SANDIA REPORT
SAND2021-12478
Printed October 2021

Codes and Standards Assessment for Hydrogen Blends into the Natural Gas Infrastructure

Austin M. Glover (SNL), Jeffrey T. Mohr (NREL), Austin R. Baird (SNL)

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

Issued by Sandia National Laboratories, operated for the United States Department of Energy by National Technology & Engineering Solutions of Sandia, LLC.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone:	(865) 576-8401
Facsimile:	(865) 576-5728
E-Mail:	reports@osti.gov
Online ordering:	http://www.osti.gov/scitech

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.gov
Online order:	https://classic.ntis.gov/help/order-methods/

ABSTRACT

Energy utilities are evaluating emerging energy technologies to reduce reliance on carbon as an energy carrier. Hydrogen has been identified as a potential substitute for carbon-based fuels that can be blended into other gaseous energy carriers, such as natural gas. However, hydrogen blending into natural gas has important implications on safety which need to be evaluated. Designers and installers of systems that utilize hydrogen gas blending into natural gas distribution systems need to adhere to local building codes and engage with the authority having jurisdiction (AHJ) for safety and permitting approvals. These codes and standards must be considered to understand where safety gaps might be apparent when injecting hydrogen into the natural gas infrastructure. This report generates a list of relevant codes and standards for hydrogen blending on existing, upgraded, or new pipelines. Additionally, a preliminary assessment was made to identify the codes and standards that need to be modified to enable this technology as well as potential gaps due to the unique nature and safety concerns of gaseous hydrogen.

ACKNOWLEDGEMENTS

This work is funded by Task 5 of CRADA 1960.00. This CRADA was completed with funding from the DOE's Hydrogen and Fuel Cell Technologies Office within the Office of Energy Efficiency and Renewable Energy (EERE), the DOE Office of Fossil Energy and Carbon Management, and Southern Company. This CRADA was a part of the DOE's H2@Scale initiative,[1] and conducted in coordination with EERE's HyBlend initiative.[2] The authors would like to thank the Southern Company for collaboration on this work. Additionally, the authors would like to thank Chris LaFleur at SNL for their internal review of this paper.

[1] https://www.energy.gov/eere/fuelcells/h2scale

[2] https://www.nrel.gov/news/program/2020/hyblend-project-to-accelerate-potential-for-blending-hydrogen-in-natural-gas-pipelines.html

CONTENTS

LIST OF FIGURES

LIST OF TABLES

This page left blank

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AHJ	authority having jurisdiction
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CGA	Compressed Gas Association
CFR	Code of Federal Regulations
CSST	corrugated stainless steel tubing
DOE	Department of Energy
DOT	Department of Transportation
EERE	Office of Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
FECM	Office of Fossil Energy and Carbon Management
FTC	Federal Trade Commission
ICC	International Code Council
IFC	International Fire Code
LH2	liquified hydrogen
LHG	liquefied hazardous gas
LNG	liquefied natural gas
MAOP	maximum allowable operating pressure
MAQ	maximum allowable quantity
NDE	non-destructive examination
NFPA	National Fire Protection Association
OCS	outer continental shelf
OORP	Office of Offshore Regulatory Programs

1. INTRODUCTION

Energy utilities are evaluating emerging energy technologies to reduce reliance on carbon as an energy carrier. Hydrogen has been identified as a potential substitute for carbon-based fuels that can be blended into other gaseous energy carriers, such as natural gas. However, hydrogen blending into natural gas has important implications on safety which need to be evaluated. Designers and installers of systems that utilize hydrogen gas blending into natural gas distribution systems need to adhere to local codes and engage with the authorities having jurisdiction (AHJ) for safety and permitting approvals. These codes and standards must be considered to understand where safety gaps might be apparent when injecting hydrogen into the natural gas infrastructure. The composition of natural gas varies by both region and season. It is composed of primarily methane, ethane, propane, and butane as well as other higher order hydrocarbons and other gases [1]. These hydrocarbons have a much higher molecular mass and volumetric heating value than that of hydrogen which lead to different combustion and safety metrics as shown in Table 1-3.

In this paper, a list of relevant codes and standards for natural gas and hydrogen use in existing, upgraded, or new pipelines will be generated. Additionally, a preliminary assessment will be made to identify the codes and standards that need to be modified to enable this technology as well as potential gaps due to the unique nature and safety concerns of blended gas. Note that there are a myriad of end uses of hydrogen and natural gas blends beyond the end of the pipeline. The range and variety of end uses are beyond the scope of this paper and many codes and standards that reference end use of the product may not be covered in this paper. The scope of this paper focuses on the transmission pipeline after the gas treatment facility to the service line before the end use of the product.

1.1. Background Information

Hydrogen is the lightest, simplest, and most abundant element in the universe. It is a simple atom consisting of only one proton and one electron, and typically occurring as diatomic hydrogen (H_2). Hydrogen is colorless and odorless and makes up 75% of the mass of the universe. The largest volume uses of hydrogen currently are petroleum refineries, ammonia manufacturing, and the synthesis of methanol.

Hydrogen is not abundantly available in pure form, and therefore must be produced from more complex compounds such as water or hydrocarbons. The most common way to produce hydrogen is to use a process called reforming, a method that uses heat to separate hydrogen from natural gas. However, hydrogen can also be produced by separating water into hydrogen and oxygen by any of a family of processes, the most common being electrolysis. Interest in hydrogen production via electrolysis powered by renewable energy, or via fossil pathways with carbon sequestration, is growing to enable decarbonization of many end-uses in industry and transportation, such as heat and power generation, steelmaking, energy storage, chemicals, and medium- and heavy-duty transportation [2] [3]. To generate power, hydrogen can be used within a gas turbine power generator (via combustion), or in a fuel cell for distributed power generation in buildings or vehicles. Hydrogen fuel cells provide power to an electric motor, and the typical combination of fuel cell and electric motor are more efficient than typical combustion engines. The DOE Hydrogen Program Plan provides more information on the framework and efforts to advance the production, transport, storage, and use of hydrogen [4].

1.2. Natural Gas Infrastructure Overview

The natural gas infrastructure is used to transport gas from areas of production to areas of consumption, through a variety of pipelines and gas service lines. Gathering pipelines are used to transport raw natural gas from production wells, offshore drilling, and tankers. These gathering lines feed to a gas processing plant, where it is cleaned and treated, then fed to transmission lines and various compressor stations. At this point in the system, hydrogen may be injected into the natural gas transmission infrastructure, or alternatively, hydrogen can be injected at the city gate prior to being fed to the end user through distribution and residential lines. Figure 1-1 shows the general pipeline infrastructure diagram for natural gas:

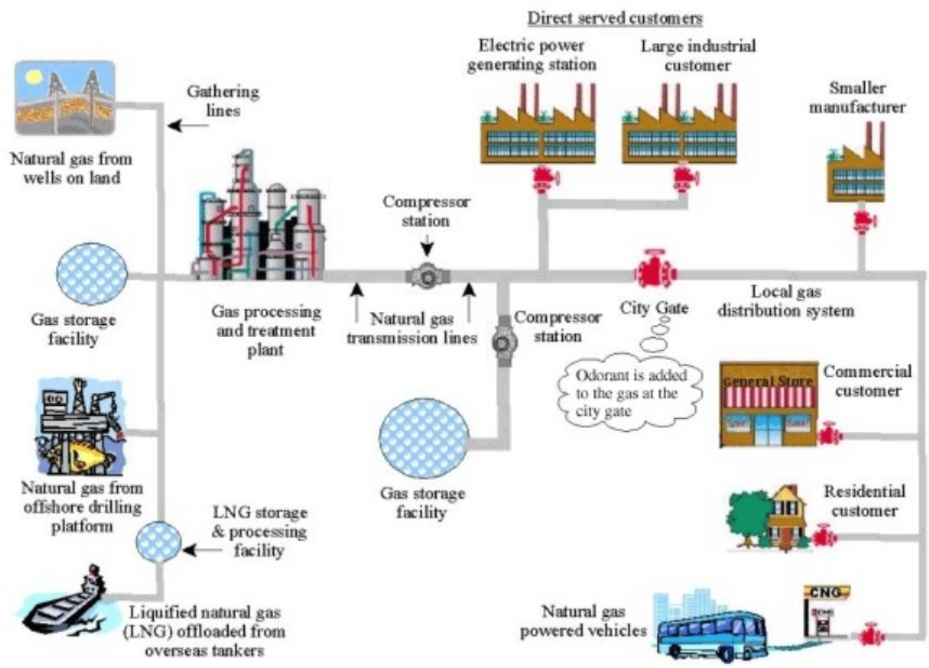

Figure 1-1. Natural Gas Pipeline Infrastructure Diagram (from [5])

Each type of pipeline in the natural gas infrastructure varies in size and pressure as shown in Table 1-1:

Table 1-1. Natural Gas Pipeline Types and Typical Usage

Pipeline Type	Pipeline Diameter	Typical Pressure	Typical End Use
Mainline Transmission Lines [6]	6" to 48"	500 to 1400 psi	Principal pipeline in a system that feeds to other pipelines and distribution lines
Interstate Pipeline [6]	24" to 36"	200 to 1500 psi	Transport natural gas across the country to high demand locations, usually to densely populated urban areas
Distribution [7]	2" to 24"	10 to 200 psi	Comes after the gate station, the gas company can monitor and control pressures as this system is an interconnected grid which leads to improved safety
Service Lines [7]	2" to 24"	10 to 200 psi	Feeds both residential and commercial systems up to the gas meter system from the distribution system

1.3. Comparing Natural Gas and Hydrogen

Natural gas is mainly composed of methane, with lower concentrations of other hydrocarbons such as ethane, propane, butane, and lesser amount of non-hydrocarbon gases. Table 1-2 below gives the typical composition of natural gas.

Table 1-2. Pipeline Quality Natural Gas Composition (from [8])

Gas	Chemical Formula	Composition (% Vol.)
Hydrocarbons		
Methane	CH_4	75-100%
Ethane	C_2H_6	0-10%
Propane	C_3H_8	0-5%
Butane	C_4H_{10}	0-2%
Non-Hydrocarbons		
Carbon Dioxide	CO_2	0-3%
Oxygen	O_2	0-1%
Nitrogen & Rare Gases	N_2	0-3%
Hydrogen Sulfide	H_2S	Trace

The composition of natural gas can vary greatly as shown in Table 1-3. Therefore, the safety and operational metrics of hydrogen enriched natural gas will be dependent not only on the blend ratio but also the initial compositions of natural gas. Table 1-3 compares some important characteristics of methane and hydrogen.

Table 1-3. Hydrogen and Natural Gas Properties at Ambient Conditions

Property	Hydrogen	Methane
Molecular Formula	H_2	CH_4
Molecular Weight (g/mol) [9]	2.016	16.043
Buoyancy (ratio to air)	0.07	0.54
Density (kg/m^3) [10] [11]	0.0899 ~14 times lighter than air	0.668 ~1.8 times lighter than air
Dynamic Viscosity (10^{-5} Pa-s) [12]	1.10	0.88
Flammability Limits (vol. %) [11]	4-74	5.3-15
Stoichiometric Concentration in Air (vol. %) [11]	29	9
Maximum laminar burning velocity (m/s) [11]	3.25	0.44
Relative radiative heat transfer (%) [11]	5-10	10-33

Natural gas properties will generally be similar to that of pure methane; however, these properties will vary based on the specific composition. As higher order hydrocarbons increase by volume, the molecular weight, density, and combustion properties are affected.

2. RELEVANT SAFETY CODES AND STANDARDS

This section outlines the relevant codes and standards that apply to blending hydrogen into the natural gas infrastructure.

2.1. ASME B31.8 – 2018: Gas Transmission and Distribution Piping Systems

The American Society of Mechanical Engineers (ASME) B31.8-2018 Gas Transmission and Distribution Piping Systems covers various gas transmission and distribution components including gas pipelines, compressor stations, metering devices, offshore components for distribution of gas to onshore locations, and more. This standard is designed as a guideline for safe pressure piping installation and prohibits designs and practices that are known to be unsafe. This code is intended for natural gas pipelines without significant quantities of hydrogen. However, since the constituents of natural gas naturally varies, the code has capacity to accept some variation in the composition of natural gas. Section 840.1 of the codes states that measures must be made to control or minimize adverse effects caused by heating value or specific gravity changes. These changes can be caused by inert gases or heavy hydrocarbon constituents in the natural gas. The concern is that "uncontrolled or unexpected variations in heating value may results in problems at the end user's burner tip or process". The code does not specifically call out hydrogen as a constituent of concern and small quantities of hydrogen may be allowable within the code in small not yet defined quantities. The concern appears to be flame stability in the end user's appliances. As interest in hydrogen enriched natural gas grows and experience is gained this code may be able to be modified to define an allowable hydrogen enriched natural gas with minimal changes.

Note, that this section discusses the 2018 version of the ASME B31.8 code.

2.1.1. Section 817 – Conditions for the Reuse of Pipe

This section specifies when a material used in a pipeline can be reused and what conditions they can be used in. There are also specific requirements for retesting materials to ensure pressure and safety requirements are met. This section of B31.8 will need to be modified or have a section added for natural gas mixtures with elevated hydrogen concentrations

2.1.2. Section 840 – Design, Installation, and Testing

This section specifies the design parameters necessary for the pipeline based on the material used per section 840.2.1-3. These will likely need to be revaluated for increased hydrogen percentage blended with natural gas.

2.1.3. Section 850 – Operating and Maintenance Procedures

This section specifies how the operating company should interact with employees and surrounding public to maintain safety. This includes maintenance and inspection methods as well as communication methods. This will likely need to be updated to include hydrogen education for the public, information on what to do in the event of a natural gas leak with elevated hydrogen content, and how to recognize a leak.

2.1.4. Section 851 – Pipeline Maintenance

This section provides requirements on how and where maintenance to the pipeline is to be performed and dictates regular leakage surveys. Also, this section defines the damage threshold to the pipeline that is considered hazardous and the conditions that require immediate repair. Finally, the pressure test cycle and leak test interval are defined to ensure the structural integrity of the pipeline.

2.1.5. Section 852 – Distribution Piping Maintenance

Patrolling, leak checking, and maintenance periods for piping, including piping downstream of the meter into residential homes, is described in this section. Many of the evaluation methods are described in depth in the non-mandatory appendix. Also, the abandonment and reinstatement of pipelines is discussed in this section.

2.1.6. Section 853 – Miscellaneous Facilities Maintenance

This section covers general maintenance requirements for compressor stations, pipe/bottle holders, pressure limiting devices, valves, and vaults. Also, it specifies personnel capacity based on setback factors.

2.1.7. Section 856 – Odorization

This section states that any gas distributed to customers that does not naturally possess a distinctive odor when the concentration is above $1/5^{th}$ of the lower explosive limit shall have an odorant added to make it detectable. This may be problematic for blended mixtures because it may be possible to have a leak in which hydrogen is released but no odorant is detectable.

2.2. ASME B31.8s – 2018: Managing System Integrity of Gas Pipelines

This standard is a non-mandatory supplement to ASME B31.8. This code describes the process an operator may use to develop an integrity management program for a pipeline system covered under ASME B31.8. It utilizes two approaches to develop an integrity management program: (i) a prescriptive approach and (ii) a performance- or risk-based approach. The intent of this code is to provide a systematic, comprehensive and integrated approach to manage safety and integrity of pipeline systems. This code is applicable to onshore, ferrous material pipelines that transport gas. The code does specifically call out hydrogen gas induced damage and hydrogen sulfide corrosion as concerns to the integrity of the pipeline. Although hydrogen blending in natural gas is not directly addressed, this code does address hydrogen and natural gas in pipelines separately.

2.3. ASME B31.12 – 2019: Hydrogen Piping and Pipelines

This standard is designed to address pipeline codes and standards of hydrogen infrastructure applications. The first edition of the code applies to design, construction, operation, and maintenance for piping, pipelines, and distribution systems in H_2 service, and targets applications including power generation, process plants, pipelines, distribution, and automotive filling station. Pipeline guidance within the code is applicable for systems that contain 10% or more hydrogen by volume. with pressures below 3,000 psig. This code addresses hydrogen pipeline service and specifically excludes blends where the hydrogen percentage is less than 10% by volume. See section 2.3.3.1. PL-1 below for code exclusions. There are three main sections in this standard, which address (i) general/common requirements, (ii) industrial piping, and (iii) pipelines. This code also includes information on material performance and pressure derating to accommodate hydrogen embrittlement. Additional rules have been added for the conversion or retrofit of existing pipeline and distribution systems for natural gas or petroleum to H_2 service.

This code applies to hydrogen service in petroleum refineries, refueling stations, chemical plants, power generation plants, semiconductor plants, cryogenic plants, hydrogen fuel appliances and related facilities (IP section) and transmission pipelines, distribution pipelines, and service lines used to transport hydrogen from production facility to point of final use. The code covers steel pipelines (e.g., the conversion of steel pipelines from ASME B31.8 to ASME B31.12) but does not cover plastic service lines. This code will need to be expanded to include plastic pipeline.

2.3.1. General Requirements (GR) Section

The GR section covers general requirements including the definitions and requirements for materials, welding, brazing, heat treatment, forming, testing, inspection, examination, operation, and maintenance.

2.3.1.1. GR-1

This section covers piping and pipelines in gaseous and liquid hydrogen service.

2.3.1.1.1. GR-1.1

This section covers up to and including the joint connection to the pressure vessels and the equipment. However, the pressure vessels and equipment themselves are not covered in this section. The design for pressure and temperature should be in accordance with IP and PL section of ASME B31.12.

2.3.1.1.2. GR-1.2

This section assigns responsibility and defines the owner, designer, construction organization, and inspector.

2.3.1.1.3. GR-1.3

This section addresses the intent of the code. This code will set forth engineering requirements deemed necessary for safe design, construction, installation of piping and pipeline systems in hydrogen service. This code uses a simple analysis to ensure safety; however, the designer may want to perform a more detailed analysis. In this case, the designer shall provide details to the owner insuring consistency with the ASME code. Piping should conform to this code and the engineering design shall specify any unusual requirements for a particular service. Code requirements shall include, but not limited to, selection and application of materials, components, and joints. Service requirements include prohibitions, limitations, conditions (e.g., temperature and pressure) and requirements for safeguarding.

2.3.1.1.4. GR-1.4

This section addresses piping that interconnects pieces or stages within a packaged equipment assembly for piping or pipeline systems. This code excludes the following:

- Exclusions specifically limited in part IP or PL of this code.
- Piping that is required to conform to other codes.
- Tubes, tube headers, crossovers, and manifolds of fired heater that are internal to the heater enclosure.

- Power boilers, pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal and connections for external piping.

2.3.1.1.5. GR-1.5 through 1.7

These sections cover terms, definitions, appendices, and nomenclature for the code.

2.3.1.2. GR-2

This section documents the general requirements of the code. It states the limitations and required qualifications for materials based on their inherent properties for use in hydrogen systems. Specific requirements include selections to resist deterioration and any effects caused by general nature, temperature, pressure, etc. Specific concerns include hydrogen embrittlement, property changes at low and ultra-low temperature, permeation, and electrostatic buildup/discharge.

2.3.1.2.1. GR-2.1.1

This section lists materials that are suitable for piping that meet requirements of part IP and addresses specifications for unlisted materials that could be used if they conform to the published specification. It explicitly prohibits use of unknown materials. Reclaimed materials may be used assuming they meet listed or unlisted material requirements and have been appropriately inspected and cleaned. Materials with multiple makings that meet the requirements of two or more specifications can be used with provisions listed in the code.

2.3.1.2.2. GR-2.1.2

This section addresses the temperature limitations of materials including cautionary and restrictive temperature limits for piping systems.

2.3.1.3. GR-4

This chapter covers the requirements and responsibilities of associated parties for inspection, examination, and testing of piping systems. Methods for inspection include: Quality control examinations and nondestructive examinations (e.g., visual, radiographic, ultrasonic, liquid penetrant, magnetic particle, and eddy current). Any special inspection method used must meet the criteria in GR-4.7 and 4.8. Testing of systems shall be in accordance with the quality system program procedure and will be reviewed by the quality control examiner and the owner's inspector.

2.3.1.4. GR-5

This chapter references operating and maintenances procedures that affect the safety of hydrogen transmission and distribution facilities. The many different hydrogen fluid services and many different types of piping and pipeline systems make it difficult for the code to prescribe a specific procedure that would work in all cases. Each operating company must develop operating and maintenance procedures based on the provisions of this code. This section outlines the required portions of an operating and maintenance procedure and suggests operation and maintenance guidelines to aid the creation of an operation and maintenance plan. This section also provides guidance on the abandoning, decommissioning, recommissioning, and repositioning of transmission lines. Additionally, inspection and leak test methods/intervals for transmission lines are prescribed.

2.3.1.5. GR-6

This section describes the requirements for development of a Quality System Program. This is to ensure quality for all hydrogen piping and pipeline systems. This section outlines the required sections of the quality manual and addresses purchasing, construction and welding plans/methods, heat treatments, operations, and examinations plans.

2.3.2. Industrial Piping (IP) Section

The IP section addresses several different aspects of hydrogen gas distribution.

2.3.2.1. IP-1

This section describes the rules for industrial piping in hydrogen service included in petroleum refineries, hydrogen refueling station, chemical plants, power generation plants, semiconductor plants, hydrogen fuel appliances, and related facilities.

2.3.2.1.1. IP-1.1

Section IP-1.1 covers the requirements for materials and components, design, fabrication, assembly, erection, inspection, examination, testing, operation, and maintenance of piping and joints connecting piping to equipment for both liquid and gaseous hydrogen and outlines exclusions to the code.

2.3.2.1.2. IP-1.2 through 1.3

This section outlines the responsibilities of the owner, designer, construction organizer, and inspector and describes the intent of the code.

2.3.2.1.3. IP-1.4

This section covers the determination of code requirements and how the code affects selection and application of materials, components, and joints. Service requirements include prohibitions, limitations, and conditions. The code requirements are the most restrictive of those that apply to multiple elements.

2.3.2.2. IP-2

Section IP-2 addresses design conditions of the hydrogen distribution system.

2.3.2.2.1. IP-2.1

This section provides the design conditions of the piping system. It also defines the required qualification of the designer. The temperatures, pressures, and forces applicable to the design of piping are defined. The code states that consideration must be given to various effects and consequent loadings. It states when/where a pressure containment or relief is required and addresses the design temperature limitations of the system. Environmental effects including fluid effects from ambient temperatures and dynamic effects from impact, wind, earthquakes, and piping loads, among other environmental impacts, are also discussed.

2.3.2.2.2. IP-2.2

This section addresses the specific design criteria that must be met including pressure and temperature ratings, stress criteria, and minimum design value requirements. It also covers the options for use of components that are specifically rated, not specifically rated, or unlisted. Additionally, specific stress calculations and conditions are discussed along with weldment requirements.

2.3.2.3. IP-3

This section states that components manufactured in accordance with specifications in table IP-8.1.1-1 will be suitable for use with the pressure and temperature ratings outlined in IP-2.2.2 or IP-2.2.3. Components not covered in table IP-8.1.1-1 should be designed following the rules in IP-3.2 and may be used for a special or more rigorous design to satisfy requirements of IP-2.2.3. The designs must be checked for adequacy of mechanical strength using the loadings in IP-2.1 or alternatively using methods described in CSA HGV 4.10.

The additional sections in IP-3 address the following types of components:

- IP-3.2 – Design requirements for straight pipe sections.
- IP-3.3 – Design specifications for curved and mitered segments of pipe.
- IP-3.4 – Branch connections (Fittings: tees, extruded outlets, branch outlets, cast or forged branch connection fittings, welding branch pipe to run pipe, etc.)
- IP-3.5 – Closures.
- IP-3.6 – Pressure design of Flanges and Blanks

2.3.2.4. IP-4

This section addresses the requirements for valves and other pressure containing piping components such as traps, strainers, and separators. The following sections cover the requirements for valves and pressure containing components:

- IP-4.1 – States where Valve requirements and specifications are listed (Table IP-8.1.1-1, IP-4.1.2, IP-2.2.4)
- IP-4.2 – Bolting and tapped holes for components.

2.3.2.5. IP-5

Section IP-5 addresses the service requirements for piping joints. Joints shall be selected to suit the piping material with consideration of joint tightness and mechanical strength under expected service. The code also gives emphasis to minimize stress on joints due to operation of valves and thermal expansion.

The additional sections cover the following joint types:

- IP-5.2 – Welded joints
- IP-5.3 – Flanged joints
- IP-5.4 – Expanded joints
- IP-5.5 – Threaded joints
- IP-5.6 – Caulked joints
- IP-5.7 – Brazed and soldered joints
- IP-5.8 – Special Joints (shall be designed as stated in IP-3.8.2)

2.3.2.6. IP-6

Section IP-6 covers the flexibility and support of piping. Piping must have sufficient flexibility to accommodate thermal expansion, contraction, or movement of piping which may cause the following: piping failure due to fatigue or overstress, leakage at joints, detrimental stresses, and distortion. This section includes hazards to consider and methods of analysis to evaluate flexibility of the piping system.

2.3.2.7. IP-7

This chapter covers the requirements of instrumentation piping connecting the instruments to other piping and/or equipment. It does not cover the instruments themselves, permanently sealed fluid filled tubing systems furnished with instruments, or temperature/pressure response devices. This chapter is mainly concerned with the piping to pressure relief devices.

2.3.2.8. IP-8

This section addresses the dimensions and ratings of components. Table IP-8.1.1-1 is included in this section (as referenced in previous sections) and covers the dimensional requirements of listed/unlisted components and threads for piping connections. The table also outlines the pressure ratings of components designed using the prescribed method.

2.3.2.9. IP-9

This section defines the roles and responsibility of those who complete the construction of the hydrogen piping. It outlines the required methods of fabrications, welding, brazing, and materials testing for construction. This chapter also outlines heat treatment requirements and forming methods of piping. Additionally, the specific assembly procedures for pipe alignment, flanged joints, threaded joints, tube joints, expanded joints, and pipe attachments and supports is defined. It also recommends pipe cleaning methods.

2.3.2.10. IP-10

This chapter covers the roles and responsibilities of those who complete inspections, quality control examinations, NDE, and specified tests of the piping systems. Examination methods include general, visual, radiographic, liquid penetrant, magnetic particle, and ultrasonic. Hardness control and testing on the welds may also be required. Leak test procedures are outlined along with mechanical and metallurgical testing. Records of testing are also required to be maintained for at least 5 years.

2.3.3. Pipelines (PL) Section

This section addresses pipelines (transmission, distribution, and service lines) for transporting hydrogen.

2.3.3.1. PL-1

This section covers requirements for materials, components, design, fabrication, assembly, erection, inspection, examination, testing, operation, and maintenance for H2 pipelines. However, there are several limitations in this code in terms of application to blending hydrogen into the natural gas infrastructure. The code does **NOT** apply to the conditions listed below:

- Pressure vessels covered by ASME BPVC

- Pipeline temperatures above 232 °C or below -62 °C
- Pipeline above 3,000 psi
- Pipeline with a moisture content greater than 20 ppm
- Pipeline below 10% hydrogen by volume

2.3.3.2. PL-2

This section defines the requirements for the specification and selection of all items/accessories that are part of the pipeline system other than the pipe itself. It also addresses acceptable methods of branch connections and the effect of changes in temperature. Additionally, the requirements for support and anchorage of exposed and buried pipeline systems is defined.

2.3.3.2.1. PL-2.1

This section addresses the specification and selection of all items and accessories that are part of the pipeline system other than the pipe itself. It covers the acceptable methods of making branch connections and the appropriate methods for accounting for the effects of temperature change. Also, it defines the methods of support and anchorage of exposed and buried pipeline systems.

2.3.3.2.2. PL-2.2

This section outlines the requirements for components used in pipelines. The following sections cover the following components:

- PL-2.2.1 – Unlisted components
- PL-2.2.2 – Valves and pressure-reducing devices
- PL-2.2.3 – Flanges
- PL-2.2.4 – Fittings other than Valves and Flanges
- PL-2.2.5 – Pressure Design of other pressure containing components.
- PL-2.2.6 – Closures

2.3.3.2.3. PL-2.3

This section outlines the requirements for reinforcements of branch lines made to pipeline. These reinforcements must be designed to control the stress level within the pipe within safe limits. Rules for determining the required reinforcement for the crotch area are also outlined. In addition, the branch connections must meet special requirements outlined in PL-2.3.2 including the conditions outlined in Table PL-2.3.2-1.

2.3.3.2.4. PL-2.4

This section outlines the reinforcement requirements for pipelines with multiple openings. This includes when two or more adjacent branches are spaced less than two times their average diameter. More than two adjacent opening are to be provided with a combined reinforcement. Additionally, reinforcement is required when the distance between two adjacent openings is less than 1 – 1/3 times their average diameter or when there are any number of closely spaced adjacent openings if the opening of a diameter encloses all such openings.

2.3.3.2.5. PL-2.5

This section covers the expected thermal expansion of low alloy steel used for pipelines and the required flexibility to account for thermal expansion or contraction.

2.3.3.2.6. PL-2.6

This section covers requirements for the restraint of pipeline to support longitudinal stress. This section covers the required calculations of longitudinal stress caused by cyclic loading, restraint (supports, soil, or terrain), and use.

2.3.3.2.7. PL-2.7

This section addresses support methods and requirements for exposed piping.

2.3.3.2.8. PL-2.8

This section addresses support methods and requirements for buried piping.

2.3.3.3. PL-3

This section addresses the provisions for design including the conditions encountered in hydrogen gas transmission and how these conditions need to be accounted for in the design of the hydrogen transmission system. It also includes the classification of pipeline based on population density.

2.3.3.3.1. PL-3.1

Section PL-3.1 covers the conditions encountered in hydrogen gas transmission and how these conditions need to be accounted for in the design of the hydrogen transmission system. Hazards that may cause additional stress on pipelines include long self-supported spans, unstable ground, mechanical or acoustic vibration, weight of special attachments, earthquakes, temperature and pressure differential, soil conditions, and environmental conditions. This sections also states that the pipeline must be designed for the specific quality of hydrogen that will be seen in the system. A pipeline may transport blends of hydrogen and other fuel gases (methane, propane, etc.); however, a potential concern is that hydrogen leak detection in cross country lines may require advanced investigative assessments. Finally, this section covers potential damage that could be caused, which includes third party activities such as construction of other facilities and the associated underground services that must be connected to the facilities in the pipeline right of way. If buildings intended for human occupancy are found to be within the impacted area, risk assessments must be performed.

2.3.3.3.2. PL-3.2 through 3.6

These sections address the classification methods for building that contain humans and the setback distance from the pipeline. Table PL-3.6.1-1 defines the limitations of the pipeline MAOP to manage the risk for buildings that contain humans by their location classification. Provisions are also made for monitoring and adjusting the location classes, as necessary.

2.3.3.3.3. PL-3.7

This section outlines design formulas and requirements for steel pipe design. The main concern with steel pipe is limiting fracture influenced by pressure, temperature, material compatibility, and environmental hazards.

2.3.3.3.4. PL-3.8

This section provides the limitations of hot taps and the conditions in which they are allowed and/or prohibited. Hot taps should not be considered routine procedure and can only be used when there is no practical alternative.

2.3.3.3.5. PL-3.9

This section addresses the precautions that should be taken to prevent combustion of hydrogen air mixtures. The subsections cover the following topics:

- PL-3.9.1 – Leakage prevention
- PL-3.9.2 – Purging of pipelines
- PL-3.9.3 – Prevention of accidental ignition

2.3.3.3.6. PL-3.10

This section covers the required testing after construction. To prove strength, a test of pressure at 150% or higher of MAOP must be held for 2 hours with water as the preferred test medium. The location classification influences test methods and should be known by the designer or test operating company. Pipelines that cross highways and railroads may be tested in the same manner as the lines on each side of the crossing. Air/inert gas testing can be done in locations class 3 and 4 provided they follow the conditions outlined in PL-3.10.5.

2.3.3.3.7. PL-3.11

This section covers the cleaning, drying, and commissioning procedures for a newly constructed pipeline. These procedures include methods of functional testing of equipment and systems and a procedure to manage the introduction of hydrogen gas. Records of testing should be completed with reference to PL-3.11.5.

2.3.3.3.8. PL-3.12

This section addresses the design and installation of pipe type and bottle type holders and the special provisions applicable to both.

2.3.3.3.9. PL-3.13

Section PL-3.13 provides requirements to control and limit the MAOP of the high-pressure distribution system. In general, the maximum pressure must follow the limits in the code and shall not exceed the design pressure of the weakest element of the system or the maximum safe pressure in which the system should be subjected (based on its operation and maintenance history).

2.3.3.3.10. PL-3.14

This section prescribes the minimum requirements for uprating pipelines or mains to a higher MAOP. This includes procedural testing and maintenance requirements for uprating.

2.3.3.3.11. PL-3.15

This section covers the required spacing of valves in the pipeline for sectionalizing and accessibility by intended valve use.

2.3.3.3.12. PL-3.16

The preferred locations for valves and pressure control stations is above ground. However, if it is not possible, this section outlines requirements for construction of vault designs to allow access.

2.3.3.3.13. PL-3.17

This section specifies the location of the customer's meter and regulator installations. These items must be above grade and protected.

2.3.3.3.14. PL-3.18

This section provides guidance on the design, installation, and general provisions for steel service lines.

2.3.3.3.15. PL-3.19

This section outlines the required inspections and NDE examinations for weldments and brazements for construction of pipeline systems above 20% of more of the specified minimum yield strength (SMYS). Examination methods are suggested including visual, radiographic, liquid penetrant, magnetic particle, ultrasonic, and hardness control and testing.

2.3.3.3.16. PL-3.20

This section states that defective welds will be repaired or removed in accordance with API 1104. Also, it defines the required welder qualifications.

2.3.3.3.17. PL-3.21

This section covers the requirements and considerations for conversion of steel pipeline from previous use to hydrogen service. For a dual service pipeline used alternatively to transport natural gas under ASME B31.8 or hydrogen under this code only the initial conversion to hydrogen service requires qualification testing. The remainder of this section covers the procedural and testing requirements for a conversion of this type.

2.4. NFPA 2 – 2020: Hydrogen Technologies Code

NFPA 2 covers general hydrogen safety requirements for storage, generation, piping, and venting as well as general safety requirements for hydrogen systems. Guidelines are specific to gaseous and liquified hydrogen respectively. This code specifies physical protection, such as the separation distances based on pressure and pipe sizes and protection requirements based on storage capacity. It also addresses hydrogen generation, compression, and processing equipment. Detection and ventilation systems are specified to ensure that hydrogen cannot accumulate in concentrations over 25% of the lower flammability limit (LFL). Using hydrogen enriched natural gas would likely require some recalibration or changes to measuring this LFL value. Like most NFPA documents, it can be named in the local building code or the CFR or any other binding requirement by the Authority Having Jurisdiction. NFPA 2 does not specifically address mixtures of hydrogen with any other flammable gases, including natural gas. Guidance may need to be added to address what concentration of hydrogen triggers the requirements of NFPA 2 to be met.

2.4.1. Chapter 4 – General Fire Safety Requirements

This chapter provides general safety requirements as well as references to requirements for prescriptive or performance-based options where permitted. Safety of hydrogen must be considered for unplanned releases, impinging fire on the hydrogen system, and external force on the hydrogen system that might lead to unsafe conditions. Assumptions include single fire and release points. Physical damage from vehicles shall be provided where required including guard posts. These general requirements would not need to be updated any further.

2.4.2. Chapter 5 – Performance Based Option

Chapter 5 provides requirements for the performance-based option to ensure code requirements are met. The AHJ is required to make the final approval of a performance-based design option. Safeguards shall ensure that, under normal and abnormal conditions, unwanted releases and exposures of failure to occupants and property are minimized. Also, it dictates that interaction with other hazardous materials that could lead to unwanted reactions is minimized. Performance-based designs shall provide a means to reduce and handle unwanted releases, provide safeguards to detect hazardous gas/vapor levels, as well as maintain power and ventilation. Identification of scenarios are identified in this chapter, including fire, pressure, deflagration, detonation, hazardous material exposure/release. Technical data and references should be provided to ensure validity of performance-based designs. Since these requirements are performance based and require review and approval by the AHJ, they would only need to be updated based on the blend ratio of hydrogen enriched natural gas and reviewed again.

2.4.3. Chapter 6 – General Hydrogen Requirements

In addition to the general fire safety requirements listed in chapter 4, chapter 6 identifies general hydrogen requirements. Maximum allowable quantity (MAQ) requirements are listed for spaces with and without dedicated gas cabinets and exhausted enclosure based on whether there are sprinklers in the space or not. If a space exceeds the MAQ, occupancy classifications must meet the local building code requirements. Piping requirements must be in accordance with applicable sections of ASME B31 (See Section 0 & 2.2) as well as ICC International Fuel Gas Code. NFPA 68 and 69 shall be followed for explosion control and prevention where required (see Section 2.7). This chapter also specifies ventilation rates of enclosures and guidance on the location of enclosure discharge panels. Additionally, sprinkler design for an area storing or using hydrogen must at least be designed as Extra Hazard Group 1 for the density/area curve. Gas detection systems are specified here. Note that if hydrogen enriched natural gas is used the gas detection system would need to be recalibrated accordingly based on the blend ratio.

2.4.4. Chapter 7 – Gaseous Hydrogen

This chapter covers gaseous hydrogen storage, use, and handling. Cylinders, containers, and tanks shall be designed, fabricated, tested, and marked to meet DOT regulations, ASME Boiler and Pressure Vessel Code, or other agency requirements. Pressure relief devices are required to ensure rupturing is prevented during thermal exposures. Pressure relief devices must also follow CGA (Compressed Gas Association) standards. Requirements are located in Table 7.1.22.9.1 for protection features based on storage capacity or if there is hydrogen generating or processing equipment. This includes electrical, bonding/grounding, explosion, detection and separation requirements. Separation distances for non-bulk gaseous hydrogen are also specified. Bulk gaseous requirements are also included, for systems storing 5,000 ft^3 or more of gaseous hydrogen. Maximum internal pipe diameters are specified based on pressure for interconnecting piping. These requirements would likely not need to be updated since storage of natural gas/hydrogen mixtures is not anticipated.

2.4.5. Chapter 8 – Liquefied Hydrogen

This chapter is similar to chapter 7 but specifies requirements for liquefied hydrogen. Cylinders, containers, and tanks shall be designed, fabricated, tested, and marked to meet DOT regulations, ASME Boiler and Pressure Vessel Code, or other agency requirements. Pressure relief devices are required to ensure rupturing is prevented during thermal exposures. Separation distances are specified for both non-bulk and bulk LH2.
There will likely not be blended liquid fuels and this requirement would not be relevant to hydrogen enriched natural gas.

2.4.6. Chapter 13 – Hydrogen Generation Systems

This chapter applies to hydrogen generating equipment that is permanently generating hydrogen at a minimum rate of 36 g/hr and shall not exceed 100 kg/hr. Siting requirements are prescribed including requirements to meet area classification per NFPA 70. Indoor systems shall meet MAQ and separation requirements. Outdoor installations shall meet MAQ separation requirements as well as classification in accordance with NFPA 70 if exhaust gas concentration exceeds 25% LFL. Specific requirements are listed based on the type of equipment such as electrolyzers and gasifiers. While these requirements would need to be met for hydrogen production systems, hydrogen enriched natural gas would likely not directly fit in with these requirements. Specialized equipment that is used for the blending process would need to considered and similar requirements to those listed in Chapter 13 may be followed.

2.5. NFPA 54 – 2018: National Fuel Gas Code/ANSI Z223.1

This code provides requirements for the installation and operation of gas piping and gas equipment of the consumer. It is based on cumulative experience of individuals and organizations acquainted with gas piping and intended to promote public safety. It applies to natural gas systems operating at 155 psi or less, liquid petroleum gas systems operating at 50 psi or less, and gas-air mixtures operating within the flammable range at pressures of 10 psi or less. The requirements listed for piping systems include design, materials, components, fabrication, assembly, installation, testing, operation, and maintenance. Also, appliances, equipment, and related accessories shall include installation, combustion, and venting. This code does not apply to fuel gas systems that use hydrogen as a fuel at any percentage.

2.5.1. Chapter 5 – Gas Piping System Design, Materials, and Components

Chapter 5 covers piping design in terms of sizing, operating pressures, interconnections, and materials. Sizing can be done using requirements via Chapter 6, engineering practice, or manufacturer specifications. Maximum pressure shall not exceed 125 psi in any piping system. LP-gas systems shall not exceed 20 psi. In a building, pressure shall not exceed 5 psi unless specific requirements are met such as welding/brazing of pipes, ventilation requirements, a dedicated mechanical room used in research or industrial purpose, and other specific requirements. Gas-air mixtures operating within the flammable range must operate at pressures of 10 psi or less. Requirements are listed for metallic and plastic piping materials. Backflow prevention shall ensure that air mixtures and contaminates cannot get into the gas supply. Between the meter and the appliance, low pressure devices shall be installed to ensure dangerous conditions do not occur during reduction of gas pressure. The operating pressures might need to be updated based on the blend ratio of hydrogen enriched natural gas. Piping material would need to be considered based on hydrogen embrittlement concerns.

2.5.2. Chapter 6 – Pipe Sizing

This chapter provides methods for pipe sizing. Tables are used to understand the pressure drop based on the fuel, inlet pressure, total length and size of piping. These tables are for natural gas or propane. These tables and methods would need to be updated if hydrogen is blended in with natural gas. Expansion of these tables based on the expected blend ratios and additional information when sizing for hydrogen would need to be added.

2.5.3. Chapter 7 – Gas Piping Installation

This chapter prescribes installation requirements including freeze protection, backfilling requirements, corrosion protection, and routing requirements. Appliances shall be listed per Chapter 9 or an engineering evaluation will need to be conducted to accept an unlisted appliance. This requirement would likely remain even for hydrogen enriched natural gas. One thing to note is the flammability range for hydrogen is much wider than natural gas as shown in Table 1-3. The likelihood of a flammable gas-air mixture would be higher as the hydrogen content increases based on the systems intended design and operation. Systems that contain air but are designed to operate outside of the flammable range (following 7.10) might need to follow requirements for operating within the flammable range (7.11).

2.5.4. Chapter 9 – Appliance, Equipment, and Accessory Installation

This chapter provides requirements for appliances and other equipment. Appliances shall be connected to the type of fuel it was designed for and shall not be converted without consultation from the installation instructions, gas supplier, or appliance manufacturer. Air for combustion and ventilation requirements for these appliances are specified in this chapter for indoor appliances. These requirements would remain valid even for hydrogen enriched natural gas as a change in fuel to the appliance would require work to ensure the combustion process is both safe and effective in the appliance.

2.5.5. Chapter 10 – Installation of Specific Appliances

Chapter 10 includes requirements for installation of appliances including furnaces, heaters, engine power air conditioners, clothes dryers, fireplaces, and more. Different requirements such as separation, clearances, flue duct sizes, and more are provided in this chapter. These requirements would be mostly valid even for hydrogen enriched natural gas, and a lot of the requirements are to follow manufacturer instructions. These requirements might change based on the blend ratio and would need to be followed.

2.5.6. Chapter 11 – Procedures to Be Followed to Place Appliance in Operation

Chapter 11 provides information on adjusting burner based on gas input, altitude, and how to verify safety devices. The set points for appliances would change based on the blend ratio of hydrogen into natural gas but overall, these requirements would remain valid.

2.5.7. Chapter 12 – Venting of Appliances

This chapter prescribes requirements for safe venting from appliances to ensure all exhaust and flue gases are directed to the outdoors. Sizing requirements are based on the appliance and overall combustion rate. The overall thickness, diameter, height, and spacing for the for-gas vents, chimneys, and more. Similar to chapter 10, these requirements would be valid. Flue duct requirements would need to be updated based on the amount of hydrogen used in the combustion process.

2.6. NFPA 55 – 2020: Compressed Gasses and Cryogenic Fluids Code

This code supersedes NFPA 43C for the storage of gaseous oxidizing materials. The replacement covers the storage of all gas cylinders and was completely revised in 2003. This expansion included the coverage of not only compressed and liquified gasses in portable and stationary containers but also at the manufactures and consumer sites. Chapter 7 covers compressed gases and compressed natural gas would fall under this section. Chapter 10 covers the storage of gaseous hydrogen and states that piping should follow ASME B31 code. Requirements for setback distances for hydrogen gaseous systems are also covered here. Chapter 11 has similar requirements but for liquid hydrogen. These setback requirements are also extracted into NFPA 2.

2.6.1. Chapter 5 – Classification of Hazards

Chapter 5 requires mixtures to be classified in accordance with the hazards of the complete mixture rather than each part of the mixture. Flammability of gas mixtures shall be classified by CGA P-23, Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components; or by physical testing in accordance with the requirements of ASTM E681, Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases), or International Organization for Standardization (ISO) 10156, Gases and gas mixtures — Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets.

2.6.2. Chapter 6 – Building-Related Controls

Section 6.5 of chapter 6 prescribes that hydrogen gas rooms be constructed with noncombustible materials with fire resistance ratings of not less than 2 hours. Not less than 25 percent of the room perimeter shall be exterior wall with doors and windows leading to the exterior only. Additional requirements for building systems are prescribed in this chapter such as MAQ requirements, sprinkler requirements, explosion control, spill control, ventilation/exhaust, and other general requirements. These requirements are valid for hydrogen enriched natural gas.

2.6.3. Chapter 7 – Compressed Gases

Compressed gas storage, use, and handling is prescribed in Chapter 7. Separation requirements based on the type of gas are prescribed, as well as requirements for pressure relief devices per the CGA standards. These requirements are valid for hydrogen enriched natural gas.

2.6.4. Chapter 8 – Cryogenic Fluids

Similar to chapter 7, chapter 8 prescribes general requirements but for cryogenic fluids. Pressure relief devices must also follow CGA standards. Separation distances are also prescribed. These requirements are valid for hydrogen enriched natural gas.

2.6.5. *Chapter 10 – Gas Hydrogen Systems*

Chapter 10 prescribes requirements for gaseous hydrogen systems. Hydrogen vent systems must follow CGA G-5.5. Venting must maintain gas concentration lower than 25% LFL. Stationary compressors shall be fitted with check and relief valves. There are specific separation requirements for bulk hydrogen based on pressure and maximum pipe size. These are similar requirements to what is listed in NFPA 2. There are mitigation means to reduce these distances such as the use of fire barriers. Underground and indoor bulk hydrogen storage requirements are also prescribed here. Maximum internal pipe diameters are specified based on pressure for interconnecting piping. These requirements would need to be considered and possibly updated for hydrogen enriched natural gas for the appropriate pressure and pipe size separation distances. Criteria for the amount of hydrogen present in a blend would need to be made to determine when the hydrogen requirements would need to be met.

2.7. NFPA 67 – 2019, NFPA 68 – 2018, & NFPA 69 – 2019

NFPA 67 Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems is designed to include information on explosion prevention and mitigation in vessels, ducts, and buildings, focusing primarily on deflagrations. The standard also covers protection against detonations in manifold pipe networks. NFPA 68 Standard on Explosion Protection by Deflagration Venting is the standard that provides performance-based options for deflagration protection using vents. The full sizing criteria for deflagration vents is included. NFPA 69 Standard on Explosion Prevention Systems provides requirements for design, installation, and operation and maintenance for various explosion prevention systems. These include active and passive systems such as control of oxidants and combustible concentration as well as explosion suppression and deflagration containment. There are both performance and prescribed requirements for these different systems in the standard.

These standards require user input and understanding of the specific fuel that is used. Combustion metrics such as flame speed and overpressure for the specific gas-air mixture is required to perform the vent size calculations. Some of these are shown for the individual fuels in Table 1-3. These standards are hydrogen and natural gas blend ready since mixed fuel combustion properties can be determined using tool sets such as Cantera to define the flame speed and other properties.

2.8. NFPA 497 – 2017: Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

NFPA 497 is a recommended practice for locations that have flammable gases, vapors, and liquids that may release into an environment where electrical equipment or systems might cause ignition. An in-depth overview of combustible material classification is listed in Chapter 4, including defining the behavior of gas based on whether it is lighter or heavier than air. Based on the blend ratio of hydrogen into natural gas, the fuel might be lighter or heavier. Furthermore, there may be separation based on the scenario since natural gas may be heavier than air (based on the hydrocarbons) but hydrogen is lighter as shown in Table 1-3. The standard breaks down the areas with combustible materials by Class and Group as well as locations by Zone or Division. If an area is not considered Class I Division 1 or Division 2, or Class I Zone 0, 1, or 2 it is considered unclassified. A Division 1 classified location is defined as a location that is likely to have an ignitable mixture under normal conditions. Division 2 is likely to have an ignitable mixture under abnormal conditions. Unclassified locations have a very infrequent condition where an ignitable mixture exists. Class I Zone 0 classified locations include inadequately ventilated locations with volatile flammable liquids, and it is not good practice to install electrical equipment in these areas. Class I Zone 1 classified locations include adequately ventilated locations where volatile flammable liquid releases are common. Class I Zone 2 classified locations generally do not have ignitable mixtures occurring during normal operations and if they do they exist for a short duration. Class I Division combustible materials are divided into Groups A, B, C, and D. Class I Zone combustible materials are divided into Groups are IIA, IIB, and IIC based on the properties. Several scenarios are reviewed in Chapter 5 to understand a variety of classification examples while considering metrics such as pressure, flow rate, grading, and equipment.

2.9. Additional Codes and Standards

Additional codes and standards include:

- API 5L – 2018: Line Pipe. This code specifies standards for line pipe, including harness and strain design requirements with specifications on pipe squareness and mill joint requirements.
- ANSI/API Specification 6D – 2014: Specification for Pipeline and Piping Valves. This code defines the requirements for the design and manufacturing for valves in pipeline and piping systems for the petroleum and natural gas industries.
- ASME B16.5 – 2020: Pipe Flanges and Flanged Fittings: NPS ½ through NPS 24, Metric/Inch Standard. This standard addresses pressure and temperature ratings, materials, dimensions, tolerances, marking, testing, and methods for designating openings for pipe flanges and flanged fittings.
- ASTM A53 – 2020: Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless. This standard addresses materials and construction for steel pipes of varying size and type.
- ASTM D2513 – 2020: Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings. This standard addresses the requirements and test methods for material, dimensions, hydrostatic burst strength, tensile strength, chemical resistance, sustained pressure, heat fusion, and impact resistance of plastic pipes, tubing, and fittings used in the distribution of natural gas. This standard also covers requirements for use with liquefied petroleum gas.
- National Association of Corrosion Engineers (NACE) SP0206 – 2016: Internal Corrosion Direct Assessment Methodology for Pipelines Carrying Normally Dry Natural Gas. This standard covers the internal corrosion direct assessment process for normally dry natural gas pipeline systems.

Generally, these codes and standards address specific components of a pipeline system and dictate that the materials/design of the components be appropriate for the fluid being transported. However, ASTM D2513 and NACE SP0206 are specific for natural gas (and liquefied petroleum gas), so hydrogen and blends are not directly addressed.

3. SUMMARY & DISCUSSION

There are many safety codes and standards that are relevant to hydrogen blending in the natural gas infrastructure. Relevant codes include those that address natural gas and hydrogen specifically, as well as those that address blended gasses. However, there are gaps that will need to be addressed when considering introducing hydrogen/natural gas blends into the current infrastructure. Through review, it was found that many of the codes do not use a specified range of natural gas concentrations or constituents. Instead, blanket statements are used that dictate the use of materials and design methods that are appropriate for the mixtures being transported.

Gaps in these codes would require modification. For instance, pipeline design guidance in the ASME B31.12 code only applies to hydrogen concentrations above 10% by volume and operating pressures below 3,000 psi. NFPA 2 applies to mixtures above 95% hydrogen by volume with no specific pressure limits. A new section may have to be written in ASME B31.8 that specifies code for conversion of used natural gas pipeline to a hydrogen enriched pipeline. This section would likely mimic the structure of sections that discuss uprating of an existing pipeline or reinstatement of a dormant pipeline with hydrogen specific measures for material compatibility, hydrogen embrittlement, and pressure derate due to the addition of hydrogen. These could likely be informed by ASME B31.12 and amended where gaps exist.

Set back distance and area classification will have to be modified to add content to address enriched hydrogen-natural gas pipelines. NFPA 2 does have set back calculation for H_2 lines but may require modification to be applied to larger pipeline systems and low-pressure systems. Note that current H_2 stations usually run small lines 3/8”- 1” at 3,000 – 15,000 PSI. NFPA 54 is the gas code for residential, after the meter, piping. This code does not currently address hydrogen as a, or component of, fuel gas. Also, there are certain requirements, such as odorization, that may be insufficient to allow end users to detect hydrogen leaks. The modification of existing safety codes and standards may only be necessary in limited conditions. Since there are current hydrogen specific codes available, it may be the case that application of those codes is required when considering modification to the current infrastructure. A determination of the concentration of hydrogen in the blend would be required for when hydrogen-specific codes would apply.

Table 3-1 shows the codes and standards that have been reviewed in the report. The rows are color coded to show where blends are directly addressed.

Table 3-1. Codes and Standards Summary Table

Reference	Summary	H_2/NG Blend Applicable?
ASME B31.8-2018	This standard covers various gas transmission and distribution components including gas pipelines, compressor stations, metering devices, offshore components for distribution of gas to onshore locations, and more.	No – this code is intended for natural gas pipelines without significant quantities of hydrogen. However, the code states that the constituents in the natural gas can vary if the fuel performs as normal in the end user's burner tips (section 840.1). It is not clear what percentage of hydrogen can be added before the flame speed of the natural gas blends is altered enough to cause burner problems. However, reference [13] estimates a range of 5-15% hydrogen
ASME B31.8s-2018	This standard describes the process an operator may use to develop an integrity management program.	Yes – both compressed gas and hydrogen gas systems are addressed in this standard.
ASME B31.12-2019	This standard is designed to address the gap between the existing natural gas pipeline codes and standards and hydrogen infrastructure applications.	Yes – this code is intended for hydrogen pipeline systems that contain 10% or more hydrogen by volume with pressures below 3,000 psig. Sections PL-3.21 covers the requirements to allow operation of a code previously used under ASME B31.8 to be converted to use under B31.12 but is currently limited to steel service lines only.
NFPA 2	NFPA 2 covers general hydrogen safety requirements for storage, generation, piping, and venting as well as general safety requirements for hydrogen systems.	No – this code is not applicable to gaseous mixtures that are less than 95% H_2 by volume.
NFPA 54	This code provides requirements for the installation and operation of gas piping and gas equipment of the consumer	No – this code applies to natural gas systems operating at 125 psi or less. It does not apply to gas systems that use hydrogen as a fuel.
NFPA 55	This code covers the storage of all gas cylinders and was completely revised in 2003. This expansion included the coverage of not only compressed and liquified gasses in only compressed and liquified gasses in portable and stationary containers but also the manufacturer's and consumer sites	Yes – both compressed gas and hydrogen gas systems are addressed in this standard.
NFPA 67, 68 & 69	NFPA 67 includes information on explosion prevention and mitigation in vessels, ducts, and buildings, focusing primarily on deflagrations. The standard also covers protection against detonations in manifold pipe networks. NFPA 68 provides performance-based options for deflagration protection using vents. The full sizing criteria for deflagration vents is included. NFPA 69 provides requirements for design, installation, and operation and maintenance for various explosion prevention systems.	Yes – sets requirements for flammable gases as a function of the gas property.
NFPA 497	NFPA 497 is a recommended practice for locations that have flammable gases, vapors, and liquids that may release into an environment where electrical equipment or systems might cause ignition	Yes – sets requirements for flammable gases as a function of the gas property.

REFERENCES

[1] NaturalGas.org, "What is Natural Gas?," 20 9 2013. [Online]. Available: http://naturalgas.org/overview/background/. [Accessed 5 6 2021].

[2] US Energy Information Administration, "Hydrogen Explained," 7 1 2021. [Online]. Available: https://www.eia.gov/energyexplained/hydrogen/.

[3] M. Momirlan and T. Veziroglu, "The properties of hydrogen as fuel tomorrow in sustainable energysystem for a cleaner planet," *International Journal of Hydrogen Energy,* vol. 30, pp. 795-802, 2005.

[4] Department of Energy, "Department of Energy Hydrogen Program Plan," 2020. [Online]. Available: https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf. [Accessed 2021].

[5] DOT PHMSA, "Natural Gas Pipeline Systems," [Online]. Available: https://primis.phmsa.dot.gov/comm/NaturalGasPipelineSystems.htm?nocache=464. [Accessed 05 10 2020].

[6] NaturalGas.org, "The Transportation of Natural Gas," 20 09 2013. [Online]. Available: http://naturalgas.org/naturalgas/transport/. [Accessed 21 09 2020].

[7] American Gas Association, "How Does the Natural Gas Delivery System Work?," [Online]. Available: https://www.aga.org/natural-gas/delivery/how-does-the-natural-gas-delivery-system-work-/#:~:text=The%20pressure%20of%20gas%20in,actually%20reached%20in%20the%20system.. [Accessed 21 09 2020].

[8] PennState College of Earth and Mineral Sciences , "Natural Gas Composition and Specifications," [Online]. Available: https://www.e-education.psu.edu/fsc432/content/natural-gas-composition-and-specifications. [Accessed 5 6 2021].

[9] Engineering ToolBox, "Molecular Weight - Common Substances," 2009. [Online]. Available: https://www.engineeringtoolbox.com/molecular-weight-gas-vapor-d_1156.html. [Accessed 07 10 2020].

[10] Engineering ToolBox, "Gases - Densities," 2003. [Online]. Available: https://www.engineeringtoolbox.com/gas-density-d_158.html. [Accessed 08 10 2020].

[11] H. Wilkening and D. Baraldi, "CFD modelling of accidental hydrogen release from pipelines," *International Journal of Hydrogen Energy,* vol. 32, 2007.

[12] Engineering ToolBox, "Gases - Dynamic Viscosity," 2014. [Online]. Available: https://www.engineeringtoolbox.com/gases-absolute-dynamic-viscosity-d_1888.html. [Accessed 08 10 2020].

[13] M. Melaina, O. Antonia and M. Penev, "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," Golden, CO, NREL, 2013, p. 1.

[14] DOT PHMSA, "Pipeline Safety Stakeholder Communications," [Online]. Available: https://primis.phmsa.dot.gov/comm/states.htm?nocache=9179. [Accessed 04 10 2020].

[15] e-CFR, "Title 49 Part 192: Transportation of Natural Gas and Other Gas by Pipeline," [Online]. Available: https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=531c923e178db0864e9a841dc478e0f3&mc=true&n=pt49.3.192&r=PART&ty=HTML#se49.3.192_11. [Accessed 04 10 2020].

[16] NCSL, "Making State Gas Pipelines Safe and Reliable: An Assessment of State Policy," 04 2011. [Online]. Available: https://www.ncsl.org/research/energy/state-gas-pipelines-federal-and-state-responsibili.aspx#:~:text=Interstate%20pipelines%20are%20managed%20by,liquefied%20natural%20gas%20facility%20construction. [Accessed 04 10 2020].

[17] Bureau of Ocean Energy Management, "OCS Lands Act History," [Online]. Available: https://www.boem.gov/oil-gas-energy/leasing/ocs-lands-act-history. [Accessed 16 12 2020].

DISTRIBUTION

Email—Internal

Name	Org.	Sandia Email Address
Joseph Ronevich	08367	jaronev@sandia.gov
Chris San Marchi	08367	cwsanma@sandia.gov
Austin Baird	08854	arbaird@sandia.gov
Austin Glover	08854	amglove@sandia.gov
Technical Library	01977	sanddocs@sandia.gov

Email—External (encrypt for OUO)

Name	Company Email Address	Company Name
Jeffrey Mohr	Jeffrey.Mohr@nrel.gov	National Renewable Energy Laboratory

This page left blank

This page left blank

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.