for electrolyzer installations.

(e) NFPA 2, ISO 26142, and ISO/TR 15916 provide considerations for the safety of hydrogen systems. ISO 14687 provides considerations on determining suitability of electrolyzer hydrogen output for various applications.

(f) CSA FC4 / CSA C22.2 No. 22734 is an adoption with U.S. and Canadian deviations of the identically titled ISO standard ISO 22734. The standard applies to the construction, safety, and performance requirements of modular or factory-matched hydrogen gas generation appliances, herein referred to as hydrogen generators, using electrochemical reactions to electrolyze water to produce hydrogen.

(g) ASME has an agenda item to determine how ASME Pressure Vessel Codes should apply to electrolyzers.

Hydrogen can also be produced through thermochemical and other processes. Standards applicable for these processes can be found in Table 6. Hydrogen generation via thermochemical, specifically via steam methane reforming (SMR) is currently the most widely used process to generate hydrogen for refineries and chemical industries. The technology is relatively more mature than electrolysis. Other processes such as microbial electrolysis, biomass dark fermentation, and photoelectrical synthesis are currently in the research stage with limited applicable standards.

Table 6: Relevant Documents for Hydrogen Production through Thermochemical and Other Processes

Applications	Relevant Documents
Hydrogen generation via thermochemical (e.g., SMR, ATR., and gasification)	• ISO 16110-1 • ISO 16110-2 • ISO 26142 • ISO/TR 15916 • ISO/TS 19883 • ISO 14687 • CGA H-10 • CGA H-11 • CGA H-12 • CGA H-13 • CGA H-14 • CGA H-15 • EIGA (IGC 155/09/E) • EIGA (IGC 122/04) • EIGA Doc 183 • NFPA 2 • NFPA 855 • NFPA 68 • NFPA 69 • NFPA 55 • NFPA 221 • IFGC – Chapter 7 • IFC • AIGA 033 • EIGA (IGC 121) • CGA G-5.5 • CGA G-5.6 • ASME B31.12 • ASME B31.3 • ASME BPVC Section VIII
Hydrogen generation via microbial and others	• N/A

2.2.2 HYDROGEN TRANSPORTATION

Hydrogen can be transported via pipelines, trucks, rail, and ships in gaseous or liquefied form as well as via chemical carrier (e.g., ammonia, liquid-organic hydrogen carrier [LOHC], and methanol) and metal hydrides. This section provides lists of relevant documents for hydrogen transportation based on various applications such as new construction of a hydrogen pipeline, retrofitting existing pipelines to hydrogen service, and compressor stations. Table 7 shows the list of relevant documents for hydrogen transportation published by ASME while Table 8 shows relevant documents issued by other organizations. The examples of potential users of these documents are listed in Table 9.

Table 7: ASME Relevant Documents for Hydrogen Transportation

Document Type	Document No.	Title
Code	ASME B31.12	Hydrogen Piping and Pipelines
Code	ASME B31.8	Gas Transmission and Distribution Piping Systems
Code	ASME B31.8S	Managing System Integrity of Gas Pipelines
Code	ASME B31.4	Pipeline Transportation Systems for Liquids and Slurries
Code	ASME B31.3	Process Piping
Code	ASME B31G	Manual for Determining the Remaining Strength of Corroded Pipelines
Code	ASME NM.1	Thermoplastic Piping Systems
Code	ASME NM.2	Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems
Code	ASME NM.3.1, 3.2, 3.3	Part 1 - Thermoplastic Material Specifications, Part 2 - Reinforced Thermoset Plastic Material Specifications, and Part 3 - Properties
Interim report	ASME STP-PT-003	Hydrogen Standardization Interim Report for Tanks, Piping, and Pipelines
Report	ASME STP-PT-006	Design Guidelines for Hydrogen Piping and Pipelines
Code	ASME BPVC Section VIII, Division 3	ASME BPVC Section VIII Div 3: Alternative Rules for Construction of High Pressure Vessels [Title of Paragraph KG-521: Composite Reinforced Pressure Vessels (CRPV) Used in Transport Service]

Table 8: Other Relevant Documents for Hydrogen Transportation

Document Type	Document No.	Title
Code of Federal Regulations	49 CFR Part 172	Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements, and Security Plans
Code of Federal Regulations	49 CFR Part 174	Carriage by Rail
Standard	IGEM/TD/1 Supplement 2	High Pressure Hydrogen Pipelines
Standard	IGEM/TD/3 Supplement 1	Repurposing of Natural Gas (NG) pipelines with MOP not exceeding 7 bar for NG/Hydrogen blends
Standard	IGEM/TD/13 Supplement 1	Pressure regulating installations for Natural Gas/Hydrogen blended mixtures at pressures not exceeding 7 bar
Standard	CSA Z662	Oil and gas pipeline systems
Standard	AMPP NACE MR0175 / ISO 15156	Petroleum And Natural Gas Industries – Materials For Use In H2S-Containing Environments In Oil And Gas Production
Standard	AMPP NACE TM0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking
Standard	DNVGL-ST-F101	Submarine Pipeline Systems
Standard	AIGA 033 EIGA (IGC 121) CGA G-5.6	Hydrogen Pipeline Systems (Harmonized Documents)
Standard	EIGA IGC Doc 15/06/E	Gaseous hydrogen stations
Standard	IGC 100/03	Hydrogen cylinders and transport vessels
Standard	API 5L	Line Pipe
Standard	API 617	Axial And Centrifugal Compressors And Expander Compressors
Standard	AIGA 087 CGA G-5.4	Standard for Hydrogen Piping Systems at User Locations (Harmonized Documents)
Standard	CGA G-5.8	High Pressure Hydrogen Piping Systems at Consumer Locations
Publication	CGA P-12	Safe Handling of Cryogenic Liquid
Position Statement	CGA PS-48	CGA Position Statement on Clarification Of Existing Hydrogen Setback Distances And Development Of New Hydrogen Setback Distances In NFPA 55
Standard	CGA H-1	Service Conditions for Portable, Reversible Metal Hydride Systems
Standard	CGA H-2	Guidelines for the Classification and Labelling of Hydrogen Storage Systems with Hydrogen Absorbed in Reversible Metal Hydrides

Document Type	Document No.	Title
Standard	CGA H-5	Installation Standards for Bulk Hydrogen Supply Systems
Code	NFPA 2	Hydrogen Technologies Code
Code	NFPA 55	Compressed Gases And Cryogenic Fluids Code
Code	CSA B51	Boiler, Pressure Vessel, and Pressure Piping Code
Standard	CSA Z662	Oil and Gas Pipeline Systems
Code	CAN-BNQ 1784	Canadian Hydrogen Installation Code
Standard	ISO 16111	Transportable Gas Storage Devices — Hydrogen Absorbed in Reversible Metal Hydride
Standard	API 618	Reciprocating Compressors For Petroleum, Chemical, And Gas Industry Services
Standard	API 1104	Welding Pipelines And Related Facilities

Table 9: Potential Users of the Documents

Applications	Examples of Document Users
Hydrogen pipelines	• Transmission Service Operators (TSOs) • Distribution Service Operators (DSOs) • Project designers • Pipe suppliers • Regulators (e.g., PHMSA and Texas RRC)
Hydrogen trucks / rail / ships	• Trucks / rail / ships OEMs • TSOs and DSOs • Project designers • Regulators (e.g., DOT)
Hydrogen chemical carriers	• Chemical plant operators • Project designers • Regulators (e.g., DOT) • Researchers and academia

2.2.2.1 PIPELINES

Table 10 provides examples of relevant documents for purpose-built new hydrogen pipeline construction.

Table 10: Relevant Documents for Hydrogen Pipelines (New Construction)

Applications	Relevant Documents
New construction: hydrogen pipelines	• ASME B31.12 • ASME STP-PT-003 • ASME STP-PT-006 • AMPP NACE MR0175 • API 1104 • API 5L • IGEM/TD/1 Supplement 2 • IGEM/TD/3 Supplement 1 • IGEM/TD/13 Supplement 1 • CSA Z662

Commentaries on the references listed in Table 10 can be found below:

(a) ASME B31.12 is the standard for hydrogen piping and pipelines.

(b) Prior to the first edition of ASME B31.12, hydrogen transmission pipeline operators appear to consider AMPP NACE MR0175.

(c) ASME B31.12 focuses on toughness management and fatigue crack growth rate (FCGR) while NACE MR 0175 focuses on hydrogen cracking prevention.

(d) ASME B31.12 is currently the most relevant standard for hydrogen and hydrogen blend pipelines.

(e) Supplemental requirements of API 5L may be needed to meet the ASME B31.12 requirements for the line pipe.

(f) API 1104 provides the starting point for the weld design with additional welding concerns per ASME B31.12.

Natural gas pipelines may be converted to hydrogen service, with examples of relevant documents shown in Table 11.

Table 11: Relevant Documents for Repurposing Natural Gas Pipelines for Hydrogen Service

Applications	Relevant Documents
Repurpose: natural gas pipelines	• ASME B31.12 • ASME STP-PT-003 • ASME STP-PT-006 • ASME B31.8 • ASME B31G • API 1104 • API 5L • AIGA 033 • EIGA (IGC 121) • CGA G-5.6 • ASME NM.1, NM.2, NM.3.1, NM 3.2, NM 3.3. • ISO 136623 • IGEM/TD/1 Supplement 2 • IGEM/TD/3 Supplement 1 • IGEM/TD/13 Supplement 1 • CSA Z662

Commentaries on the references listed in Table 11 can be found below:

(a) ASME B31.12 provides requirements on the conversion of existing pipelines to hydrogen service.

(b) In the US, natural gas lines typically follow the design requirements described in ASME B31.8 and 49CFR Part 192 and are constructed of steel pipe meeting the requirements of API 5L.

(c) Conversion of NG lines for hydrogen service requires a side-by-side comparison between ASME B31.8 and B31.12.

(d) PHMSA provides guidance on changes of product, applicable to the case of conversion of existing pipelines to hydrogen service.

(e) AIGA 033, EIGA (IGC 121), and CGA G-5.6 harmonized documents provide recommended practices on the requalification of existing pipelines for hydrogen service (Appendix H).

(f) The ASME non-metallic materials code (ASME NM.1 to NM.3) should be reviewed when repurposing non-metallic natural gas distribution networks.

(g) ISO 13623 covers gas pipelines and addresses hydrogen as a Category E product. No specific guidance is given for hydrogen, other than for cases with sour service, and from excess CP.

Liquid and slurry pipelines may be converted to hydrogen service, with examples of relevant documents shown in Table 12.

Table 12: Relevant Documents for Repurposing Liquid and Slurry Pipelines for Hydrogen Service	
Applications	**Relevant Documents**
Repurpose: liquid and slurry pipelines	•ASME B31.12 •ASME STP-PT-003 •ASME STP-PT-006 •ASME B31.4 •ASME B31G •API 1104 •API 5L

Commentaries on the references listed in Table 12 can be found below:

(a) Liquid and slurry lines typically follow the design requirements described in ASME B31.4.
(b) ASME B31.12 provides requirements on conversion of existing pipelines to hydrogen service.
(c) PHMSA provides guidance on changes of product, applicable to the case of conversion of existing pipelines to hydrogen service.
(d) Conversion of liquid or slurry lines for hydrogen service requires a side-by-side comparison between ASME B31.4 and B31.12.

For natural gas – hydrogen blend pipelines, Table 13 provides a list of relevant documents.

Table 13: Relevant Documents for Natural Gas – Hydrogen Blend Pipelines	
Applications	**Relevant Documents**
Natural gas – hydrogen blend pipelines	• ASME B31.12 • ASME STP-PT-003 • ASME STP-PT-006 • ASME B31.8 • ASME B31G • API 1104 • API 5L • ASME NM.1, NM.2, NM.3.1, NM 3.2, NM 3.3. • IGEM/TD/1 Supplement 2 • IGEM/TD/3 Supplement 1 • IGEM/TD/13 Supplement 1 • CSA Z662

Commentaries on the references listed in Table 13 can be found below:

(a) NG lines and hydrogen lines typically follow ASME B31.8 and B31.12, respectively.
(b) ASME B31.12 provides requirements on the conversion of existing pipelines to hydrogen service.
(c) PHMSA provides guidance on changes of product, applicable to the case of conversion of existing pipelines to hydrogen service.
(d) The 2019 edition of ASME B31.12 states the code is not applicable up to 10% hydrogen by volume. No further discussions are provided pertaining to the basis of the 10% limit.
(e) The ASME non-metallic materials code (ASME NM.1 to NM.3) will have to be reviewed when blending hydrogen in natural gas distribution networks.

Conversion into hydrogen service will not only impact the pipeline, but also pipeline system components such as compressor stations. Table 14 provides a list of relevant documents pertaining to repurposing compressor stations designed for natural gas to hydrogen service.

Table 14: Relevant Documents for Repurposing Compressor Station for Hydrogen Service

Applications	Relevant Documents
Compressor Station	•ASME B31.12 •ASME STP-PT-003 •ASME STP-PT-006 •ASME B31.8 •API 617 •API 618

Commentaries on the references listed in Table 13 can be found below:

(a) While API 617 and 618 discuss some limitations of compressors exposed to hydrogen service, guidelines on refitting compressors designed for natural gas into hydrogen or natural gas – hydrogen blend service are not provided.
(b) Comparisons between ASME B31.12 and B31.8 on the requirements for compressor stations will have to be established when refitting natural gas compressor stations for hydrogen service.

Pertaining to offshore hydrogen pipelines, Table 15 provides a list of relevant documents. ASME B31.12 appears to be developed mainly for onshore pipelines. Offshore pipelines require further requirements laid out in DNVGL-ST-F101 with additional considerations for hydrogen service to be assessed.

Table 15: Relevant Documents for Offshore Hydrogen Pipelines

Applications	Relevant Documents
Offshore hydrogen pipelines	•DNVGL-ST-F101 •ASME B31.12

2.2.2.2 TRUCKS / RAIL / SHIPS

When transporting hydrogen in trucks, by rail, and by ships, the relevant standards for hydrogen storage and handling discussed in Section 2.2.3 will also apply as hydrogen is transported in a transportable container such as a storage tube for compressed gaseous hydrogen and cryogenic tank (road tanker) when transporting liquefied hydrogen. The current US regulations for tanker trucks are covered in Department of Transportation (DOT) 49 CFR Part 172 (provisions T75 and TP5) while rail transport is covered in DOT 49 CFR Part 174.

2.2.2.3 CHEMICAL CARRIERS

Hydrogen can be transported via chemical carriers such as in the form of ammonia, methanol, liquid organic hydrogen carrier (LOHC), and metal hydrides. These modes of transportation typically require chemically bonding hydrogen with the carrier prior to transportation (e.g., through pipelines, trucks, rail, and ships) and a reconversion process, either fully or partially, to hydrogen. A list of relevant documents pertaining to hydrogen transportation via chemical carriers is shown in Table 16.

Table 16: Other Relevant Documents for Hydrogen Chemical Carriers

Applications	Relevant Documents
Ammonia	• ASME B31.3 • ASME B31.4 • API 1104 • API 5L
LOHC / Methanol	• ASME B31.3 • API 1104 • API 5L
Metal hydrides	• ISO 16111 •CGA H-1 •CGA H-2

Commentaries on the applications and references in Table 16 can be found below:

(a) Ammonia transport via pipeline and ships has been well established due to the long history of ammonia use for fertilizer.
(b) ASME B31.4 is applicable for long-distance ammonia transport.
(c) ASME B31.3 is applicable for plant / process piping.
(d) Effectiveness of hydrogen transport using liquid organic hydrogen carrier (LOHC) is subject to further research. However, the LOHC is liquid at ambient conditions allowing potential retrofitting of the existing liquid pipeline for hydrogen transport.
(e) ISO 16111 defines the requirements applicable to the material, design, construction, and testing of transportable hydrogen gas storage systems, referred to as “metal hydride assemblies”.

2.2.3 HYDROGEN STORAGE

Hydrogen can be stored in gaseous or liquefied form in pressure vessels. Table 17 shows the list of relevant documents for hydrogen storage published by ASME while

Table 18 shows relevant documents issued by other organizations. The examples of potential users of these documents are listed in Table 19. The potentially relevant documents for various hydrogen applications can be found in Table 20 through Table 23.

Table 17: ASME Relevant Documents for Hydrogen Storage

Document Type	Document No.	Title
Code	BPVC Section VIII, Division 1	Boiler and Pressure Vessel Code Section VIII, Division 1 Rules for Construction of Pressure Vessels
Code	BPVC Section VIII, Division 2	Boiler and Pressure Vessel Code Section VIII, Division 2 Rules for Construction of Pressure Vessels - Alternative Rules
Code	BPVC Section VIII, Division 3	Boiler and Pressure Vessel Code Section VIII, Division 3 Alternative Rules for Construction of High Pressure Vessels
Code	BPVC Section X	Fiber-Reinforced Plastic Pressure Vessels
Report	STP-PT-003	Hydrogen Standardization Interim Report For Tanks, Piping, And Pipelines
Report	STP-PT-005	Design factor guidelines for high pressure composite hydrogen tanks
Report	STP-PT-017	Properties for Composite Materials in Hydrogen Service
Report	STP-PT-021	Nondestructive Testing and Evaluation Methods for Composite Hydrogen Tanks
Report	STP-PT-023	Guidelines for In-Service Inspection of Composite Pressure Vessels
Report	STP-PT-043	Flawed Cylinder Testing
Report	STP-PT-064	Evaluation of Fracture Properties Test Methods for Hydrogen Service

Table 18: Other Relevant Documents for Hydrogen Storage

Document Type	Document No.	Title
Code	NFPA 55	Compressed Gases and Cryogenic Fluids Code [Chapter 10: Gas Hydrogen Systems]
Standard	IGC 100/03/E, EIGA	Hydrogen Cylinders and Transport Vessels
Standard	IGC 114/09, EIGA	Operation of Static Cryogenic Vessels
Standard	IGC 06/02, EIGA	Safety in Storage, Handling and Distribution of Liquid Hydrogen
Standard	ISO 16111	Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride
Standard	ISO 11114-1	Gas Cylinders – Compatibility of cylinder and valve materials with gas contents – Part 1: Metallic materials
Standard	ISO 11114-2	Gas Cylinders – Compatibility of cylinder and valve materials with gas contents – Part 2: Non-metallic materials
Standard	ISO 11114-4	Transportable Gas Cylinders – Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement
Standard	ISO 9809-1	Gas Cylinders – Design, construction and testing of refillable seamless steel gas cylinders and tubes – Part 1: Quenched and tempered steel cylinders and tubes with tensile strength less than 1100 MPa
Standard	ISO 11120	Gas cylinders – Refillable seamless steel tubes of water capacity between 150 l and 3000 l – Design, construction and testing
Standard	ISO 20421-1	Cryogenic vessels – Large transportable vacuum insulated vessels – Part 1: Design, fabrication, inspection and testing
Standard	ISO 20421-2	Cryogenic vessels – Large transportable vacuum insulated vessels – Part 2: Operational requirements
Standard	ISO 21010	Cryogenic vessels – Gas/materials compatibility
Standard	ISO 21011	Cryogenic vessels – Valves for cryogenic service
Standard	ISO/WD 19884	Gaseous Hydrogen – Cylinders and Tubes for Stationary Storage
Standard	EN 17533	Gaseous Hydrogen – Cylinders and Tubes for Stationary Storage
Standard	EN 17339	Transportable Gas Cylinders – Fully Wrapped Carbon Composite Cylinders and Tubes for Hydrogen
Standard	CGA H5	Standard for Bulk Hydrogen Supply Systems
Standard	CGA H-3	Cryogenic Hydrogen Storage
Publication	CGA P-12	Safe Handling of Cryogenic Liquids
Publication	CGA P-28	OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems
Publication	CGA P-41	Locating Bulk Liquid Storage Systems in Courts

Document Type	Document No.	Title
Position Statement	CGA PS-20	The Direct Burial of Gaseous Hydrogen Storage Tanks
Position Statement	CGA PS-46	Roofs Over Hydrogen Storage Systems
Position Statement	CGA PS-33	Use of Liquefied Petroleum Gas or Propane Tanks as Compressed Hydrogen Storage Buffers
Specification	API 5CT	Specification for Casing and Tubing
Specification	49 CFR 178.37	Specification 3AA and 3AAX seamless steel cylinders

Table 19: Potential Users of the Documents

Applications	Examples of Document Users
Gas storage in Storage tanks, Cylinders, and Vessels (Stationary storage and transport)	Transmission Service Operators (TSOs) Storage Operators Cylinders and Vessel Manufacturers Regulators (e.g., PHMSA, OSHA, EPA)
Cryogenic vessels (Stationary storage and transport)	Storage Operators Cylinders and Vessel Designers and Manufacturers Regulators (e.g., PHMSA, OSHA, EPA)
Metal hydrides (Stationary storage and transport)	Storage Operators Regulators (e.g., PHMSA)
Underground vessel storage	Transmission Service Operators (TSOs) Storage Operators Regulators (e.g., PHMSA, OSHA, EPA)

Pertaining to stationary gaseous hydrogen storage, Table 20 provides a list of relevant documents. The listed documents provide considerations on:

(a) Requirements for design, fabrication, inspection, testing, and certification of pressure vessels used for hydrogen service (Division 3 only).
(b) Nondestructive evaluation (NDE) techniques, in-service inspection procedures, and fracture testing procedures (Division 3 only).
(c) Installation, storage, use, and handling of compressed hydrogen.
(d) Material compatibility of hydrogen with cylinder and valve.
(e) Safety concerns with roofs over stationary storage and recommendations for safe weather protection.
(f) Safety considerations for converting Liquefied petroleum gas (LPG) or propane service vessels for hydrogen.
(g) Pressure relief device selection and sizing for compressed hydrogen gas..

Stationary storage tanks for hydrogen typically meet ASME BPVC Section VIII Division 1, though Division 2 tanks are also available in the market. However, for high pressure storage (e.g., vehicle service stations), ASME BPVC Section VIII, Division 3 is typically used. ASME BPVC Section VIII Division 3, Article KD-10 currently covers hydrogen pressures over 6,000 psi. However, some experimental work in carbon steel has shown that even at low hydrogen partial pressures, hydrogen can have a significant effect. This has been identified as a gap that should be addressed. Additionally, ASME BPVC Section VIII, Divisions 1 and 2 do not address hydrogen service at all.

Table 20: Relevant Documents for Stationary Gaseous Hydrogen Storage

Applications	Relevant Documents
Stationary gas storage in storage tanks, cylinders, and vessels	• ASME BPVC Section VIII and X • ASME STP-PT-003 • ASME STP-PT-005 • ASME STP-PT-021 • ASME STP-PT-023 • NFPA 55 • IGC 100/03, EIGA • ISO 11114-1 • ISO 11114-2 • ISO 11114-4 • ISO 9809-1 • ISO 11120 • ISO/WD 19884 • EN 17533 • CGA H5 • CGA PS-20 • CGA PS-46 • CGA PS-33 • CGA S-1.1 • CGA S-1.3

Pertaining to transportable gaseous hydrogen storage, Table 21 provides a list of relevant documents. The listed documents provide considerations on:

(a) Requirements for construction and use of pressure vessels for transport (ASME BPVC Section VIII, Division 3).
(b) Nondestructive evaluation (NDE) techniques, in-service inspection procedures, and fracture testing procedures (ASME BPVC Section VIII, Division 3).
(c) Installation, storage, use, and handling of compressed hydrogen.
(d) Material compatibility of hydrogen with cylinder and valve.
(e) Pressure relief device selection and sizing for compressed hydrogen gas.

Table 21: Relevant Documents for Transportable Gaseous Hydrogen Storage	
Applications	**Relevant Documents**
Transportable gas storage in storage tanks, cylinders, and vessels	• 49 CFR 178.37 • ASME BPVC Section VIII and XII • ASME STP-PT-005 • ASME STP-PT-017 • ASME STP-PT-021 • ASME STP-PT-023 • NFPA 55 • IGC 100/03, EIGA • ISO 11114-1 • ISO 11114-2 • ISO 11114-4 • ISO 9809-1 • ISO 11120 • EN 17339 • CGA H5 • CGA S-1.1 • CGA S-1.2

Pertaining to stationary and transportable cryogenic hydrogen storage, Table 22 provides a list of relevant documents. The listed documents provide considerations on:

(a) Installation, storage, use, and handling of cryogenic hydrogen.
(b) Design and operation of liquid hydrogen for stationary storage and transport.
(c) Storage, safe handling, and safe use of cryogenic liquids.
(d) Safe siting, installation, and operation of bulk cryogenic storage systems.
(e) Requirements for design, fabrication, inspection, testing, and operations.
(f) Material compatibility with cylinders and valves.
(g) Process safety management and risk management guidance.

Table 22: Relevant Documents for Stationary and Transportable Cryogenic Hydrogen Storage

Applications	Relevant Documents
Cryogenic stationary storage and transport	• 49 CFR 178.37 • NFPA 55 • IGC 114/09, EIGA • IGC 06/02, EIGA • ISO 20421-1 • ISO 20421-2 • ISO 21010 • ISO 21011 • CGA H-3 • CGA H5 • CGA P-12 • CGA P-28 • CGA P-41

Hydrogen can also be stored in other means of storage such as underground gaseous vessels and metal hydrides. Table 23 shows a list of relevant documents providing considerations on:

(a) Underground gaseous hydrogen storage in vessels.
(b) Material, design, construction, and testing of metal hydrides storage assemblies used for transport.
(c) Design, manufacture, testing, inspection, and approval of cylinders for portable reversible metal hydride system.

Table 23: Relevant Documents for Other Types of Hydrogen Storage

Applications	Relevant Documents
Underground gaseous hydrogen storage in vessels	• CGA PS-20
Hydrogen storage in reversible metal hydrides for transport	• ISO 16111 • CGA C-21

2.2.4 HYDROGEN END USE

Hydrogen end use covers a wide range of applications, from industrial/residential heating, to power generation, and mobility. Relevant ASME documents for hydrogen end use can be found in Table 24. An extensive list of standards for hydrogen end use from other organizations is summarized in Table 25. The majority of standards established for hydrogen end use appear to be closely related to fuel cells due to the relatively more mature technologies and commercialization history compared to industrial/residential heating, both as pure hydrogen and blended with natural gas. The potential users of these documents are listed in Table 26 and commentaries on relevant documents for each end use application are provided from Table 27 to Table 29.

Table 24: ASME Relevant Documents for Hydrogen End Use

Document Type	Document No.	Title
Code	B31.3	Process Piping
Code	B31.12	Hydrogen Piping and Pipelines
Code	PTC 50	Performance Test Code for Fuel Cell Power Systems Performance
Code	BPVC	Boiler and Pressure Vessel Code (Section VIII, Division 3 only. Divisions 1 and 2 are silent on hydrogen service)

Table 25: Other Relevant Documents for Hydrogen End Use

Document Type	Document No.	Title
Code	NFPA 2	Hydrogen Technologies Code
Code	NFPA 52	Vehicular Natural Gas Fuel Systems Code
Code	NFPA 55	Compressed Gases and Cryogenic Fluids Code
Standard	NFPA 50A	Standard for Gaseous Hydrogen Systems at Consumer Sites
Standard	NFPA 50B	Standard for Liquefied Hydrogen Systems at Consumer Sites
Standard	NFPA 853	Standard for the Installation of Stationary Fuel Cell Power Systems
Standard	ISO 13984	Liquid Hydrogen – Land vehicle fuelling system interface
Standard	ISO 13985	Liquid Hydrogen – Land vehicle fuel tanks
Standard	ISO 14687-1	Hydrogen fuel – Product specification – Part 1: All applications except proton exchange membrane (PEM) fuel cell for road vehicles
Standard	ISO 14687-2	Hydrogen fuel – Product specification – Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles
Standard	ISO/PAS 15594	Airport hydrogen fueling facility operations
Standard	ISO/TS 15869	Gaseous hydrogen and hydrogen blends – Land vehicle fuel tanks
Standard	ISO/TS 19880	Gaseous hydrogen – Fueling stations

Document Type	Document No.	Title
Standard	ISO 16110-1	Hydrogen generators using fuel processing technologies – Part 1: Safety
Standard	ISO 16110-2	Hydrogen generators using fuel processing technologies – Part 2: Test methods for performance
Standard	ISO 17268	Gaseous hydrogen land vehicle refuelling connection devices
Standard	ISO 22734	Hydrogen generators using water electrolysis – Part 1: Industrial and commercial applications
Standard	ISO 26142	Hydrogen detection apparatus – Stationary applications
Standard	ISO 23828	Fuel cell road vehicles – Energy consumption measurement – Vehicles fuelled with compressed hydrogen
Standard	ISO/TR 11954	Fuel cell road vehicles – Maximum speed measurement
Standard	ISO 23273-2	Fuel cell road vehicles – Safety specifications – Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen
Standard	ISO 23273-3	Fuel cell road vehicles – Safety specifications – Part 3: Protection of persons against electric shock
Standard	IGC 23/00, EIGA	Safety training of employees
Standard	IGC 134/05	Potentially explosive atmosphere – EU Directive 1999/92/EC
Standard	ANSI/CSA FC-1	Stationary Fuel Cell Power Systems
Standard	ANSI/CSA FC-3	Portable Fuel Cell Power Systems
Standard	CSA HPRD1	Basic Requirements for Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers
Code	CSA B51	Boiler, pressure vessel, and pressure piping code
Standard	CGA H-4	Terminology Associated with Hydrogen Fuel Technologies
Standard	CGA G-5.3	Commodity Specification for Hydrogen
Standard	CGA G-5.4	Hydrogen Piping Systems at User Locations
Standard	CGA G-5.5	Standard for Hydrogen Vent Systems
Standard	CGA C-6.4	Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and Hydrogen Gas Vehicle (HGV) Fuel Containers and Their Installations
Standard	EN 17124	Hydrogen fuel – Product specification and quality assurance for hydrogen refuelling points dispensing gaseous hydrogen
Standard	SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices
Standard	SAE J2601	Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
Recommended Practices	SAE J2615	Testing Performance of Fuel Cell Systems for Automotive Applications
Recommended Practices	SAE J2616	Testing Performance of the Fuel Processor Subsystem of an Automotive Fuel Cell System
Standard	IEC 62282-2	Fuel Cell Technologies – Part 2: Fuel Cell Modules

Document Type	Document No.	Title
Standard	IEC 62282-3	Fuel Cell Technologies – Part 3: Stationary Fuel Cell Power Systems
Standard	IEC 62282-5	Fuel Cell Technologies – Part 5: Portable Fuel Cell Power Systems
Standard	IEC 62282-6	Fuel Cell Technologies – Part 6: Micro Fuel Cell Power Systems
Standard	IEC 62282-7	Fuel Cell Technologies – Part 7: Test Methods – Single Cell Performance Tests for Polymer Electrolyte Fuel Cells (PEFC)
Recommended Practices	SAE J1766	Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing
Recommended Practices	SAE J2572	Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fueled by Compressed Gaseous Hydrogen
Recommended Practices	SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety
Recommended Practices	SAE J2617	Recommended Practice for Testing Performance of PEM Fuel Cell Stack Sub-System for Automotive Applications
Standard	ISO/TR 15916	Basic considerations for the safety of hydrogen systems
Standard	SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
Standard	SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles

Table 26: Potential Users of the Documents

Applications	Examples of Document Users
Industrial heating	Iron and steel production operators Oil production and refining operators Chemical plant operators Regulators
Domestic heating	Transmission operators Distribution operators Regulators
Mobility	Technology manufacturers Light and heavy-duty vehicle manufacturers Maritime, rail, and aviation manufacturers Regulators Hydrogen service station equipment manufacturers and operators.
Power generation	Power plant operators Regulators

Pertaining to hydrogen use for industrial and domestic heating, Table 27 provides a list of relevant documents. Commentaries on the references listed in Table 27 can be found below:

(a) ASME B31.3 and B31.12 provide requirements for design, construction, operation, inspection, and maintenance of pipelines used for hydrogen transport for industrial and domestic heating.
(b) ASME BPVC Sections provide requirements for the design, construction, operation, inspection, and maintenance of pressure vessels and boilers for industrial and domestic heating.
(c) ASME PTC 50 provides performance requirements of fuel cells for heating.
(d) NFPA 2 includes safety requirements for hydrogen combustion applications.
(e) NFPA 55, 50A, and 50B provide safeguards for the installation, storage, use, and handling of compressed and cryogenic fluids in cylinders and tanks at consumer sites.
(f) NFPA 853 provides fire prevention and protection requirements for buildings and facilities that use fuel cell systems.
(g) ISO/TR 15916 provides safety guidelines for gas and liquid use in combustion and heating applications.
(h) ISO 16110 applies to the safety and performance test methods for stationary fuel cells
(i) ISO 22734 defines construction, safety, and performance requirements for hydrogen generators for industrial and domestic use.
(j) ISO 26142 defines test methods and apparatus for hydrogen detection.
(k) ISO 23273 specifies essential requirements for preventing hydrogen related hazards in fuel cell vehicles
(l) IGC 23/00 specifies safety training procedures for hydrogen handling and use.
(m) IGC 134/21 includes handling and storage of gases and liquids for industrial applications.
(n) CGA H-4 describes technologies for hydrogen use for combustion.
(o) IEC 62282 applies to stationary and portable fuel cell systems for various applications.

Table 27: Relevant Documents for Industrial and Domestic Heating

Applications	Relevant Documents
Industrial and domestic heating	• ASME B31.3 • ASME B31.12 • ASME BPVC • ASME PTC 50 • NFPA 2 • NFPA 55 • NFPA 50A • NFPA 50B • NFPA 853 • ISO/TR 15916 • ISO 16110 • ISO 22734 • ISO 26142 • ISO 23273 • EIGA IGC 23/00 • EIGA IGC 134/21 • CGA H-4 • IEC 62282

Pertaining to hydrogen use for power generation, Table 28 provides a list of relevant documents. Commentaries on the references listed in Table 28 can be found below:

(a) The ASME BPVC provides requirements for design, construction, operation, inspection, and maintenance of pressure vessels and boilers for power generation.
(b) ASME PTC 50 provides performance requirements of fuel cells for electricity and thermal energy.
(c) NFPA 55, 50A, and 50B provide safeguards for the installation, storage, use, and handling of compressed and cryogenic fluids in cylinders and tanks at consumer sites.
(d) NFPA 853 provides fire prevention and protection requirements for buildings and facilities that use fuel cell systems.
(e) ISO/TR 15916 provides safety guidelines for gas and liquid use in power generation applications.
(f) ISO 16110 applies to the safety and performance test methods for stationary fuel cells.
(g) ISO 26142 defines test methods and apparatus for hydrogen detection.
(h) IGC 23/00 specifies safety training procedures for hydrogen handling and use.
(i) ANSI/CSA FC-1 and FC-3 define the safe operation and acceptable performance of stationary and portable fuel cell power systems.
(j) IEC 62282 applies to stationary and portable fuel cell systems for various applications.

Table 28: Relevant Documents for Power Generation

Applications	Relevant Documents
Power generation	• ASME BPVC • ASME PTC 50 • NFPA 55 • NFPA 50A • NFPA 50B • NFPA 853 • ISO/TR 15916 • ISO 16110 • ISO 26142 • EIGA IGC 23/00 • ANSI/CSA FC-1 • ANSI/CSA FC-3 • IEC 62282

Pertaining to hydrogen use for the mobility industry, Table 29 provides a list of relevant documents. Commentaries on the references listed in Table 29 can be found below::

(a) ASME PTC 50 provides procedures and methods for performance characterization of fuel cells for mobility.
(b) NFPA 2 provides safety requirements for dispensing and fueling of hydrogen for vehicles, vehicle servicing, and repair.

(c) NFPA 2 provides safety requirements for fuel cell power generation.
(d) NFPA 52 provides requirements for design, installation, operation, and maintenance of compressed gas and liquefied gas for light and heavy-duty vehicles, marine, rail, and aviation.
(e) NFPA 55, 50A, and 50B provide safeguards for installation, storage, use, and handling of compressed and cryogenic fluids in cylinders and tanks at consumer sites.
(f) ISO 13984 and 13985 specify liquid hydrogen refueling requirements and fuel tank construction requirements for land vehicles.
(g) ISO 14687 and EN 17124 specify minimum quality characteristics of hydrogen fuel for vehicle fueling and for PEM fuel cells in vehicles.
(h) ISO/PAS 15594 specifies fueling procedures and hydrogen storage requirements for aviation fueling.
(i) ISO TS 15869 specifies requirements for refillable fuel tanks for hydrogen gas storage for land vehicles.
(j) ISO/TR 15916 provides safety guidelines for gas and liquid use.
(k) ISO 16110 applies to the safety and performance test methods for stationary fuel cells.
(l) ISO 17268 defines the design, safety, and operation of gaseous hydrogen land vehicle refueling connectors.
(m) ISO/TS 19880 recommends safety design characteristics for hydrogen gas fueling stations for light duty land vehicles.
(n) ISO 26142 defines test methods and apparatus for hydrogen detection.
(o) ISO 23828 specifies energy consumption measurement procedures for fuel cell passenger cars and light duty trucks that use compressed hydrogen.
(p) ISO/TR 11954 describes procedures for maximum road speed for fuel cell passenger cars and light duty trucks that use compressed hydrogen.
(q) IGC 23/00 specifies safety training procedures for hydrogen handling and use
(r) CSA HPRD1 specifies requirements for pressure relief devices on fuel containers used for hydrogen vehicles.
(s) CSA B51 contains requirements for high-pressure gas cylinders and storage vessels used in vehicles and hydrogen refueling station piping systems.
(t) CGA H-4 describes technologies for hydrogen use in fuel cells.
(u) CGA G-5.3 specifies guidelines for gaseous and liquid hydrogen for fuel cell applications
(v) CGA G-5.5 provides design guidelines for hydrogen vent systems in gaseous and liquid hydrogen systems at user sites.
(w) CGA C-6.4 provides procedures for periodic examination and inspection of fuel containers for vehicles.
(x) SAE J2600 applies to the design and testing of compressed hydrogen land vehicle fueling connectors, nozzles, and receptacles.
(y) SAE J2601 established protocols and process limits for hydrogen fueling of light duty vehicles
(z) SAE J2615 and J2616 are intended for performance testing and design verification of fuel cell systems designed for automotive applications.

(aa) IEC 62282 applies to stationary and portable fuel cell systems for various applications.

(bb) SAE J1766, J2572, and J2578 present guidelines for fuel cell vehicle crash integrity testing, procedures for testing of vehicles using fuel cell and compressed hydrogen, and fuel cell vehicle safety.

(cc) SAE J2617 provides procedures to verify the performance and design specifications of PEM fuel cells for automotive applications.

(dd) SAE J2579 defines design, construction, operational, and maintenance requirements for hydrogen fuel storage and handling in land vehicles

(ee) SAE J2719 provides hydrogen fuel quality standard for PEM fuel cell vehicles.

Table 29: Relevant Documents for Mobility

Applications	Relevant Documents
Mobility	• ASME PTC 50 • NFPA 2 • NFPA 52 • NFPA 55 • NFPA 50A • NFPA 50B • ISO 13984 • ISO 13985 • ISO 14687 • ISO/PAS 15594 • ISO/TS 15869 • ISO/TR 15916 • ISO 16110 • ISO 17268 • ISO/TS 19880 • ISO 26142 • ISO 23828 • ISO/TR 11954 • EIGA IGC 23/00 • CSA HPRD1 • CSA B51 • CGA H-4 • CGA G-5.3 • CGA G-5.5 • CGA C-6.4 • EN 17124 • SAE J2600 • SAE J2601 • SAE J2615 • SAE J2616 • IEC 62282 • SAE J1766 • SAE J2572 • SAE J2617 • SAE J2579 • SAE J2719

ABBREVIATIONS AND ACRONYMS

AIGA Asia Industrial Gases Association
AMPP Association for Metal Protection and Performance
ANSI American National Standards Institute
API American Petroleum Institute
ASME American Society of Mechanical Engineers
ASME ST-LLCASME Standards Technology, LLC
ASTM American Society for Testing and Materials
BNQ Bureau de Normalisation du Québec
BPVC Boiler and Pressure Vessel Code
CAN Canadian Standard (Standards Council of Canada)
CGA Compressed Gas Association
CRPV Composite Reinforced Pressure Vessels
CSA Canadian Standards Association
DOT Department of Transportation (United States)
EIGA European Industrial Gases Association
EN European Standards
EPA Environmental Protection Agency
FCGR Fatigue crack growth rate
IFC International Fire Code
IGC Industrial Gases Council
IGEM Institution of Gas Engineers and Managers
INGAA Interstate Natural Gas Association of America
ISO International Organization for Standardization
NACE National Association of Corrosion Engineers International; (Now part of AMPP) **NFPA** National Fire Protection Agency
NG Natural Gas
NPS Nominal Pipe Size
OD Outer Diameter
OSHA Occupational Safety and Health Administration
PHMSA Pipeline and Hazardous Materials Safety Administration
PVP Pressure Vessel and Piping
SAE Society of Automotive Engineers
STP Standards Technology Publication
UL Underwriter's Laboratory

DEFINITIONS

The terminologies used throughout this report are defined in this section to maintain consistency throughout the report as it is recognized that some definitions (e.g., codes, standards, and guidelines) may vary in the industry and across organizations.

Codes

An engineering code is a group of general rules or systematic procedures that contain mandatory requirements, specific prohibitions, and nonmandatory guidance for design, fabrication, installation, and inspection. Codes are intended to set forth engineering requirements deemed necessary for safe design and construction of piping, pressure vessels, or other related engineered equipment.

While codes contain mandatory requirements, prohibitions, and general guidance, codes are not intended to be a design or operation handbook. Therefore, codes are intended to be used and employed by knowledgeable engineers, trained, and experienced in the application of the codes.

Standards

A Standard is a specific set of engineering requirements, prepared by professional societies or committees, which have been accredited by the American National Standards Institute (ANSI) in the US, or the International Organization for Standardization (ISO) internationally. Some Codes developed by ASME Committees have been adopted and approved by ANSI and are therefore also Standards. Therefore, some Codes are also Standards, and the terminology is often used interchangeably. The use of ASME Standards is non-mandatory, unless the standard has been incorporated into regulations, or contractually required.

Recommended Practices / Guidelines

Recommended practices and guidelines are documents prepared by a professional group or committee containing good engineering practices. Adoption of recommended practices and guidelines is optional, and companies may also develop their own internal recommended practices in order to have consistency in design and operation across multiple projects.

Code Case

Code Cases represent alternatives or additions to existing Code requirements. Code Cases are written as a Question and Reply and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. The most common applications for Code Cases are as follows:

- **(a)** to permit early implementation of an approved Code revision based on an urgent need
- **(b)** to permit the use of a new material for Code construction
- **(c)** to gain experience with new materials or alternative requirements prior to incorporation directly into the Code

Interim Report / Report

An Interim report or a report is intended to address priority topical areas addressing standardization issues pertaining to various topics. An example of an interim report is ASME *STP-PT-003 Hydrogen Standardization Interim Report for Tanks, Piping, and Pipelines* with the following description:

“This interim report is intended to address priority topical areas with pressure technology applications for hydrogen infrastructure development. The scope of this interim report includes addressing standardization issues related to storage tanks, transportation tanks, portable tanks, and piping and pipelines. It is anticipated that the contents and recommendations of this report may be revised as further research and development becomes available."

Position Statement

A Position Statement appears to be the term used by the Compressed Gas Association (CGA) intended to provide further clarifications pertaining to specific topics. No official definition is provided by CGA, however, an example of a position statement document based on CGA PS-48-2016 can be found below:

"CGA Position Statement on Clarification of Existing Hydrogen Setback Distances and Development of New Hydrogen Setback Distances in NFPA 55."

Outline

Outline is a term primarily used by Underwriter's Laboratory (UL) that appears to correspond to sets of requirements similar to a standard. An example of an outline document description based on UL 2264A *Outline of Investigation for Water Electrolysis Type Hydrogen Generators* can be found below:

"This Outline covers safety requirements for hydrogen generators that electrolyze water to produce hydrogen."

Publication

A publication appears to be a generic term used by the CGA to provide information on a specific issue, for example, the description for *CGA P-12: Safe Handling of Cryogenic Liquids* can be found below:

"This publication provides general information about the properties, transportation, storage, safe handling, and safe use of the cryogenic liquids commonly used by industry and institutions."

APPENDIX A – ASME TECHNICAL PAPERS

Examples of ASME technical papers (e.g., through the Pressure Vessels & Piping Conference [PVP]) relevant to hydrogen application can be found in Table 30.

Table 30: ASME Technical Papers Relevant to Hydrogen Service

No	Technical Paper
1	Drexler, E, Slifka, A, Amaro, R, & Lauria, D. "Fatigue Crack Growth Rates of API X70 Pipeline Steels in Pressurized Hydrogen Gas Compared with an X52 Pipeline in Hydrogen Service." International Hydrogen Conference (IHC 2016): Materials Performance in Hydrogen Environments. Ed. Somerday, BP, & Sofronis, P. ASME Press, 2017. https://doi.org/10.1115/1.861387_cH22
2	Thomas, A., and Szpunar, J. A. (January 13, 2021). "Effect of Cold-Rolling on Hydrogen Diffusion and Trapping in X70 Pipeline Steel." ASME. J. Eng. Mater. Technol. July 2021; 143(3): 031002. https://doi.org/10.1115/1.4049320
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