Hydrogen Technologies Safety Guide

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National Renewable Energy Laboratory

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Technical Report
NREL/TP-5400-60948
January 2015

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List of Acronyms

AHJ	authority having jurisdiction
ANSI	American National Standards Institute
ASM	American Society of Materials
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing Materials
BPV	boiler and pressure vessel
CFC	California Fire Code
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CSA	Canadian Standards Association
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
H_2	hydrogen
HGV	hydrogen gas vehicle
IBC	International Building Code
IFC	International Fire Code
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
OSHA	Occupational Safety and Health Administration
PEM	proton exchange membrane
PHA	process hazard analysis
SAE	Society of Automotive Engineers
UL	Underwriters Laboratories

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Introduction

The purpose of this guide is to provide basic background information on hydrogen technologies. It is not intended to be a comprehensive collection of hydrogen technologies safety information. It is intended to provide project developers, code officials, and other interested parties the background information to be able to put hydrogen safety in context. For example, code officials reviewing permit applications for hydrogen projects will get an understanding of the industrial history of hydrogen, basic safety concerns, and safety requirements.

What are hydrogen technologies? For the purposes of this report they are processes that use or produce hydrogen. Hydrogen can be used as fuel to power internal combustion engines or fuel cells, or as an energy carrier. Hydrogen has been used as an industrial chemical for more than a century. The Haber process for producing ammonia was developed in 1909 (Austin 1984), and the production of ammonia accounts for approximately half of the hydrogen produced worldwide (Ramachandran and Menon 1998). Approximately 40% of hydrogen produced is used to hydrogenate petroleum products. Hydrogen is also used in several industrial processes including the following:

- Glass production
- Electronics manufacturing
- Coolant applications (low viscosity and high heat transfer) (Austin 1984).

Safety requirements for industrial uses of hydrogen are relatively well established. The National Fire Protection Association (NFPA) and the Compressed Gas Association (CGA) have published safety standards that address the storage, use, and handling of hydrogen in industrial applications that date back to the first edition of NFPA 567 (later renumbered as NFPA 50A) (National Fire Protection Association 1963) circa 1960.

In the last 20 years there has been a developing interest in using hydrogen as a fuel for fuel cells, primarily proton exchange membrane (PEM) fuel cells. PEM fuel cells are the preferred fuel cell technology for vehicles and other new applications because of their fast start-up time and low operating temperature. These fuel cells are used for stationary power, primarily in backup power units, and to produce electricity for electric vehicles. Hydrogen fuel cell vehicles require fueling at intervals comparable to a gasoline powered vehicle. This fueling activity will likely require vehicle owners and operators to operate fueling equipment, although in some states all fueling is conducted by fueling station personnel. Fueling a hydrogen fuel cell vehicle requires approximately five minutes. This exposure of the general public to hydrogen represents a significant change in the hydrogen risk spectrum from that of trained workers in a controlled environment handling hydrogen.

Placing hydrogen at public fueling stations and using it in vehicles has created a need for new safety requirements. These requirements reside in several documents and are addressed in the Regulations, Codes, and Standards section of this document.

This document is organized into the following seven sections:

- Introduction

- Physical properties of hydrogen
- History of hydrogen technologies
- Overview of regulations, codes, and standards for hydrogen technologies
- Material selection for hydrogen technologies
- Component selection for hydrogen technologies
- Overview of permitting hydrogen technologies.

Table 1 (U.S. Census Bureau 2012) shows that approximately 174,000 gasoline equivalent gallons of hydrogen were consumed in 2011. This is well under 1% of the total alternative fuels consumed in that year. However, this number should increase as zero-emission-vehicle mandates drive increased usage of fuel cell vehicles. This table shows that hydrogen fuel cell vehicles are in the developmental phase. Each year has shown an increase in the number of vehicles and the amount of fuel consumed, but the totals are very small relative to other alternative fuels.

Table 1. Comparison of Total Vehicles and Fuel Consumed by Alternative Fuel Type

Fuel Type	2003	2004	2005	2006	2007	2008	2009	2010	2011
Compressed Natural Gas									
Total Vehicles	114,406	118,532	117,699	116,131	114,391	113,973	114,270	115,863	118,214
Total Fuel Consumed[a]	133,222	158,903	166,878	172,011	178,565	189,358	199,513	210,007	220,247
Electricity									
Total Vehicles	47,485	49,536	51,398	53,526	55,730	56,901	57,185	57,462	67,295
Total Fuel Consumed[a]	5,141	5,269	5,219	5,104	5,037	5,050	4,956	4,847	7,635
Ethanol, 85 percent									
Total Vehicles	176,799	211,800	246,363	297,099	364,384	450,327	504,297	618,506	862,837
Total Fuel Consumed[a]	26,071	31,581	38,074	44,041	54,091	62,464	71,213	90,323	137,165
Hydrogen									
Total Vehicles	9	43	119	159	223	313	357	421	527
Total Fuel Consumed[a]	2	8	25	41	66	117	140	152	174
Liquefied Natural Gas									
Total Vehicles	2,640	2,717	2,748	2,798	2,781	3,101	3,176	3,354	3,436
Total Fuel Consumed[a]	13,503	20,888	22,409	23,474	24,594	25,554	25,652	26,072	26,242
Liquefied Petroleum Gas									
Total Vehicles	190,369	182,864	173,795	164,846	158,254	151,049	147,030	143,037	139,477
Total Fuel Consumed[a]	224,697	211,883	188,171	173,130	152,360	147,784	129,631	126,354	124,457
Other Fuels									
Total Vehicles	0	0	3	3	3	3	3	0	0
Total Fuel Consumed[a]	0	0	2	2	2	2	2	0	0

[a] Fuel consumption unit: thousand gasoline equivalent gallons.

General Safety Issues and Physical Properties of Hydrogen

Hydrogen is a flammable gas with a wide flammability range (4%–75% by volume) and relatively low ignition energy (0.02 millijoules) (McCarty et al. 1981). It has a very low density and therefore must be stored at high pressures (10,000–15,000 psi range) to achieve enough mass for practical use. The ease of ignition and high storage pressure of hydrogen create a large portion of the risk associated with hydrogen usage.

Hydrogen also has the ability to attack—and damage to the point of leakage—certain materials that are used for the construction of storage containers, piping, valves, and other appurtenances. This destructive capability is sometimes referred to as hydrogen embrittlement (Cramer and Covino 2003). The mechanisms of hydrogen embrittlement can be complex and vary with several physical parameters including temperature and pressure. Hydrogen's ability to escape through materials based on its destructive abilities and small molecule size also contributes to the risk associated with hydrogen usage.

Hydrogen is the lightest element with an atomic number of 1. It is a colorless, odorless, flammable gas. Table 2 (McCarty et al. 1981) shows several key properties including the following:

- Hydrogen has a specific gravity of 0.0696, which explains its powerful buoyancy.
- Hydrogen has a boiling point of −423°F, which means that it takes a lot of energy to liquefy hydrogen and that liquid hydrogen presents hazards as a cryogenic fluid.
- It is not on the U.S. Environmental Protection Agency (EPA) List of Lists,[1] which means that it is not generally considered a pollutant.
- It has a liquid density of 4.23 lb/ft^3, which means that it is a light liquid—there is more mass of hydrogen in a gallon of water than in a gallon of liquid hydrogen.
- Because of the very low boiling point, a liquid release of hydrogen will rapidly vaporize and very likely not reach the ground in liquid form.

[1] The EPA List of Lists is the list of all materials regulated by the EPA, http://www.epa.gov/emergencies/tools.htm#lol.

Table 2. Hydrogen Properties

	U.S. Units	SI Units
Chemical formula	H_2	H_2
Molecular weight	2.016	2.016
NFPA rating	Health=0 Flammability=4 Instability=0	
DOT classification	2.1	
EPA list of lists	No	
Vapor pressure at −423°F (−252.8°C)	14.69 psia	101.283 kPa
Density of the gas at boiling point and 1 atm	0.083 lb/ft^3	1.331 kg/m^3
Specific gravity of the gas at 32°F and 1 atm (air=1)	0.0696	0.0696
Specific volume of the gas at 70°F (21.1°C) and 1 atm	192.0 ft^3/lb	11.99 m^3/kg
Specific gravity of the liquid at boiling point and 1 atm	0.0710	0.0710
Density of the liquid at boiling point and 1 atm	4.23 lb/ft^3	67.76 kg/m^3
Boiling point at 14.69 psia (101.283 kPa)	−423.0°F	−252.8°C
Melting point at 14.69 psia (101.283 kPa)	−434.5°F	−259.2°C
Critical temperature	−399.8°F	−239.9°C
Critical pressure	188 psia	1296.212 kPa, abs
Critical density	1.88 lb/ft^3	30.12 kg/m^3
Triple point	−434.8°F at 1.021 psia	−259.3°C at 7.042 kPa, abs
Latent heat of fusion at triple point	24.97 Btu/lb	58.09 kJ/kg
Latent heat of vaporization at boiling point	191.7 Btu/lb	446.0 kJ/kg
Specific heat of the gas at 70°F (21.1°C) and 1 atm		
C_p	3.425 Btu/(lb)(°F)	14.34 kJ/(kg)(°C)
C_v	2.418 Btu/(lb)(°F)	10.12 kJ/(kg)(°C)
Ratio of specific heats	1.42	1.42
Solubility in water vol/vol at 60°F (15.6°C)	0.019	0.019
Flammable limits in air	4% to 75%	
Air required for combustion	-	
Autoignition temperature	752°F	400°C

The following paragraphs describe each table parameter in more detail.

1. Molecular weight. The molecular weight of a material is used in many calculations. For example, a basic equation used in industrial hygiene—calculating the required flow rate to dilute material—requires the use of the molecular weight. The specific gravity (and density) of a gas is proportional to the molecular weight. This means that as the molecular weight of a material increases, the gas density increases. This relationship does not hold true for liquids where the specific gravity of a liquid does not necessarily increase with the molecular weight of the material.

2. Chemical formula. The chemical formula shows the atoms that make up a chemical molecule and their approximate configuration. This information is important for several reasons. First, it tells what atoms make up the material. Second, the molecular configuration often indicates properties of the material. For example, materials that contain OH (oxygen–hydrogen) groups will likely have specific chemical properties.

3. NFPA rating. The NFPA rating system gives information on health hazards, flammability hazards, instability hazards, and other special hazards such as whether a material is an oxidizer. For health, flammability, and instability hazards, a scale of 0 to 4 is used with hazard level increasing with increasing numeric magnitude. The criteria that define the hazard levels are set forth in NFPA 704 Identification of the Hazards of Materials for Emergency Response 2001 edition.

   DOT classification. The U.S. Department of Transportation (DOT) has a list of hazardous materials in 49 CFR 172.101. This hazard class identifies what the primary hazard of the material is and what packaging requirements, weight restrictions, and other shipping safety requirements would apply. The hazard classification scheme is listed in Table 3.

Table 3. DOT Hazard Classification Scheme

Label code	Label name
1	Explosive
1.1 1	Explosive 1.11
1.2 1	Explosive 1.21
1.3 1	Explosive 1.31
1.4 1	Explosive 1.41
1.5 1	Explosive 1.51
1.6 1	Explosive 1.61
2.1	Flammable Gas
2.2	Non-Flammable Gas
2.3	Poison Gas
3	Flammable Liquid
4.1	Flammable Solid
4.2	Spontaneously Combustible

4.3	Dangerous When Wet
5.1	Oxidizer
5.2	Organic Peroxide
6.1 (inhalation hazard, Zone A or B)	Poison Inhalation Hazard
6.1 (other than inhalation hazard, Zone A or B)	Poison
7	Radioactive
8	Corrosive
9	Class 9

4. EPA listed hazardous substance. These are substances listed in 40 CFR Table 302.4. These are materials that are considered hazardous wastes if released into the environment. The column will either be marked as Yes, meaning the material is listed, or No, meaning the material is not listed. If the material is listed the reportable quantity will be shown in pounds. Note that there may be materials not listed that must be reported because they meet the definition of an unlisted waste under 40 CFR 261.2. However, this definition addresses solid materials and would likely not apply to most of the materials covered in this chapter. Also, most of these materials would be regulated as air pollutants and would be subject to air pollution control requirements under 40 CFR.

5. Boiling point. The NFPA 30 Flammable and Combustible Liquids Code defines the boiling point as follows:

    The temperature at which the vapor pressure of a liquid equals the surrounding atmospheric pressure.

    For purposes of defining the boiling point, atmospheric pressure shall be considered to be 14.7 psia (760 mm Hg). For mixtures that do not have a constant boiling point, the 20 percent evaporated point of a distillation performed in accordance with ASTM D 86, Standard Method of Test for Distillation of Petroleum Products, shall be considered to be the boiling point.

    The boiling point is the temperature at which a material will make the phase transition from liquid to gas. This piece of information is critical in understanding what is happening to a material as the storage temperature changes. Many materials are stored under conditions such that the ambient temperature and eventually the material temperature can drop below the boiling point and the material will make a phase transition from a gas to a liquid.

6. Melting point. The melting point is the temperature at which a material makes the transition from the solid phase to the liquid phase. This information is important in determining the physical state of a material. There may be storage conditions that bring a material into the solid phase.

7. Vapor pressure. The pressure of a vapor exerted by a pure liquid in equilibrium at a given temperature is referred to as the vapor pressure. The pressure exerted by the vapor is independent as long as there is liquid present. When all of the liquid in a system is vaporized, a further increase in volume will decrease the system pressure in accordance with the ideal gas law.

8. Gas density. The gas density is important data because it is the mass per unit volume at a given temperature and pressure. This is used to determine the pressure required to load a given mass of material into a gas storage container.

9. Gas specific density. This is the density relative to the density of air and will be a strong indicator of whether the gas will rise or sink after a release.

10. Liquid density. This is the mass per unit volume. Unlike gases, the density of liquids is not correlated to molecular weight.

11. Flammable limits in air. The flammable limits are the lower volume limit concentration of a chemical in air that will continue to propagate a flame once initiated. The flame would propagate at any concentration from the lower limit until it reaches an upper limit where the fuel to air ratio is too rich and the flame is quenched. The upper limit may be of concern in a situation where a container with a saturated atmosphere is being vented. During the ventilation process the concentration will move from saturation through the upper flammable limit and into the concentration range where sustained combustion will occur.

12. Net heat of combustion. The heat of combustion is a measure of the amount of energy released during the combustion of a specific chemical. This information is a strong indicator of the impact that a chemical would have if it were involved in a fire.

13. Specific heat. The specific heat of a substance is the amount of heat it absorbs per degree of increased temperature. It is expressed as the thermal energy required to raise a unit mass of the chemical one temperature degree. The constant pressure and constant volume specific heats are given where data are available.

14. Air required for combustion. The air required for combustion is the volume of air required to achieve a stoichiometric mixture that will propagate a flame once initiated.

15. Ignition temperature. The temperature at which a chemical ignites.

History of Hydrogen Technologies

Hydrogen has been used in industrial applications for more than 100 years (Austin 1984). As a result, the physical properties of hydrogen are well understood for many applications. The effect of hydrogen on a range of materials has been studied and there is extensive literature available on the properties of hydrogen and its effects on materials.

With the emergence of hydrogen fuel cell applications, the following areas are new:

- Storage of high pressure hydrogen in composite materials
- The potential exposure of the general public to high-pressure hydrogen fueling operations
- The location of high-pressure storage containers on vehicles where they are subject to the stresses of vehicle operation
- The widespread use of high-pressure hydrogen storage systems where they could be modified or damaged by individuals unqualified to work on these systems.

Discovery of Hydrogen

In 1761, Robert Boyle was able to produce hydrogen from reacting iron filings and dilute acids (Lewis 2001). In 1776, Henry Cavendish identified hydrogen as a unique substance. In 1783, Antoine Lavoisier produced hydrogen (from iron) and named the material hydrogen (Lewis 2001). In 1839 a British scientist, Sir William Robert Grove, developed the first hydrogen-powered fuel cell (Lewis 2001). He was able to produce an electric current flow by constructing a cathode, anode, ceramic membrane, and mixed acid conductive medium. This discovery eventually led to the current hydrogen-powered fuel cell.

Hydrogen has been a known material for more than 200 years. As a result of this relatively early discovery compared to other elements and the widespread industrial use, hydrogen properties are relatively well known. Hydrogen is arguably the most studied element (Rigden 2003). It has the simplest atomic structure, and as a result of that simple structure it has been used to verify fundamental atomic properties.

Hydrogen Use and Applications

Hydrogen has many industrial applications, the two most important (based on usage) being ammonia production and hydrogenation of petroleum products to improve combustion characteristics (Ramachandran and Menon 1998). Hydrogen is used in smaller quantities in a variety of industries and applications. Some of these applications are described below.

Glass Manufacturing

Larger panes of glass are manufactured using a tin bath upon which molten glass is deposited. The bath creates a flat smooth surface. To prevent oxidation, the tin bath is provided with a positive pressure protective atmosphere consisting of a mixture of nitrogen and hydrogen (Austin 1984).

Industrial Heat Transfer Fluid

Hydrogen is used as coolant in electric generating equipment. Its relatively low viscosity and high heat capacity make it an effective cooling material.

Hydrogen has a constant pressure heat capacity of 3.41 Btu/(lb R) and a gaseous viscosity of 88.05 micropoise. It has a thermal conductivity of 0.17064 Watts/(m K) (McCarty et al. 1981). Hydrogen can be used in approximately 100% concentration, which means that there is no oxygen present to support combustion.

The absence of oxygen in its cooling gas also means the generator's high-voltage insulation system will not be damaged by any corona activity in the generator's stator windings. The localized electric field near a conductor can be sufficiently concentrated to ionize air close to the conductors. This ionized air can create an electrical discharge that has the potential to damage equipment or ignite materials in their flammable concentration range. This is a significant factor in the machine's reliability.

Semiconductor Manufacturing

Hydrogen is used in semiconductor manufacturing primarily because of its reducing or oxygen scavenging properties (Wolff 2008). It is also an extremely effective heat transfer fluid, which is an advantageous property in some operations. Hydrogen is used in the following semiconductor manufacturing operations:

- Semiconductor manufacturing
- Semiconductor sintering
- Semiconductor packaging
- Wafer annealing.

Ammonia Production via the Haber-Bosch Process

The Haber-Bosch process can produce large amounts of ammonia. Fritz Haber discovered a chemical reaction to produce ammonia and Carl Bosch developed the technology for commercial-scale production of ammonia (Austin 1984). This process is significant because it allows ammonia production on a scale to support large crop production. Ammonia and associated compounds are critical for providing nitrogen to crops.

The Haber process for production of ammonia is shown in the following chemical reaction:

$$1/2N_2\,(g) + 3/2H_2\,(g) \leftrightarrow NH_3\,(g).$$

The yield for this reaction is increased by using an iron catalyst and increasing the reaction pressure. Hydrogen is a raw feedstock for this reaction. Because of the demand for ammonia, hydrogen is an industrial gas that is produced in large quantities.

Hydrogen in the Petrochemical Industry

Hydrogen is used to reduce double bonds to single bonds in hydrocarbons. This reduction process produces hydrocarbon fuels that have better combustion characteristics in internal combustion engines. Hydrogenation of petrochemicals is one of the largest uses of hydrogen.

Hydrogen as a Fuel for Fuel Cells

As mentioned earlier, hydrogen can be converted into electricity using a fuel cell. These fuel cells can be placed in vehicles to provide electricity for vehicles powered by electric motors or they can be used as stationary sources of electricity. They offer advantages including no combustion emissions and, in the case of stationary fuel cells, reliable power that can be used in emergency situations such as storms or grid outages.

The basic reaction in a hydrogen-powered fuel cell is as follows:

$H_2 + 1/2O_2 \rightarrow H_2O + e^-$ (Larminie and Dicks 2003)

This reaction typically takes place in the presence of a platinum catalyst. The cost of the catalyst is one of the major factors that determine the overall cost of the fuel cell or cells. A single fuel cell does not provide sufficient power for most applications, so the fuel cells are stacked to increase power; hence the term fuel cell stack is used to describe the fuel cells used in both stationary and vehicular applications.

Hydrogen Safety Incidents

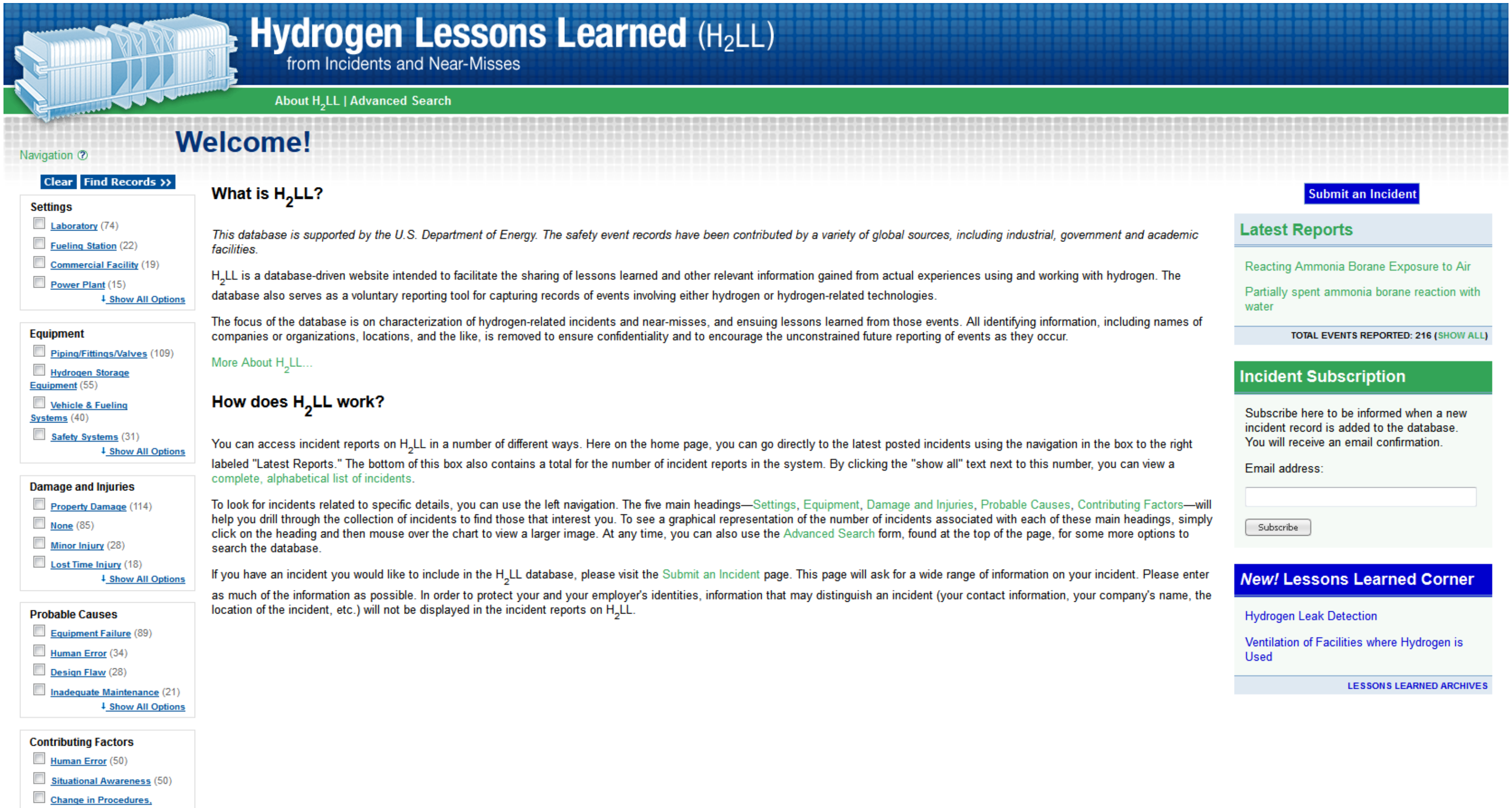
Pacific Northwest National Laboratory, a DOE national laboratory, administers a database of hydrogen incidents called H_2LL, or Hydrogen Lessons Learned.[2] This database contains information about incidents that have been voluntarily reported although identifying information has been removed. These lessons learned provide information on safety issues and concerns with hydrogen technologies, but because they are not part of a systematic program of monitoring and reporting on defined processes, frequency information cannot be derived from this database. This database contains approximately 200 entries and is organized using the following classifications:

- Settings
- Equipment
- Damages and injuries
- Probable causes
- Contributing factors.

Many of these entries describe events involving the industrial use of hydrogen or hydrogen usage for applications other than fuel cell electric vehicles or the infrastructure required to support these vehicles. There are very few entries involving the retail use of hydrogen or hydrogen applications that involve exposure to the general public.

The following page shows a screenshot of the database home page.

[2] H_2LL: Hydrogen Lessons Learned from Incidents and Near-Misses, http://h2tools.org/lessons/.


Hydrogen Lessons Learned (H2LL)
from Incidents and Near-Misses
About H2LL | Advanced Search
Navigation
Welcome!
Clear
Find Records
Settings
Laboratory (74)
Fueling Station (22)
Commercial Facility (19)
Power Plant (15)
Show All Options
Equipment
Piping/Fittings/Valves (109)
Hydrogen Storage Equipment (55)
Vehicle & Fueling Systems (40)
Safety Systems (31)
Show All Options
Damage and Injuries
Property Damage (114)
None (85)
Minor Injury (28)
Lost Time Injury (18)
Show All Options
Probable Causes
Equipment Failure (89)
Human Error (34)
Design Flaw (28)
Inadequate Maintenance (21)
Show All Options
Contributing Factors
Human Error (50)
Situational Awareness (50)
Change in Procedures,
What is H2LL?
This database is supported by the U.S. Department of Energy. The safety event records have been contributed by a variety of global sources, including industrial, government and academic facilities.
H2LL is a database-driven website intended to facilitate the sharing of lessons learned and other relevant information gained from actual experiences using and working with hydrogen. The database also serves as a voluntary reporting tool for capturing records of events involving either hydrogen or hydrogen-related technologies.
The focus of the database is on characterization of hydrogen-related incidents and near-misses, and ensuing lessons learned from those events. All identifying information, including names of companies or organizations, locations, and the like, is removed to ensure confidentiality and to encourage the unconstrained future reporting of events as they occur.
More About H2LL...
How does H2LL work?
You can access incident reports on H2LL in a number of different ways. Here on the home page, you can go directly to the latest posted incidents using the navigation in the box to the right labeled "Latest Reports." The bottom of this box also contains a total for the number of incident reports in the system. By clicking the "show all" text next to this number, you can view a complete, alphabetical list of incidents.
To look for incidents related to specific details, you can use the left navigation. The five main headings—Settings, Equipment, Damage and Injuries, Probable Causes, Contributing Factors—will help you drill through the collection of incidents to find those that interest you. To see a graphical representation of the number of incidents associated with each of these main headings, simply click on the heading and then mouse over the chart to view a larger image. At any time, you can also use the Advanced Search form, found at the top of the page, for some more options to search the database.
If you have an incident you would like to include in the H2LL database, please visit the Submit an Incident page. This page will ask for a wide range of information on your incident. Please enter as much of the information as possible. In order to protect your and your employer's identities, information that may distinguish an incident (your contact information, your company's name, the location of the incident, etc.) will not be displayed in the incident reports on H2LL.
Submit an Incident
Latest Reports
Reacting Ammonia Borane Exposure to Air
Partially spent ammonia borane reaction with water
TOTAL EVENTS REPORTED: 216 (SHOW ALL)
Incident Subscription
Subscribe here to be informed when a new incident record is added to the database. You will receive an email confirmation.
Email address:
Subscribe
New! Lessons Learned Corner
Hydrogen Leak Detection
Ventilation of Facilities where Hydrogen is Used
LESSONS LEARNED ARCHIVES

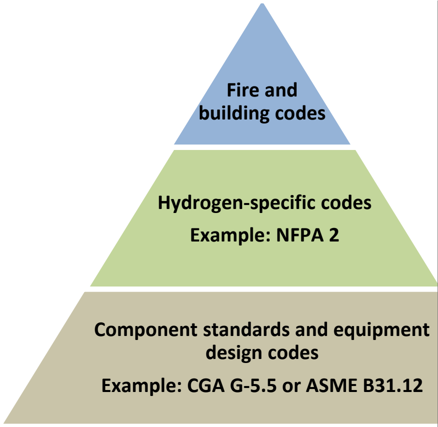
Regulations, Codes, and Standards

Hydrogen technologies are controlled through codes and standards in a manner similar to other fuels. Figure 1 illustrates the codes and standards hierarchy. The top level of the pyramid consists of building and fire codes that are directly adopted by jurisdictions and are therefore the law in the jurisdiction in which they are adopted. Any code or standard referenced in the body of a building or fire code adopted by a jurisdiction becomes a legally enforceable document in that jurisdiction. These reference documents must be written in an enforceable format to be referenced in building or fire codes. In the topical area of hydrogen technologies these documents comprise the second level of the pyramid. Key documents at this second level include the NFPA 2 Hydrogen Technologies Code and the NFPA 853 Standard for Fuel Cell Energy Systems.

These documents contain references to component standards, which comprise the bottom or third rung of the pyramid. These component standards must also be written in legally enforceable text to be referenced by these second-level codes and standards. Examples of these documents include the CGA S series of documents for pressure relief devices and the American Society of Mechanical Engineers (ASME) B31.12 standard for piping.

Viewed as a package, these documents address all key aspects of system design, construction, operation, and maintenance. Compliance with these requirements should reduce the system risk to a safe level.

The timeline in Figure 1 reflects the development of hydrogen codes and standards over the last eight years.



2014	2013	2012	2011	2010	2009	2008	2007	2006	2005
California references NFPA 2 in CFC		IFC references NFPA 2							IFC Chapter 22 Hydrogen Fueling
Draft 2nd ed. NFPA 2 developed	NFPA 55 published with clarified setback tables	NFPA 52 authority added to NFPA 2		NFPA 2 1st ed.	NFPA 2 draft	Task Group Bulk Hydrogen	Task Group Bulk Hydrogen	NFPA 2 first committee meeting	NFPA 52 2006 ed. w/ hydrogen fueling
SAE J2601 revision complete	SAE J2579 reissue	CGA H-10 issued	SAE J2719 issued		CSA H series of drafts issued	ASME B31.12 issued	CSA HGV 4		UL2267

Figure 1. Timeline of codes and standards development and the codes and standards hierarchy

At the federal level there are regulations, such as 29 CFR 1910 Subpart H Hazardous Materials, that specifically address the storage, use, and handling of hydrogen. Table 4 gives an overview of the regulations, codes, and standards that address hydrogen technologies safety.

Table 4. Overview of Regulations, Codes, and Standards Related to Hydrogen Infrastructure Safety

Federal Regulations	
OSHA Regulations 29 CFR 1910 Subpart H	Safe storage, use, and handling of hydrogen in the workplace
DOT Regulations 49 CFR 171-179	Safe transport of hydrogen in commerce
U.S. National Codes	
International Building Code (IBC)	General construction requirements for building based on occupancy class
International Fire Code (IFC)/NFPA 1 Uniform Fire Code	Requirements for hydrogen fueling stations, flammable gas, and cryogenic fluid storage
International Mechanical Code (IMC)	Requirements for ventilation for hydrogen usage in indoor locations
International Fuel Gas Code (IFGC)	Requirements for flammable gas piping
Hydrogen Technologies Specific Fire Codes and Standards	
NFPA 2 Hydrogen Technologies Code	Comprehensive code for hydrogen technologies constructed of extract material from documents such as NFPA 55 and 853 and original material
NFPA 55 Compressed Gas and Cryogenic Fluids Code	Comprehensive gas safety code that addresses flammable gases as a class of hazardous materials and also contains hydrogen-specific requirements
NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Systems	Covers installation of all commercial fuel cells including hydrogen PEM fuel cells
Hydrogen Technologies Component, Performance, and Installation Standards	
ASME B31.3 and B31.12 Piping and Pipelines	Piping design and installation codes that also cover material selection
ASME Boiler and Pressure Vessel (BPV) Code	Addresses design of steel alloy and composite pressure vessels
CGA S series	Addresses requirements for pressure relief devices for containers
CGA H Series	Components and systems
UL 2075	Sensors
CSA H series of hydrogen component standards	
CSA FC1	Stationary fuel cells
SAE J2601/SAE J2600	Dispensing and dispenser nozzles

The following sections from the OSHA regulations (found in 29 CFR §1910 Subpart H) address the storage, use, and handling of gaseous and liquefied hydrogen. Although these regulations are based on older NFPA documents they are federal regulations. Many jurisdictions will accept compliance with current codes and standards as meeting the OSHA regulations.

§ 1910.103 Hydrogen.

(a) *General*—(1) *Definitions.* As used in this section (i) Gaseous hydrogen system is one in which the hydrogen is delivered, stored and discharged in the gaseous form to consumer's piping. The system includes stationary or movable containers, pressure regulators, safety relief devices, manifolds, interconnecting piping and controls. The system terminates at the point where hydrogen at service pressure first enters the consumer's distribution piping.

(ii) Approved—Means, unless otherwise indicated, listed or approved by a nationally recognized testing laboratory. Refer to § 1910.7 for definition of nationally recognized testing laboratory.

(iii) Listed—See "approved".

(iv) ASME—American Society of Mechanical Engineers.

(v) DOT Specifications—Regulations of the Department of Transportation published in 49 CFR Chapter I. (vi) DOT regulations—See § 1910.103 (a)(1)(v).

(2) *Scope*—(i) *Gaseous hydrogen systems.* (*a*) Paragraph (b) of this section applies to the installation of gaseous hydrogen systems on consumer premises where the hydrogen supply to the consumer premises originates outside the consumer premises and is delivered by mobile equipment.

(*b*) Paragraph (b) of this section does not apply to gaseous hydrogen systems having a total hydrogen content of less than 400 cubic feet, nor to hydrogen manufacturing plants or other establishments operated by the hydrogen supplier or his agent for the purpose of storing hydrogen and refilling portable containers, trailers, mobile supply trucks, or tank cars.

(ii) *Liquefied hydrogen systems.* (*a*) Paragraph (c) of this section applies to the installation of liquefied hydrogen systems on consumer premises.

(*b*) Paragraph (c) of this section does not apply to liquefied hydrogen portable containers of less than 150 liters (39.63 gallons) capacity; nor to liquefied hydrogen manufacturing plants or other establishments operated by the hydrogen supplier or his agent for the sole purpose of storing liquefied hydrogen and refilling portable containers, trailers, mobile supply trucks, or tank cars.

(b) *Gaseous hydrogen systems*—(1) *Design*—(i) *Containers.* (*a*) Hydrogen containers shall comply with one of the following:

(*1*) Designed, constructed, and tested in accordance with appropriate requirements of ASME Boiler and Pressure Vessel Code, section VIII—Unfired Pressure Vessels—1968, which is incorporated by reference as specified in § 1910.6.

(*2*) Designed, constructed, tested and maintained in accordance with U.S. Department of Transportation Specifications and Regulations.

(*b*) Permanently installed containers shall be provided with substantial noncombustible supports on firm noncombustible foundations.

(*c*) Each portable container shall be legibly marked with the name "Hydrogen" in accordance with the marking requirements set forth in § 1910.253(b)(1)(ii). Each manifolded hydrogen supply unit shall be legibly marked with the name "Hydrogen" or a legend such as "This unit contains hydrogen."

(ii) *Safety relief devices.* (*a*) Hydrogen containers shall be equipped with safety relief devices as required by the ASME Boiler and Pressure Vessel Code, section VIII Unfired Pressure Vessels, 1968 or the DOT Specifications and Regulations under which the container is fabricated.

(*b*) Safety relief devices shall be arranged to discharge upward and unobstructed to the open air in such a manner as to prevent any impingement of escaping gas upon the container, adjacent structure or personnel. This requirement does not apply to DOT Specification containers having an internal volume of 2 cubic feet or less.

(*c*) Safety relief devices or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner which would interfere with proper operation of the device.

(iii) *Piping, tubing, and fittings.* (*a*) Piping, tubing, and fittings shall be suitable for hydrogen service and for the pressures and temperatures involved. Cast iron pipe and fittings shall not be used.

(*b*) Piping and tubing shall conform to section 2—"Industrial Gas and Air Piping"—Code for Pressure Piping, ANSI B31.1–1967 with addenda B31.1–1969, which is incorporated by reference as specified in § 1910.6.

(*c*) Joints in piping and tubing may be made by welding or brazing or by use of flanged, threaded, socket, or compression fittings. Gaskets and thread sealants shall be suitable for hydrogen service.

(iv) *Equipment assembly.* (*a*) Valves, gauges, regulators, and other accessories shall be suitable for hydrogen service.

(*b*) Installation of hydrogen systems shall be supervised by personnel familiar with proper practices with reference to their construction and use.

(*c*) Storage containers, piping, valves, regulating equipment, and other accessories shall be readily accessible, and shall be protected against physical damage and against tampering.

(*d*) Cabinets or housings containing hydrogen control or operating equipment shall be adequately ventilated.

(*e*) Each mobile hydrogen supply unit used as part of a hydrogen system shall be adequately secured to prevent movement.

(*f*) Mobile hydrogen supply units shall be electrically bonded to the system before discharging hydrogen.

(v) *Marking.* The hydrogen storage location shall be permanently placarded as follows: "HYDROGEN—FLAMMABLE GAS—NO SMOKING—NO OPEN FLAMES," or equivalent.

(vi) *Testing.* After installations, all piping, tubing, and fittings shall be tested and proved hydrogen gas tight at maximum operating pressure.

(2) *Location*—(i) *General.* (*a*) The system shall be located so that it is readily accessible to delivery equipment and to authorized personnel.

(*b*) Systems shall be located aboveground.

(*c*) Systems shall not be located beneath electric power lines.

(*d*) Systems shall not be located close to flammable liquid piping or piping of other flammable gases.

(*e*) Systems near aboveground flammable liquid storage shall be located on ground higher than the flammable liquid storage except when dikes, diversion curbs, grading, or separating solid walls are used to prevent accumulation of flammable liquids under the system.

(ii) *Specific requirements.* (*a*) The location of a system, as determined by the maximum total contained volume of hydrogen, shall be in the order of preference as indicated by Roman numerals in Table H–1.

TABLE H–1

Nature of location	Size of hydrogen system		
	Less than 3,000 CF	3,000 CF to 15,000 CF	In excess of 15,000 CF
Outdoors	I	IDI	
In a separate building	II	II	II
In a special room	III	III	Not permitted
Inside buildings not in a special room and exposed to other occupancies	IV	Not permitted	Not permitted

(*b*) The minimum distance in feet from a hydrogen system of indicated capacity located outdoors, in separate buildings or in special rooms to any specified outdoor exposure shall be in accordance with Table H–2.

(*c*) The distances in Table H–2 Items 1 and 3 to 10 inclusive do not apply where protective structures such as adequate fire walls are located between the system and the exposure.

TABLE H–2

Type of outdoor exposure		Size of hydrogen system: Less than 3,000 CF	3,000 CF to 15,000 CF	In excess of 15,000 CF
1. Building or structure	Wood frame construction [1]	10	25	50
	Heavy timber, noncombustible or ordinary construction [1]	0	10	[2] 25
	Fire-resistive construction [1]	0	0	0
2. Wall openings	Not above any part of a system	10	10	10
	Above any part of a system	25	25	25
3. Flammable liquids above ground	0 to 1,000 gallons	10	25	25
	In excess of 1,000 gallons	25	50	50
4. Flammable liquids below ground—0 to 1,000 gallons	Tank	10	10	10
	Vent or fill opening of tank	25	25	25
5. Flammable liquids below ground—in excess of 1,000 gallons	Tank	20	20	20
	Vent or fill opening of tank	25	25	25
6. Flammable gas storage, either high pressure or low pressure	0 to 15,000 CF capacity	10	25	25
	In excess of 15,000 CF capacity	25	50	50
7. Oxygen storage	12,000 CF or less [4]	--	--	--
	More than 12,000 CF [5]	--	--	--
8. Fast burning solids such as ordinary lumber, excelsior or paper		50	50	50
9. Slow burning solids such as heavy timber or coal		25	25	25
10. Open flames and other sources of ignition		25	25	25
11. Air compressor intakes or inlets to ventilating or air-conditioning equipment		50	50	50
12. Concentration of people [3]		25	50	50

[1] Refer to NFPA No. 220 Standard Types of Building Construction for definitions of various types of construction. (1969 Ed.)
[2] But not less than one-half the height of adjacent side wall of the structure.
[3] In congested areas such as offices, lunchrooms, locker rooms, time-clock areas.
[4] Refer to NFPA No 51, gas systems for welding and cutting (1969).
[5] Refer to NFPA No 566, bulk oxygen systems at consumer sites (1969).

(*d*) Hydrogen systems of less than 3,000 CF when located inside buildings and exposed to other occupancies shall be situated in the building so that the system will be as follows:

(*1*) In an adequately ventilated area as in paragraph (b)(3)(ii)(*b*) of this section.

(*2*) Twenty feet from stored flammable materials or oxidizing gases.

(*3*) Twenty-five feet from open flames, ordinary electrical equipment or other sources of ignition.

(*4*) Twenty-five feet from concentrations of people.

(*5*) Fifty feet from intakes of ventilation or air-conditioning equipment and air compressors.

(*6*) Fifty feet from other flammable gas storage.

(*7*) Protected against damage or injury due to falling objects or working activity in the area.

(*8*) More than one system of 3,000 CF or less may be installed in the same room, provided the systems are separated by at least 50 feet. Each such system shall meet all of the requirements of this paragraph.

(3) *Design consideration at specific locations*—(i) *Outdoor locations.* (*a*) Where protective walls or roofs are provided, they shall be constructed of noncombustible materials.

(*b*) Where the enclosing sides adjoin each other, the area shall be properly ventilated.

(*c*) Electrical equipment within 15 feet shall be in accordance with subpart S of this part.

(ii) *Separate buildings.* (*a*) Separate buildings shall be built of at least noncombustible construction. Windows and doors shall be located so as to be readily accessible in case of emergency. Windows shall be of glass or plastic in metal frames.

(*b*) Adequate ventilation to the outdoors shall be provided. Inlet openings shall be located near the floor in exterior walls only. Outlet openings shall be located at the high point of the room in exterior walls or roof. Inlet and outlet openings shall each have minimum total area of one (1) square foot per 1,000 cubic feet of room volume. Discharge from outlet openings shall be directed or conducted to a safe location.

(*c*) Explosion venting shall be provided in exterior walls or roof only. The venting area shall be equal to not less than 1 square foot per 30 cubic feet of room volume and may consist of any one or any combination of the following: Walls of light, noncombustible material, preferably single thickness, single strength glass; lightly fastened hatch covers; lightly fastened swinging doors in exterior walls opening outward; lightly fastened walls or roof designed to relieve at a maximum pressure of 25 pounds per square foot.

(*d*) There shall be no sources of ignition from open flames, electrical equipment, or heating equipment.

(*e*) Electrical equipment shall be in accordance with subpart S of this part for Class I, Division 2 locations.

(*f*) Heating, if provided, shall be by steam, hot water, or other indirect means.

(iii) *Special rooms.* (*a*) Floor, walls, and ceiling shall have a fire-resistance rating of at least 2 hours. Walls or partitions shall be continuous from floor to ceiling and shall be securely anchored. At least one wall shall be an exterior wall. Openings to other parts of the building shall not be permitted. Windows and doors shall be in exterior walls and shall be located so as to be readily accessible in case of emergency. Windows shall be of glass or plastic in metal frames.

(*b*) Ventilation shall be as provided in paragraph (b)(3)(ii)(*b*) of this section.

(*c*) Explosion venting shall be as provided in paragraph (b)(3)(ii)(*c*) of this section.

(*d*) There shall be no sources of ignition from open flames, electrical equipment, or heating equipment.

(*e*) Electric equipment shall be in accordance with the requirements of subpart S of this part for Class I, Division 2 locations.

(*f*) Heating, if provided, shall be by steam, hot water, or indirect means.

(4) *Operating instructions.* For installations which require any operation of equipment by the user, legible instructions shall be maintained at operating locations.

(5) *Maintenance.* The equipment and functioning of each charged gaseous hydrogen system shall be maintained in a safe operating condition in accordance with the requirements of this section. The area within 15 feet of any hydrogen container shall be kept free of dry vegetation and combustible material.

(c) *Liquefied hydrogen systems*—(1) *Design*—(i) *Containers.* (*a*) Hydrogen containers shall comply with the following: Storage containers shall be designed, constructed, and tested in accordance with appropriate requirements of the ASME Boiler and Pressure Vessel Code, section VIII—Unfired Pressure Vessels (1968) or applicable provisions of API Standard 620, Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks, Second Edition (June 1963) and appendix R (April 1965), which is incorporated by reference as specified in § 1910.6.

(*b*) Portable containers shall be designed, constructed and tested in accordance with DOT Specifications and Regulations.

(ii) *Supports.* Permanently installed containers shall be provided with substantial noncombustible supports securely anchored on firm noncombustible foundations. Steel supports in excess of 18 inches in height shall be protected with a protective coating having a 2-hour fire-resistance rating.

(iii) *Marking.* Each container shall be legibly marked to indicate “LIQUEFIED HYDROGEN—FLAMMABLE GAS.”

(iv) *Safety relief devices.* (*a*)(*1*) Stationary liquefied hydrogen containers shall be equipped with safety relief devices sized in accordance with CGA Pamphlet S–1, part 3, Safety Relief Device Standards for Compressed Gas Storage Containers, which is incorporated by reference as specified in § 1910.6.

(*2*) Portable liquefied hydrogen containers complying with the U.S. Department of Transportation Regulations shall be equipped with safety relief devices as required in the U.S. Department of Transportation Specifications and Regulations. Safety relief devices shall be sized in accordance with the requirements of CGA Pamphlet S–1, Safety Relief Device Standards, part 1, Compressed Gas Cylinders and part 2, Cargo and Portable Tank Containers.

(*b*) Safety relief devices shall be arranged to discharge unobstructed to the outdoors and in such a manner as to prevent impingement of escaping liquid or gas upon the container, adjacent structures or personnel. See paragraph (c)(2)(i)(*f*) of this section for venting of safety relief devices in special locations.

(*c*) Safety relief devices or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner which would interfere with proper operation of the device.

(*d*) Safety relief devices shall be provided in piping wherever liquefied hydrogen could be trapped between closures.

(v) Piping, tubing, and fittings. (*a*) Piping, tubing, and fittings and gasket and thread sealants shall be suitable for hydrogen service at the pressures and temperatures involved. Consideration shall be given to the thermal expansion and contraction of piping systems when exposed to temperature fluctuations of ambient to liquefied hydrogen temperatures.

(*b*) Gaseous hydrogen piping and tubing (above –20 °F.) shall conform to the applicable sections of Pressure Piping section 2—Industrial Gas and Air Piping, ANSI B31.1–1967 with addenda B31.1–1969. Design of liquefied hydrogen or cold (–20 °F. or below) gas piping shall use Petroleum Refinery Piping ANSI B31.3–1966 or Refrigeration Piping ANSI B31.5–1966 with addenda B31.5a–1968 as a guide, which are incorporated by reference as specified in § 1910.6.

(*c*) Joints in piping and tubing shall preferably be made by welding or brazing; flanged, threaded, socket, or suitable compression fittings may be used.

(*d*) Means shall be provided to minimize exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members, and surfaces not suitable for cryogenic temperatures. Only those insulating materials which are rated nonburning in accordance with ASTM Procedures D1692–68, which is incorporated by reference as specified in § 1910.6, may be used. Other protective means may be used to protect personnel. The insulation shall be designed to have a vapor-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation. The insulation material and outside shield shall also be of adequate design to prevent attrition of the insulation due to normal operating conditions.

(*e*) Uninsulated piping and equipment which operate at liquefied-hydrogen temperature shall not be installed above asphalt surfaces or other combustible materials in order to prevent contact of liquid air with such materials. Drip pans may be installed under uninsulated piping and equipment to retain and vaporize condensed liquid air.

(vi) *Equipment assembly.* (*a*) Valves, gauges, regulators, and other accessories shall be suitable for liquefied hydrogen service and for the pressures and temperatures involved.

(*b*) Installation of liquefied hydrogen systems shall be supervised by personnel familiar with proper practices and with reference to their construction and use.

(*c*) Storage containers, piping, valves, regulating equipment, and other accessories shall be readily accessible and shall be protected against physical damage and against tampering. A shutoff valve shall be located in liquid product withdrawal lines as close to the container as practical. On containers of over 2,000 gallons capacity, this shutoff valve shall be of the remote control type with no connections, flanges, or other appurtenances (other than a welded manual shutoff valve) allowed in the piping between the shutoff valve and its connection to the inner container.

(*d*) Cabinets or housings containing hydrogen control equipment shall be ventilated to prevent any accumulation of hydrogen gas.

(vii) *Testing.* (*a*) After installation, all field-erected piping shall be tested and proved hydrogen gas-tight at operating pressure and temperature.

(*b*) Containers if out of service in excess of 1 year shall be inspected and tested as outlined in (*a*) of this subdivision. The safety relief devices shall be checked to determine if they are operable and properly set.

(viii) *Liquefied hydrogen vaporizers.* (*a*) The vaporizer shall be anchored and its connecting piping shall be sufficiently flexible to provide for the effect of expansion and contraction due to temperature changes.

(*b*) The vaporizer and its piping shall be adequately protected on the hydrogen and heating media sections with safety relief devices.

(*c*) Heat used in a liquefied hydrogen vaporizer shall be indirectly supplied utilizing media such as air, steam, water, or water solutions.

(*d*) A low temperature shutoff switch shall be provided in the vaporizer discharge piping to prevent flow of liquefied hydrogen in the event of the loss of the heat source.

(ix) *Electrical systems.* (*a*) Electrical wiring and equipment located within 3feet of a point where connections are regularly made and disconnected, shall be in accordance with subpart S of this part, for Class I, Group B, Division 1 locations.

(*b*) Except as provided in (*a*) of this subdivision, electrical wiring, and equipment located within 25 feet of a point where connections are regularly made and disconnected or within 25 feet of a liquid hydrogen storage container, shall be in accordance with subpart S of this part, for Class I, Group B, Division 2 locations. When equipment approved for class I, group B atmospheres is not commercially available, the equipment may be—

(*1*) Purged or ventilated in accordance with NFPA No. 496–1967, Standard for Purged Enclosures for Electrical Equipment in Hazardous Locations,

(*2*) Intrinsically safe, or

(*3*) Approved for Class I, Group C atmospheres. This requirement does not apply to electrical equipment which is installed on mobile supply trucks or tank cars from which the storage container is filled.

(x) *Bonding and grounding.* The liquefied hydrogen container and associated piping shall be electrically bonded and grounded.

(2) *Location of liquefied hydrogen storage*—(i) *General requirements.* (*a*) The storage containers shall be located so that they are readily accessible to mobile supply equipment at ground level and to authorized personnel.

(*b*) The containers shall not be exposed by electric power lines, flammable liquid lines, flammable gas lines, or lines carrying oxidizing materials.

(*c*) When locating liquefied hydrogen storage containers near above-ground flammable liquid storage or liquid oxygen storage, it is advisable to locate the liquefied hydrogen container on ground higher than flammable liquid storage or liquid oxygen storage.

(*d*) Where it is necessary to locate the liquefied hydrogen container on ground that is level with or lower than adjacent flammable liquid storage or liquid oxygen storage, suitable protective means shall be taken (such as by diking, diversion curbs, grading), with respect to the adjacent flammable liquid storage or liquid oxygen storage, to prevent accumulation of liquids within 50 feet of the liquefied hydrogen container.

(*e*) Storage sites shall be fenced and posted to prevent entrance by unauthorized personnel. Sites shall also be placarded as follows: "Liquefied Hydrogen—Flammable Gas—No Smoking—No Open Flames."

(*f*) If liquefied hydrogen is located in (as specified in Table H–3) a separate building, in a special room, or inside buildings when not in a special room and exposed to other occupancies, containers shall have the safety relief devices vented unobstructed to the outdoors at a minimum elevation of 25 feet above grade to a safe location as required in paragraph (c)(1)(iv)(*b*) of this section.

(ii) *Specific requirements.* (*a*) The location of liquefied hydrogen storage, as determined by the maximum total quantity of liquefied hydrogen, shall be in the order of preference as indicated by Roman numerals in the following Table H–3.

TABLE H–3—MAXIMUM TOTAL QUANTITY OF LIQUEFIED HYDROGEN STORAGE PERMITTED

Nature of location	Size of hydrogen storage (capacity in gallons)			
	39.63 (150 liters) to 50	51 to 300	301 to 600	In excess of 600
Outdoors	I	I	I	I
In a separate building	II	II	II	Not permitted
In a special room	III	III	Not permitted	Do.
Inside buildings not in a special room and exposed to other occupancies	IV	Not permitted	Do.	Do.

NOTE: This table does not apply to the storage in dewars of the type generally used in laboratories for experimental purposes.

(*b*) The minimum distance in feet from liquefied hydrogen systems of indicated storage capacity located outdoors, in a separate building, or in a special room to any specified exposure shall be in accordance with Table H–4.

TABLE H–4—MINIMUM DISTANCE (FEET) FROM LIQUEFIED HYDROGEN SYSTEMS TO EXPOSURE [1,2]

Type of Exposure	Liquefied hydrogen storage (capacity in gallons)		
	39.63 (150 liters) to 3,500	3,501 to 15,000	15,001 to 30,000
1. Fire-resistive building and fire walls [3]	5	5	5
2. Noncombustible building [3]	25	50	75
3. Other buildings [3]	50	75	100
4. Wall openings, air-compressor intakes, inlets for air-conditioning or ventilating equipment	75	75	75
5. Flammable liquids (above ground and vent or fill openings if below ground) (see 513 and 514)	50	75	100
6. Between stationary liquefied hydrogen containers	5	5	5
7. Flammable gas storage	50	75	100
8. Liquid oxygen storage and other oxidizers (see 513 and 514)	100	100	100
9. Combustible solids	50	75	100
10. Open flames, smoking and welding	50	50	50
11. Concentrations of people	75	75	75

[1] The distance in Nos. 2, 3, 5, 7, 9, and 12 in Table H-4 may be reduced where protective structures, such as firewalls equal to height of top of the container, to safeguard the liquefied hydrogen storage system, are located between the liquefied hydrogen storage installation and the exposure.
[2] Where protective structures are provided, ventilation and confinement of product should be considered. The 5-foot distance in Nos. 1 and 6 facilitates maintenance and enhances ventilation.
[3] Refer to Standard Types of Building Construction, NFPA No. 220-1969 for definitions of various types of construction.
In congested areas such as offices, lunchrooms, locker rooms, time-clock areas.

(iii) *Handling of liquefied hydrogen inside buildings other than separate buildings and special rooms.* Portable liquefied hydrogen containers of 50 gallons or less capacity as permitted in Table H–3 and in compliance with subdivision (i)(f) of this subparagraph when housed inside buildings not located in a special room and exposed to other occupancies shall comply with the following minimum requirements:

(*a*) Be located 20 feet from flammable liquids and readily combustible materials such as excelsior or paper.

(*b*) Be located 25 feet from ordinary electrical equipment and other sources of ignition including process or analytical equipment.

(*c*) Be located 25 feet from concentrations of people.

(*d*) Be located 50 feet from intakes of ventilation and air-conditioning equipment or intakes of compressors.

(*e*) Be located 50 feet from storage of other flammable-gases or storage of oxidizing gases.

(*f*) Containers shall be protected against damage or injury due to falling objects or work activity in the area.

(*g*) Containers shall be firmly secured and stored in an upright position.

(*h*) Welding or cutting operations, and smoking shall be prohibited while hydrogen is in the room.

(*i*) The area shall be adequately ventilated. Safety relief devices on the containers shall be vented directly outdoors or to a suitable hood. See paragraphs (c)(1)(iv)(b) and (c)(2)(i)(f) of this section.

(3) *Design considerations at specific locations*—(i) *Outdoor locations.* (*a*) Outdoor location shall mean outside of any building or structure, and includes locations under a weather shelter or canopy provided such locations are not enclosed by more than two walls set at right angles and are provided with vent-space between the walls and vented roof or canopy.

(*b*) Roadways and yard surfaces located below liquefied hydrogen piping, from which liquid air may drip, shall be constructed of noncombustible materials.

(*c*) If protective walls are provided, they shall be constructed of noncombustible materials and in accordance with the provisions of paragraph (c)(3)(i)(*a*) of this section.

(*d*) Electrical wiring and equipment shall comply with paragraph (c)(1)(ix) (*a*) and (*b*) of this section.

(*e*) Adequate lighting shall be provided for nighttime transfer operation.

(ii) *Separate buildings.* (*a*) Separate buildings shall be of light noncombustible construction on a substantial frame. Walls and roofs shall be lightly fastened and designed to relieve at a maximum internal pressure of 25 pounds per square foot. Windows shall be of shatterproof glass or plastic in metal frames. Doors shall be located in such a manner that they will be readily accessible to personnel in an emergency.

(*b*) Adequate ventilation to the outdoors shall be provided. Inlet openings shall be located near the floor level in exterior walls only. Outlet openings shall be located at the high point of the room in exterior walls or roof. Both the inlet and outlet vent openings shall have a minimum total area of 1 square foot per 1,000 cubic feet of room volume. Discharge from outlet openings shall be directed or conducted to a safe location.

(*c*) There shall be no sources of ignition.

(*d*) Electrical wiring and equipment shall comply with paragraphs (c)(1)(ix) (*a*) and (*b*) of this section except that the provisions of paragraph (c)(1)(ix)(*b*) of this section shall apply to all electrical wiring and equipment in the separate building.

(*e*) Heating, if provided, shall be by steam, hot water, or other indirect means.

(iii) *Special rooms.* (*a*) Floors, walls, and ceilings shall have a fire resistance rating of at least 2 hours. Walls or partitions shall be continuous from floor to ceiling and shall be securely anchored. At least one wall shall be an exterior wall. Openings to other parts of the building shall not be permitted. Windows and doors shall be in exterior walls and doors shall be located in such a manner that they will be accessible in an emergency. Windows shall be of shatterproof glass or plastic in metal frames.

(*b*) Ventilation shall be as provided in paragraph (c)(3)(ii)(*b*) of this section.

(*c*) Explosion venting shall be provided in exterior walls or roof only. The venting area shall be equal to not less than 1 square foot per 30 cubic feet of room volume and may consist of any one or any combination of the following: Walls of light noncombustible material; lightly fastened hatch covers; lightly fastened swinging doors opening outward in exterior walls; lightly fastened walls or roofs designed to relieve at a maximum pressure of 25 pounds per square foot.

(*d*) There shall be no sources of ignition.

(*e*) Electrical wiring and equipment shall comply with paragraph (c)(1)(ix) (*a*) and (*b*) of this section except that the provision of paragraph (c)(1)(ix)(*b*) of this section shall apply to all electrical wiring and equipment in the special room.

(*f*) Heating, if provided, shall be steam, hot water, or by other indirect means.

(4) *Operating instructions*—(i) *Written instructions*. For installations which require any operation of equipment by the user, legible instructions shall be maintained at operating locations.

(ii) *Attendant*. A qualified person shall be in attendance at all times while the mobile hydrogen supply unit is being unloaded.

(iii) *Security*. Each mobile liquefied hydrogen supply unit used as part of a hydrogen system shall be adequately secured to prevent movement.

(iv) *Grounding*. The mobile liquefied hydrogen supply unit shall be grounded for static electricity.

(5) *Maintenance*. The equipment and functioning of each charged liquefied hydrogen system shall be maintained in a safe operating condition in accordance with the requirements of this section. Weeds or similar combustibles shall not be permitted within 25 feet of any liquefied hydrogen equipment.

[39 FR 23502, June 27, 1974, as amended at 43 FR 49746, Oct. 24, 1978; 53 FR 12121, Apr. 12, 1988; 55 FR 32015, Aug. 6, 1990; 58 FR 35309, June 30, 1993; 61 FR 9236, 9237, Mar. 7, 1996; 69 FR 31881, June 8, 2004; 72 FR 71069, Dec. 14, 2007]

Material Selection for Hydrogen Technologies

Hydrogen can damage storage, piping, and appurtenance materials through processes that are partially a function of the relatively small size of the hydrogen molecule. There is an extensive literature that covers the destructive capabilities of hydrogen and its effects on materials. Volume 13a of the American Society of Materials (ASM) handbook series, "Corrosion: Fundamentals, Testing, and Protection," has a chapter devoted to hydrogen (Cramer and Covino 2003).

This guide is primarily focused on assisting with deployment of emerging hydrogen technologies, so there will be no literature review. Instead there is a brief discussion of the resources available to use when selecting materials for use in hydrogen fueling systems and storage systems for stationary fuel cells. Several of these resources are found in codes and standards documents. The ASME documents provide key requirements for deploying hydrogen technologies.

The ASME B31.12 Hydrogen Pipelines and Piping code specifies materials that can be used for hydrogen applications. This material selection information is found in Chapter GR-2 of the code.

The ASME BPV code provides extensive information on material selection and testing for hydrogen usage. This material covers the use of both metals and composite materials for container construction. This topic is initially covered in Section A, Part UG. The ASME BPV Section XIII also contains Code Case 2579-3 Composite Reinforced Pressure Vessels for Gaseous H2 Service.

Both of these ASME documents are or will be referenced in building and fire codes and are therefore likely enforceable requirements in most jurisdictions in the United States.

The ASME B31.12 documents give procedures for calculating pipe diameters based on operation parameters. Chapter GR-2—Materials addresses the following topics:

- Materials and specification
- Temperature limitations
- Impact testing methods and acceptance criteria
- Fluid service requirements for materials
- Deterioration of materials in service
- Joining and auxiliary materials.

The Canadian Standards Association (CSA) document CSA CHMC-1 addresses material testing for hydrogen applications. ANSI/CSA CHMC 1—2014 Test Method for Evaluating Material Compatibility in Compressed Hydrogen Applications—Phase I—Metals has the following scope:

> This standard provides uniform test methods for evaluating material compatibility with compressed hydrogen applications. The results of these tests are intended to provide a basic comparison of materials performance in applications utilizing compressed hydrogen. This standard is not intended to replace the targeted testing

which may be necessary to qualify the design of a component manufactured for use in hydrogen applications.

The American Society of Testing Materials (ASTM) has published a book on hydrogen embrittlement entitled "Hydrogen Embrittlement: Prevention and Control ASTM STP 692." This book covers the different test methods used to evaluate metals susceptibility to hydrogen attack.

Sandia National Laboratories has published a guide for selecting materials for hydrogen technology applications. This document is a compendium of papers detailing the material selection criteria for different types of materials that could potentially be used for hydrogen applications. It can be found at the following website: http://www.sandia.gov/matlsTechRef/.

Component Selection for Hydrogen Technologies

Hydrogen component selection and material selection are closely related topics. Components must be sized to handle the design loads and materials must be selected that can perform safely and reliably over the life of the component. Hydrogen has been used in industrial processes so there is information on components that will perform in hydrogen environments that can be used in developing hydrogen applications such as hydrogen fuel cell vehicles and stationary hydrogen-powered fuel cells. There are several codes and standards that set component design or performance requirements. The following are some of the documents that address component design:

- ASME B31.12 Hydrogen Pipelines and Piping for pipe sizing procedures
- CGA S-1.1 through 1.3 for pressure relief devices for hydrogen storage containers
- ASME BPV Section XIII for hydrogen containers
- DOT 49 CFR 171-179 for hydrogen cylinders
- CGA H.3 for hydrogen vent systems
- UL 2075 for hydrogen sensors
- NIST Handbook 44 for hydrogen meters
- CSA HGV 4.2 for hydrogen hoses
- CSA HGV 4.2 for hydrogen nozzles.

Hydrogen storage systems typically include the following components:

- Valves
- Pressure relief devices
- Pumps/compressors
- Sensors/detection systems
- Storage containers
- Vent stacks.

Hydrogen dispensing systems typically include the following additional components:

- Meters
- Nozzles
- Dispensing hoses
- Emergency shutoffs or “E stops”
- Sensors for detecting hydrogen leaks.

Component selection consists of sizing and system design. This section cannot address system design because that topic is too complex for a guidance document. Generally, hydrogen systems should be designed by engineers with training and experience in system design. Many states require that the system be designed by a licensed professional engineer and that all drawings and related design documents be sealed.

Design standards for hydrogen system components include the following:

- ASME Boiler and Pressure Vessel Code for tank design
- The CGA S-1.1 through 1.3 for pressure relief device standards
- The CGA H-7 for hydrogen vent systems
- ASME B31.12 for hydrogen piping
- The UL 2075 standard for hydrogen sensors
- The CSA H-7 for hydrogen fueling nozzles
- The CSA H-4 for hydrogen fueling hoses.

The National Renewable Energy Laboratory (NREL) conducted a process hazard analysis (PHA) on a representative hydrogen fueling system to better understand the relative risks of the pieces of the system. See Appendix A for a full description of the PHA, which gives a picture of the components of most concern in a hydrogen fueling system.

The results of this analysis show that the following three nodes present the greatest risk:

1. Compressors
2. Fueling hoses
3. Fueling nozzles.

Only fueling hoses had any failure scenarios that, after safety measures were considered, had risks above the low risk level. This result is significant because individuals are directly exposed to fueling hoses during fueling operations.

There are a variety of problems with the fueling system components. These problems generally fall under the heading of unintended releases brought on by both the high pressure and temperature variations that these systems must accommodate. NREL technology validation data were used to develop frequency ratings for the incidents associated with system components. The relative ranking shown in Table A-3 demonstrates the importance of compressor performance. The NREL data show a relatively high number of leaks in compressors. These leaks often have a significant impact on fueling system performance because they require shutting systems down to repair the compressor.

The PHA analysis provided a ranking of hydrogen fueling system component risks. This ranking is important for prioritizing safety and performance issues and research required to resolve these issues.

The high level of public exposure for hoses and nozzles makes them of particular concern. The general public will conduct vehicle fueling and handle the fueling nozzle and hose. A failure of either of these components could have severe short- and long-term impacts.

The Permitting Process

The permitting process is actually several processes typically involving multiple permits and agencies. The processes are in place to protect public safety, public health, and the environment. An example of the permits, agencies, and purposes for these multiple processes is shown in Table 5.

The permitting processes can be broken down into the following seven stages that help define the overall process and the timeline for completing all of the required components:

1. Preliminary project scoping
2. Station design
3. Approval process
4. Station/dispenser construction
5. Station/dispenser startup
6. Station/dispenser operation
7. Station/dispenser maintenance.

The required permits address all of these phases, but the permitting structure does not correlate on a one-to-one basis with the chronological steps required to build and operate a dispensing station. Table 5 and Table 6 list elements of the permitting and approval processes. The difference between these tables is that there are regulatory agencies that typically issue a permit after the applicant has shown compliance with requirements and agencies that approve of an applicant's submission without issuing a permit.

Table 5. Hydrogen Dispensing Station Permitting/Potential Permits Required

Permit	Agency	Permit / Permit Scope
Construction	Building department	Permit to construct general / Address safety construction issues
Drainage	Engineering department	Permit to construct drainage / Modification to sewer drainage
Site grading	Engineering department	Permit to construct grading / Modification to site elevation
Electrical	Building/electrical department	Electrical permit / Modification to electrical service
Demolition	Building department	Construction permit / Demolish structures required for dispenser construction
Food services	Health department	Food sales
Air emission impacts	State air pollution control agency	Air quality permit or no impact declaration
Fire safety	Fire department plans review office	Fire safety permit / General fire code compliance
Water quality	Water quality management agency	Liquid discharges to the environment

Table 6. Hydrogen Dispensing Station Approvals

Approval	Agency	Approval Scope
State environmental quality act	Self-enforcing although local authority having jurisdiction (AHJ) has first opportunity to enforce	Approval or finding of no significant impact/ environmental agency having jurisdiction
Zoning	Local zoning board	Zoning approval/allows construction and operation at defined location
State accidental release prevention program	Local administering agency (for example county health or fire department) and U.S. EPA	Approved submission or finding of non-applicability/ requires an evaluation of the impact of the release of a regulated materials from the site and a plan in the event of a release

The Permit Applicant

The administrative process for reviewing and approving projects may vary by jurisdiction but there are common elements. These basic elements are as follows:

1. Presubmittal review and feedback (optional but highly recommended)
2. Review and feedback to applicant
3. Formal submission of application
4. Public meeting (on an as needed basis determined by both administrative law and the jurisdiction's determination as to whether public input should be solicited)
5. Adjustments in the permit application (as needed) based on public input
6. Review of modified application and feedback to application
7. Resubmittal of modified application
8. Issuance of permit
9. Project construction
10. Site inspection to determine that project built as shown in final design plans
11. Periodic inspections to determine ongoing compliance.

The presubmittal review, although not typically required, is a critical step in this process. It occurs at a time when significant problems could be identified and potentially averted. Examples of problems that could be averted are:

1. Identification of problems at the proposed site that the applicant is not aware of
2. Identification of requirements the project must meet that the applicant had not evaluated in the draft application
3. Any history of issues with similar projects in the jurisdiction.

Permit Template and Example Permit

Template—Hydrogen Dispenser Added to Existing Fueling Station

For this template a single dispenser is added to an existing fueling station. The addition of a single dispenser still will trigger construction requirements. The dispenser will require at least the following elements:

- A dispensing platform
- Vehicle crash protection
- Electrical service
- Hydrogen storage or generation equipment or both for dispenser that has hydrogen generating and storage capability
- Lighting
- Compressors to compress the hydrogen to vehicle storage pressure
- Dispenser with fueling hose and nozzle
- Piping from the gaseous hydrogen storage system to the dispenser
- Fire protection system
- Maintenance system
- Unique construction requirements such as handicapped parking requirements.

Hydrogen Vehicle Infrastructure Codes and Standards Citations

This section lists codes and standards typically used for U.S. hydrogen vehicle and infrastructure projects. To determine which codes and standards apply to a specific project, identify the codes and standards currently in effect within the jurisdiction where the project will be located. Some jurisdictions also have unique ordinances or regulations that could apply. For example, the State of Michigan has state regulations that address hydrogen systems. These regulations would address the installation and operation of hydrogen fueling stations.

AHJs typically enforce the codes and standards in effect in their jurisdiction. However, many jurisdictions do not adopt the most recent building and fire codes. Jurisdictions cannot automatically reference the most current codes but instead must follow an administrative law process to update adoptions of codes and standards. There are costs associated with this process that may prevent jurisdictions from updating reference codes.

AHJs have the option of enforcing the most current code requirements to protect public safety. For example, although there is not a reference to the NFPA 2 Hydrogen Technologies Code in the 2012 International Fire Code, an AHJ could enforce these requirements to protect public safety. The 2015 International Fire Code references the NFPA 2 Hydrogen Technologies Code.

There are also both equivalency and performance-based compliance options in fire codes. The equivalency option allows the use of alternative measures that provide an equal or greater level of safety. The performance-based approach is similar but sets performance criteria that must be met in place of prescriptive code requirements. Both options require AHJ approval.

Find hydrogen vehicle and infrastructure codes and standards in these categories:

- Annual Inspections and Approvals
- General Station Requirements
- Gaseous Hydrogen Storage, Compression, and Generation Systems
- Liquefied Hydrogen Storage Systems
- Dispensing Systems
- Piping and Tubing for All Systems
- Valving and Fittings for All Systems
- Venting and Other Equipment
- Fire Safety

Annual Inspections and Approvals

Inspection Requirements

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

- 7.0 Maintenance and Repair

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 9 Maintenance

International Fire Code (International Code Council, 2012)

- 406.2 Frequency (of employee training)
- 901.6 Inspection, Testing, and Maintenance
- 901.6.2 Records (of systems inspection and maintenance)
- 2206.2.1.1 Inventory Control for Underground Tanks
- 3204.5.2 Corrosion Protection
- 3205.4 Filling and Dispensing

Personnel Issues and Training

International Fire Code (International Code Council, 2009)

- 406 Employee Training and Response Procedures
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 4.6 Personnel Training
- 4.7 Fire Department Liaison

Operation Approvals—Dispensing

International Fire Code (International Code Council, 2009)

- 2204.2 Attended Self-Service Motor Fuel-Dispensing Facilities
- 2204.3 Unattended Self-Service Motor Fuel-Dispensing Facilities
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 6.2 General Requirements
- 6.3 Requirements for Dispensing Devices

Operation Approvals—Fire and Emergency Planning

International Fire Code (International Code Council, 2009)

- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 2209.3.2.6.2 Fire-Extinguishing Systems
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5.1 Protection from Vehicles
- 2209.5.2 Emergency Shutoff Valves
- 2209.5.3 Emergency Shutdown Controls
- 2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 7.3.5 Fixed Fire Protection

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 6.3.7 Requirements for Dispensing Devices

General Station Requirements

Site Requirements for Fueling Stations

NFPA 2 Hydrogen Technologies Code (National Fire Protection Association, 2011)

- 6.6.1 Weather Protection- Classification of Weather Protection as an Indoor Versus Outdoor Area
- 6.12 Gaseous Hydrogen Detection Systems
- 6.17.1 Mechanical Exhaust Ventilation

Canopy Tops

International Building Code (International Code Council, 2009)

- 406.5.2.1 Canopies use to support gaseous hydrogen systems

International Fire Code (International Code Council, 2009)

- 2209.3.2.6 Canopy Tops
- 2209.3.3 Canopies

Fuel Delivery

International Fire Code (International Code Council, 2009)

- 105.6.8 Compressed Gases
- 105.6.10 Cryogenic Fluids
- 2205.1 Tank Filling Operation for Class I, II, or IIIA Liquids
- 3205.4 Filling and Dispensing

Vehicle Access

International Fire Code (International Code Council, 2009)

- 105.6.8 Compressed Gases

Weather Protection

International Fire Code (International Code Council, 2009)

- 2209.3.2.2 Weather Protection
- 2704.13 Weather Protection

General Safety Requirements

International Fire Code (International Code Council, 2009)

- 2209.5 Safety Precautions
- 2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
- 2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
- 3003 General Requirements
- 3203 General Safety Requirements
- 3503 General Requirements

Repair Facilities

International Fire Code (International Code Council, 2012)

- 2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
- 2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers

Gaseous Hydrogen Storage, Compression, and Generation Systems

NFPA 2 Hydrogen Technologies Code (National Fire Protection Association, 2011)

- 7.1.1.3 Building Occupancy Classification for Hydrogen Storage
- 7.1.3 Listed and Approved Hydrogen Equipment
- 7.1.4 Metal Hydride Systems (including systems on industrial trucks)
- 7.1.5 Containers, Cylinders, and Tanks (this section refers to both the ASME BPB Section XIII or Transport Canada, Transportation of Dangerous Goods Regulations)
- 7.1.5.5 Pressure-Relief Devices
- 7.1.6 Labeling Requirements
- 7.1.6.4 Piping Systems
- 7.1.7 Security (including physical protection and securing containers)
- 7.1.8 Valve Protection
- 7.1.9 Separation from Hazardous Conditions
- 7.1.10 Service and Repair
- 7.1.11 Unauthorized Use
- 7.1.12 Containers, Cylinders, and Tanks Exposed Fire
- 7.1.13 Leaks, Damage, or Corrosion
- 7.1.14 Surfaces (on which containers would be placed)
- 7.1.15 Piping (including reference to ASME B31.12, Process Piping)
- 7.1.16 Valves (required accessibility)
- 7.1.17 Vent Pipe Termination
- 7.1.18 Cathodic Protection
- 7.1.19 Transfer (reference to CGA P-1 Safe Handling of Compressed Gases in Containers)
- 7.1.21 Emergency Shut-off Valves
- 7.1.22 Excess Flow Control (requirements for leak detection and emergency shut-off or excess flow control)

- 7.1.23 Ignition Control
- 7.2 Nonbulk GH2
- 7.2.1 Nonbulk GH2 General (separation from incompatible materials)
- 7.2.2 Nonbulk GH2 Storage (includes separation distances for nonbulk GH2 storage systems, systems 5,000 scf or less)
- 7.2.3 Nonbulk GH2 Use
- 7.2.4 Nonbulk GH2 Handling
- 7.3 Bulk GH2 Systems
- 7.3.1 Bulk GH2 Systems General Requirements
- 7.3.2 Bulk GH2 Systems Storage (contains Table 7.3.2.3.1.2 (a), (b), and (c) for above ground system separation distances)
- 7.3.3 Bulk GH2 Systems Use
- 7.3.4 Handling of Bulk GH2 Systems

International Fire Code (International Code Council, 2009)

- 2209.5 Safety Precautions
- 3003 General Requirements
- 3503 General Requirements

Storage Containers

CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association, 2006)

CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association, 2005)

International Fire Code (International Code Council, 2009)

- 2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
- 3003.2 Design and Construction
- 3503.1.2 Storage Containers

Compression Systems and Equipment

International Fire Code (International Code Council, 2009)

- 2209.2 Equipment
- 2209.3 Location on Property
- 2209.5.3.1 System Requirements
- 2209.5.4.2.1 Minimum Rate of Discharge

Design of Gaseous Storage Systems—Barrier Walls

International Fire Code (International Code Council, 2009)

- 2209.3.1.1 Barrier Wall Construction – Gaseous Hydrogen

On-Site Hydrogen Production

International Fire Code (International Code Council, 2009)

- 2209.3.1 Separation from Outdoor Exposure Hazards

International Fuel Gas Code (International Code Council, 2009)

- 703.1 General Requirements

Natural Gas

ASME B31.8, Gas Transmission and Distribution Systems (American Society of Mechanical Engineers, 2003)

Liquefied Hydrogen Storage Systems

NFPA 2 Liquefied Hydrogen Requirements

NFPA 2 Hydrogen Technologies Code (National Fire Protection Association, 2011)

- 8.1.2 Containers – Design, Construction, and Maintenance (refers to ASME BPV, Rules for Unfired Pressure Vessels and Transport Canada *Transportation of Dangerous Goods Regulations*)
- 8.1.3 Design (of systems)
- 8.1.3.1 Piping Systems (refers to ASME B31.3 Process Piping)
- 8.1.4 Pressure Relief Devices (refers to CGA S-1.1 through 1.3)
- 8.1.5 Pressure Relief Vent Piping
- 8.1.6 Marking (refers to NFPA 704 Standard System for the Identification of the Hazards of Materials for Emergency Response)
- 8.1.7 Security
- 8.1.8 Separation from Hazardous Conditions
- 8.1.9 Electrical Wiring and Equipment (general reference to NFPA 70 National Electrical Code)
- 8.1.10 Service and Repair
- 8.1.11 Unauthorized Use
- 8.1.12 Leaks, Damage, and Corrosion
- 8.1.13 Lighting
- 8.1.14 Emergency Shutoff Valves
- 8.1.15 Dispensing Areas
- 8.1.16 Operations (for mobile fueling equipment)

- 8.2 Nonbulk LH2 (storage, handling and use shall be in accordance with Chapter 1–6 and 8 as applicable)
- 8.3 Bulk LH2 Systems (cutoff is = or > 150 liters)
- 8.3.1.2.1.1 Fire Resistance for Steel Supports
- 8.3.1.2.1.2 Container Marking
- 8.3.1.2.2 Vent System Requirements (including reference to CGAG-5.5)
- 8.3.1.2.3 Piping, Tubing, and Fittings (including reference to ASME B31.3 Process Piping)
- 8.3.1.2.4 Equipment Assembly (including location of emergency shutoff valves)
- 8.3.1.2.5 LH2 Vaporizers
- 8.3.1.2.6 Electrical Systems (sets electrically classified areas and refer to NFPA 70)
- 8.3.1.2.7 Bonding and Grounding
- 8.3.1.2.8 Stationary Pumps and Compressors
- 8.3.1.2.9 Emergency Shutdown System
- 8.3.2 Bulk LH2 Systems Storage
- 8.3.2.1.3 Placarding Site
- 8.3.2.1.4.1 Construction of the Inner Vessel
- 8.3.2.1.4.2 Construction of the Vacuum Jacket (Outer Vessel)
- 8.3.2.1.4.3 Nonstandard Containers (can be used with AHJ approval)
- 8.3.2.1.4.4 Concrete Containers
- 8.3.2.1.4.5 Foundations and Supports
- 8.3.2.2 Indoor Storage
- 8.3.2.2.2 Detaching Buildings (including requirements for explosion control)
- 8.3.2.3 Outdoor Storage
- 8.3.2.4 Aboveground Tanks
- 8.3.2.4.2 Physical Protection
- 8.3.2.4.3 Flood Protection
- 8.3.2.4.4 Drainage
- 8.3.2.4.5 Siting Locations (Including Table 8.3.2.4.5.1 Minimum Distance from Liquefied Hydrogen Systems to Exposures)
- 8.3.2.5 Underground Tanks

- 8.3.3 Bulk LH2 Systems Use
- 8.3.3.1.5 Inspection (requirements for annual inspection and recordkeeping)
- 8.3.4 Bulk LH2 Systems Handling
- 8.3.4.2 Carts and Trucks
- 8.3.4.4 Closed Containers
- 8.3.4.5 Cargo Transport Unloading
- 8.3.4.6 Overfilling

Liquid Hydrogen Storage—Equipment Location

International Fire Code (International Code Council, 2009)

- 2209.3 Location on Property
- 3203.5.4 Physical Protection
- 3203.6 Separation from Hazardous Conditions
- 3204.3.1.1 Location
- 3204.4.2 Location
- 3504 Storage

Liquid Hydrogen Storage—Storage Containers

International Fire Code (International Code Council, 2009)

- 2703.2 Systems, Equipment, and Processes
- 3203.1 Containers
- 3203.5 Security
- 3203.6 Separation from Hazardous Conditions
- 3204.3.1 Stationary Containers
- 3204.4 Underground Tanks

Dispensing Systems

NFPA 2 Hydrogen Technologies Code (National Fire Protection Association, 2011)

- 10.2.1 System Approvals
- 10.3.1.1 System Component Qualifications
- 10.3.1.4 Pressure Relief Devices
- 10.3.1.5 Pressure Gauges
- 10.3.1.6 Pressure Regulators
- 10.3.1.7 Fuel Lines and Piping Systems

- 10.3.1.8 Hose and Hose Connections
- 10.3.1.9 Valves
- 10.3.1.10 System Testing
- 10.3.1.11 System Maintenance
- 10.3.1.12 Equipment Security and Vehicle Protection
- 10.3.1.13 Compressed and Gas Processing Systems
- 10.3.1.14 Vehicle Fueling Dispenser System Operation
- 10.3.1.15 Vehicle Fueling Connection
- 10.3.1.16 Installation of Electrical Equipment
- 10.3.1.17 Stray or Impressed Currents and Bonding
- 10.3.1 18 Installation of Emergency Shutdown Equipment
- 10.3.1.19 Fire Protection
- 10.3.2.2.3.1.3 Separation Distances for Outdoor Gaseous Hydrogen Dispensing Systems

Vaporizers

International Fire Code (International Code Council, 2009)

- 2209.2 Equipment
- 2209.3 Location on Property
- 3203.1.3 Foundations and Supports
- 3203.2.2 Vessels or Equipment Other than Containers
- 3203.5.3 Securing of Vaporizers

International Fuel Gas Code (International Code Council, 2009)

- 708 Design of Liquefied Hydrogen Systems Associated with Hydrogen Vaporization Operations

Dispensing, Operations, and Maintenance Safety—Gaseous Hydrogen

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 9 Maintenance

International Fire Code (International Code Council, 2009)

- 2204 Dispensing Operations
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 9.2.2 Tank Filling and Bulk Delivery

- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

Dispensing, Operations, and Maintenance Safety—Liquid Hydrogen

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 9 Maintenance

International Fire Code (International Code Council, 2009)

- 2204 Dispensing Operations
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 9.2.2 Tank Filling and Bulk Delivery
- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

Piping and Tubing for All Systems

ASME B31.12, Hydrogen Piping and Pipelines (American Society of Mechanical Engineers, 2012)

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)

- F323.4(5) Specific Material Considerations—Metals
- IX K305 Pipe

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

- 3.1 General
- 3.2 Piping Materials
- 5.0 Installation
- 5.1 Piping Installation General
- 5.2 Piping Installation Above Ground Installation
- 5.3 Piping Installation Underground Installation

International Fuel Gas Code (International Code Council, 2012)

- 101.2.1 Gaseous Hydrogen Systems
- 704 Piping, Use, and Handling

705 Testing of Hydrogen Piping Systems CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association, 2006)

- 10.0 External Piping

Valving and Fittings for All Systems

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)

- IX K306 Fittings, Bends, and Branch Connections
- IX K307 Valves and Specialty Components

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

- 3.3.2 Isolation Valves
- 3.3.3 Emergency Isolation Valves
- 3.3.4 Excess Flow Valves
- 3.3.5 Check Valves
- 3.3.7 Gasket and Sealing Materials
- 3.3.8 Additional Requirements
- 5.0 Installation
- 5.1 Installation General

Venting and Other Equipment

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 6.0 Vent System
- 6.2 Sizing
- 6.3 Design
- 6.4 Materials
- 6.5 Components
- 7 Installation

International Fire Code (International Code Council, 2009)

- 2209.5.4 Venting of Hydrogen Systems
- 2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers
- 3003.16.8 Connections
- 3005.5 Venting
- 3203.3 Pressure Relief Vent Piping

- 3204.4.5 Venting of Underground Tank

Fire Safety

Construction

International Fire Code (International Code Council, 2009)

- 911 Explosion Control
- 2209.5 Safety Precautions

International Fuel Gas Code (International Code Council, 2009)

- 706.3 Outdoor Gaseous Hydrogen Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

- 9.12 Stray or Impressed Currents and Bonding

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 7.1.6 Separation from Hazardous Conditions

Equipment

International Fire Code (International Code Council, 2009)

- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5 Safety Precautions

Signage

International Fire Code (International Code Council, 2009)

- 2204.3.5 Emergency Procedures
- 2209.5.2.1 Identification

CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association, 2006)

- 6.0 Tank Design and Manufacturing Criteria
- 7.0 Inner Vessel
- 8.0 Outer Jacket

Stationary and Portable Fuel Cell Systems Codes and Standards Citations

This section lists codes and standards typically used for stationary and portable fuel cell systems projects. To determine which codes and standards apply to a specific project, you need to identify the codes and standards currently in effect within the jurisdiction where the project will be located. Some jurisdictions also have unique applicable ordinances or regulations.

Find stationary and portable fuel cell systems codes and standards in these categories:

- Balance of Plant
- Compressed Hydrogen Gas Storage
- Design
- Electrical Equipment
- Equipment Safety
- Fire Safety
- Fuel Lines
- Operation Approvals
- Periodic Inspections
- Setbacks and Footprints
- Transportation

Balance of Plant

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2012)

- Metallic Piping
- Flue Gas Venting Systems
- 1.11.2.1 Shut-off Valves
- 1.11.2.2 Supply Fuel Valves

International Fire Code (International Code Council 2012)

- 5003.2.2 Piping, Tubing, Valves, and Fittings
- 5003.3 Release of Hazardous Materials
- 5303.3 Pressure Relief Devices
- 5303.4.3 Piping Systems
- 5303.6 Valve Protection
- 5305.3 Piping Systems
- 5305.4 Valves
- 5305.5 Venting

International Fuel Gas Code (International Code Council 2012)

- 703.3 Pressure Relief Devices

- 704 Piping, Use and Handling

International Mechanical Code (International Code Council 2012)

- 305 Piping Support
- 401 General
- 501 Exhaust Systems
- 502 Required Systems
- 510 Hazardous Exhaust Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2013)

- 7.3.1.3 Piping Systems
- 7.3.1.4 Valves
- 10.2.3 Hydrogen-Venting Systems
- 10.2.3.1 Venting Requirements

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping
- 6.4.3.6 Ventilation Air
- 7.1.1 General
- 7.2.2 When Natural Ventilation Permitted
- 7.3 Exhaust Systems

Compressed Hydrogen Gas Storage

International Building Code (International Code Council 2012)

- 414.4 Hazardous Materials Systems

International Fire Code (International Code Council 2012)

- 5003.2 Systems, Equipment, and Processes
- 5003.2.1 Design and Construction of Containers, Cylinders, and Tanks
- 5003.2.4 Installation of Tanks
- 5003.2.5 Empty Containers and Tanks
- 5003.4 Material Safety Data Sheets
- 5003.9.2 Security
- 5003.9.3 Protection from Vehicles

- 5003.9.9 Shelf Storage
- 5004 Storage
- 5303.1 Containers, Cylinders, and Tanks
- 5303.2 Design and Construction
- 5303.4.1 Stationary Compressed Gas Containers, Cylinders, and Tanks
- 5303.4.2 Portable Containers, Cylinders, and Tanks
- 5303.5 Security
- 5303.6.1 Compressed Gas Container, Cylinder, or Tank Protective Caps or Collars
- 5303.10 Unauthorized Use
- 5303.12 Leaks, Damage, or Corrosion
- 5303.13 Surface of Unprotected Storage or Use Areas
- 5303.14 Overhead Cover
- 5304 Storage of Compressed Gases
- 5305.1 Compressed Gas Systems
- 5803.1.2 Storage Containers
- 5803.1.3 Emergency Shutoff
- 5803.1.4 Ignition Source Control

International Fuel Gas Code (International Code Council 2012)

- 303 Appliance Location
- 409 Shutoff Valves
- 703.2 Containers, Cylinders, and Tanks
- 703.5 Security

International Mechanical Code (International Code Council 2012)

- 303 Equipment & Appliance Location

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2010)

- 7.1.4 Listed and Approved Hydrogen Equipment
- 7.1.6 Containers, Cylinders and Tanks
- 10.3.2 Location of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping

- 6.4.3.1 Hydrogen Piping Shutoff Valve
- 6.4.3.2 Hydrogen Piping
- 6.4.3.5 Hydrogen Piping
- 6.4.3.7 Hydrogen Piping

Design

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2004)

- 1.2 Power Systems Design
- 1.3 Physical Environment and Operating Conditions
- 1.4 Selection of Materials
- 1.6 Cabinets

International Building Code (International Code Council 2012)

- 307.1.1 Maximum Allowable Quantities
- 414.1 General
- 414.2 Control Areas
- 1609 Wind Loads
- 1612 Flood Loads
- 1808 Foundations

International Fire Code (International Code Council 2012)

- 5003.1.1 Maximum Allowable Quantities per Control Area
- 5003.1.3 Quantities Not Exceeding the Maximum Allowable Quantity per Control Area
- 5003.1.4 Quantities Exceeding the Maximum Allowable Quantity per Control Area
- 5003.2.8 Seismic Protection
- 5003.8 Construction Requirements
- 5003.8.1 Buildings
- 5003.8.2 Required Detached Buildings
- 5003.8.3 Control Areas
- 5003.8.4 Gas Rooms
- 5003.8.5 Exhausted Enclosures
- 5003.8.6 Gas Cabinets
- 5003.8.7 Hazardous Materials Storage Cabinets

- 5004.12 Outdoor Storage

International Fuel Gas Code (International Code Council 2012)

- 301 General
- 302 Structural Safety
- 633 Stationary Fuel Cell Power Systems
- 635 Gaseous Hydrogen Systems

International Mechanical Code (International Code Council 2012)

- 301 General
- 302 Protection of Structure
- 924 Stationary Fuel Cell Power Systems
- 926 Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 7.1.4 Listed and Approved Hydrogen Equipment
- 10.2.2 Piping Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 4.2 Prepackaged, Self-Contained Fuel Cell Power Systems
- 4.3 Pre-Engineered Fuel Cell Power Systems
- 4.4 Engineered and Field-Constructed Fuel Cell Power Systems
- 5.1.1 (2) General Siting
- 6.4.1 Gaseous Hydrogen Storage

Electrical Equipment

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2004)

- 1.12 Electrical Safety

International Fire Code (International Code Council, 2009)

- 5003.9.4 Electrical Wiring and Equipment
- 5003.9.5 Static Accumulation
- 5303.8 Wiring and Equipment
- 5803.1.5 Electrical

International Fuel Gas Code (International Code Council 2012)

- 703.4 Venting

- 703.6 Electrical Wiring and Equipment

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2007)

- 8.1.3 Electrical Equipment and Components

Equipment Safety

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2004)

- 1.3.3 Physical Environmental
- 1.3.6 System Purging
- 1.3.7 Vibration, Shock and Bump
- 1.3.8 Handling, Transportation, and Storage
- 1.3.9 Protection against Fire and Explosion Hazards

International Building Code (International Code Council 2012)

- 414.6 Outdoor Storage, Dispensing, and Use

International Fire Code (International Code Council 2012)

- 5003.1 Hazardous Materials
- 5003.2.3 Equipment, Machinery, and Alarms
- 5003.2.9 Testing
- 5003.9 General Safety Precautions
- 5003.9.1 Personnel Training and Written Procedures
- 5003.9.8 Separations of Incompatible Materials
- 5003.12 Outdoor Control Areas
- 5005 Use, Dispensing, and Handling
- 5303.7 Separations from Hazards
- 5305 Use and Handling of Compressed Gases
- 5305.2 Controls
- 5305.6 Upright Use
- 5305.7 Transfer
- 5305.9 Material-Specific Regulations
- 5305.10 Handling
- 5805 General Use

International Fuel Gas Code (International Code Council 2012)

- 705 Testing of Hydrogen Piping Systems
- 706 Location of Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2013)

- 7.1.11 Separation from Hazardous Conditions
- 7.6 Flammable Gases

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 5.1.1 General Siting
- 5.1.2 General Siting
- 5.2 Outdoor Installations
- 9.2 Outdoor Installations

Fire Safety

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2012)

- 1.5 General Requirements
- 1.6 Cabinets
- 1.16 Marking, Labeling, and Packaging
- 1.16.2 FC Power System Marking
- 1.19.4.2 Installation Manual

International Building Code (International Code Council 2012)

- 907 Fire Alarms and Detection Systems

International Fire Code (International Code Council 2012)

- 401 General Emergency Planning and Preparedness
- 406 Employee Training and Response Procedures
- 5003.9.1.1 Fire Department Liaison
- 5303.4 Gas Marking
- 5303.11 Exposure to Fire
- 5303.16.13 Accessway
- 5503.4 Liquid Marking

International Fuel Gas Code (International Code Council 2012)

- 305 Installation

International Mechanical Code (International Code Council 2012)

- 304 Installation

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2010)

- 7.1.8 Labeling Requirements
- 10.2.1 Marking
- 10.6.1.2 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 5.1.3 General Siting
- 5.2 Outdoor Installations
- 6.1.2 General
- 8.1.2 Fuel Cell Fire Protection and Detection
- 9.2 Outdoor Installations
- 9.5 Fire Protection

Fuel Lines

ANSI/CSA America FC 1-2012, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2004)

- 1.8.1 Metallic Piping

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 20103

- 7.3.1.3 Piping Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping

Operation Approvals

ANSI/CSA America FC 1-2012, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

- 1.16.1 Marking, Labeling and Packaging
- 1.16.2 FC Power System Marking
- 1.16.4.2 Installation Manual

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association 2008)

- 4.4 Regulating Authorities of Employee Safety and Health

International Fire Code (International Code Council 20012

- 105.6.8 Compressed Gases
- 404.3.2 Fire Safety Plans
- 406 Employee Training and Response Procedures
- 5003.5 Hazard Identification Signs
- 5003.6 Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2013)

- 4.7 Personnel Training
- 4.8 Fire Department Liaison
- 7.1.8 Labeling Requirements
- 10.2.1 Marking
- 10.3.2 Location of Gaseous Hydrogen Systems
- 10.6.1.2 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 6.1.2 General
- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping
- 8.2 Fire Prevention and Emergency Planning

Periodic Inspections

ANSI/CSA America FC 1-2012, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association 2004)

- 1.16.4.5 Maintenance Manual

International Fire Code (International Code Council 2012)

- 5003.2.6 Maintenance
- 5303.9 Service and Repair

International Fuel Gas Code (International Code Council 2012)

- 707 Operation and Maintenance of Gaseous Hydrogen Systems

Setbacks and Footprints

International Fire Code (International Code Council 2012)

- 5003.7 Separations from Hazards
- 5003.9.8 Separations of Incompatible Materials
- 5004 Storage of Compressed Gases

International Fuel Gas Code (International Code Council 2012)

- 706 Location of Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2013)

- 10.3.2 Locations

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association 2010)

- 6.4.1 Gaseous Hydrogen Storage

Transportation

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association 2008)

- 4.1 Transportation Regulating Authorities
- 4.2 Container Regulations
- 4.3 Container Filling Regulations
- 6.2 Flammable Gases

International Fire Code (International Code Council 20012

- 105.6.8 Compressed Gases
- 404.3.2 Fire Safety Plans
- 5005 Use, Dispensing, and Handling
- 5305.7 Transfer
- 5805 General Use

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association 2013)

- 7.3 Use and Handling
- 8.3.5 Overfilling
- 10.3.2 Location of Gaseous Hydrogen Systems

Example Permit

Section 1 of the permit application requires basic identifying information be submitted.

Section 2 of the permit application identifies which code requirements need to be complied with depending on whether the dispenser is being added to an existing station or whether the dispenser is at a new stand-alone station.

The technical installation requirements address the following specific elements of station safety:

- Approval/listing and labeling requirements
- Piping code compliance
- Storage vessel stamps/approval.

Section 3 consists of a standard certification statement that could be modified as needed by the jurisdiction. By signing the certification statement the applicant agrees to comply with the standard permit conditions and other applicable requirements. This consent would give the jurisdiction the option of allowing the applicant to proceed with installation and operation of the dispensing equipment.

Section 4 of the document gives an example of a checklist the jurisdiction could develop to track key information on the application. The example under Section 4 contains only a few items of the many that the jurisdiction might wish to track.

This permit package also includes a schematic drawing depicting a typical installation (Figure 2). The purpose of the schematic is only to show how the station equipment could be arranged and is not intended to convey any permit requirements.

Section 1. Basic Identifying Information

Jurisdiction of ___________________, ______________(state)

Building/Fire Permit For Hydrogen Dispensing Installation

Compliance with the following permit will allow the construction and operation of a hydrogen dispensing installation in the __________________ jurisdiction. This permit addresses the following situations:

1. The addition of a hydrogen dispensing and storage system to an existing fueling station
2. TBD

This permit contains a general reference to the fire and building codes or equivalent codes used in the jurisdiction. All work and installed equipment will comply with the requirements of XXXX code used in the jurisdiction. The jurisdiction maintains the authority/responsibility to conduct any inspections deemed necessary to protect public safety.

Section 2. Sample Permit Structure

Topic	Permit Requirements
Siting	Do storage and dispenser systems meet separation distance requirements?
Mechanical	Is equipment listed or approved? • Valves • Pressure relief devices • Piping • Containers • Hoses • Nozzles
Electrical	Is equipment proximate to dispenser classified?
Maintenance	Have maintenance requirements been defined in permit application? Is there documentation required?
Emergency response	Are E-stops accessible? Do they have a plan? Are personnel trained? Is communication with the fire department and other emergency responders clearly defined?
Sensors	Do sensors detect releases or upset conditions? Is the information from sensors conveyed to the process equipment, operators, and fire department?

Section 3. Owner Responsibility Statement

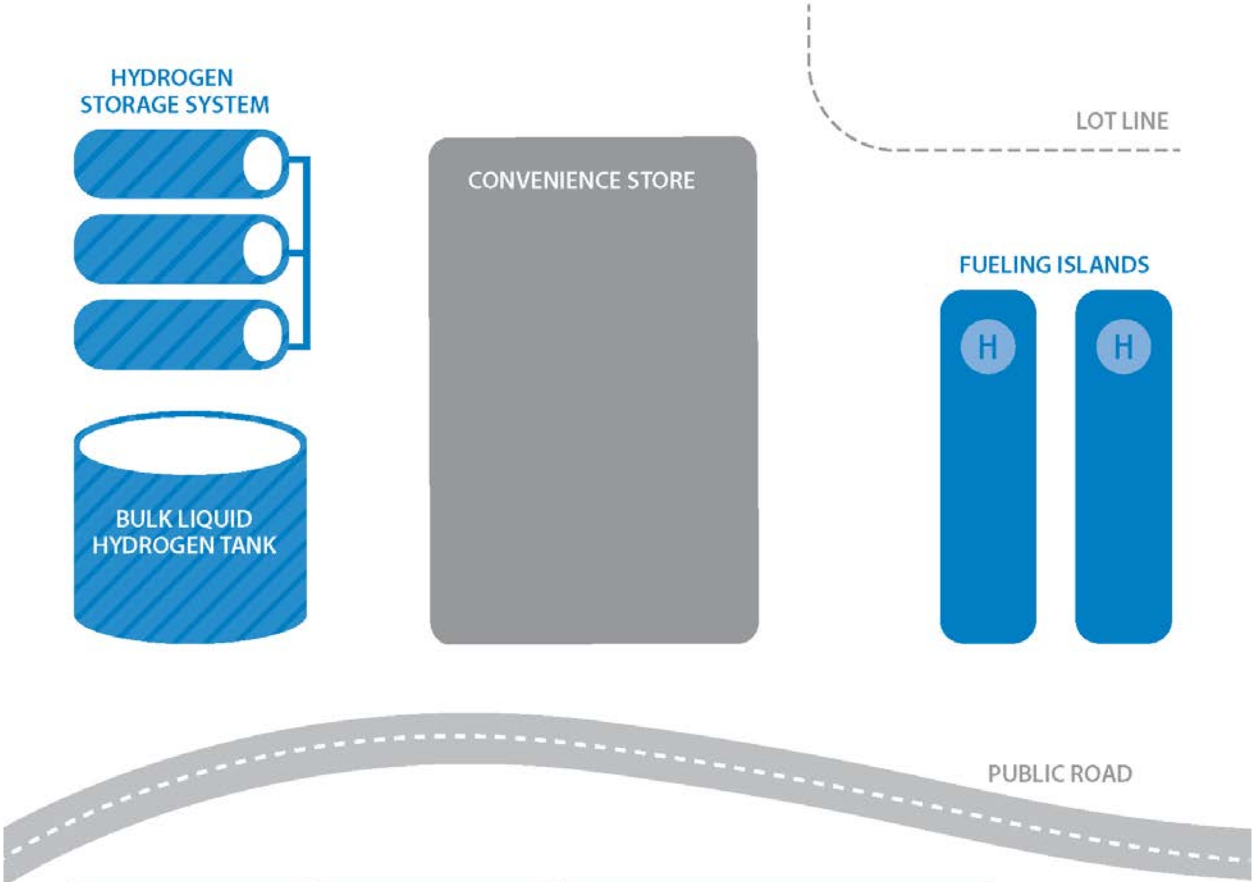
I hereby certify that the electrical work described on this permit application shall be/has been installed in compliance with the conditions in this permit and the codes and standards currently adopted and enforced within the jurisdiction of installation. By agreeing to the above requirements, the licensee or owner shall be permitted to construct and operate the charging station.

Signature of Owner Date

Section 4. Jurisdiction Checklist

Information each jurisdiction would add to permit such as:

1. Unique requirements in the jurisdiction such as seismic requirements
2. Summary of Risk Management Plan (RMP) analysis if subject to RMP
3. Summary of compliance with environmental regulations if applicable.



SYSTEM	EXPOSURE	SETBACK DISTANCE NFPA 2 Hydrogen technologies Code 2011 edition
Dispenser	Building, lot line	10 feet
Gaseous hydrogen (15,000 psi)	Opening in building	34 feet
Gaseous hydrogen (15,000 psi)	Public road/property line	34 feet
Liquid hydrogen (100,000 L)	Opening in building	75 feet
Liquid hydrogen (100,000 L)	Public road/property line	75 feet

Figure 2. Schematic of a typical hydrogen dispensing station with single dispenser with gaseous and liquid hydrogen storage

References

Austin, G. (1984). *Shreve's Chemical Process Industries*. New York: McGraw-Hill, Inc.

Cramer, S.D.; Covino, B.S., Jr. (2003). *Corrosion: Fundamentals, Testing, and Protection*. ASM Handbook Volume 13a. Materials Park, OH: ASM International.

Larminie, J.; Dicks, A. (2003). *Fuel Cell Systems Explained*. Chichester, West Sussex, England: John Wiley & Sons Ltd.

Lewis, R.J., Sr. (2001). *Hawley's Condensed Chemical Dictionary*. New York: John Wiley & Sons, Inc.

McCarty, R.D.; Hord, J.; Roder, H.M. (1981). *Selected Properties of Hydrogen (Engineering Design Data)*. Washington, DC: U.S. Department of Commerce, National Bureau of Standards.

National Fire Protection Association. (1963). *NFPA 567 Gaseous Hydrogen Systems at Consumer Sites*. Boston: National Fire Protection Association.

Ramachandran, R.; Menon, R.K. (1998). "An Overview of Industrial Uses of Hydrogen." *International Journal of Hydrogen Energy* (23:7); pp. 593-598.

Rigden, J.S. (2003). *Hydrogen: The Essential Element*. Boston: Harvard University Press.

U.S. Census Bureau. (2012). "Transportation." *Statistical Abstract of the United States: 2012*. Washington, DC: U.S. Census Bureau.

Wolff, D. (2008). "Expanding Use of Onsite UHP Hydrogen Production Improves Safety, Quality and Productivity in Epitaxy Operations." *41st International Symposium on Microelectronics 2008 (IMAPS 2008)*; November 2-6, 2008, Providence, Rhode Island. Washington, DC: International Microelectronics and Packaging Society (IMAPS); pp. 405-412.

Informational Websites

DOE Hydrogen and Fuel Cells Program:
http://www.hydrogen.energy.gov/

DOE Alternative Fuels Data Center:
http://www.afdc.energy.gov/

DOE Fuel Cell Technologies Office Safety, Codes and Standards:
http://energy.gov/eere/fuelcells/safety-codes-and-standards

NREL Hydrogen and Fuel Cell Research:
http://www.nrel.gov/hydrogen/

Sandia National Laboratories Hydrogen and Fuel Cells Program:
http://energy.sandia.gov/energy/renewable-energy/hydrogen

Pacific Northwest National Laboratory Hydrogen and Fuel Cells:
http://www.pnnl.gov/fuelcells/

Appendix A. NREL Process Hazard Analysis on a Representative Hydrogen Fueling Station

The National Renewable Energy Laboratory (NREL) conducted a process hazard analysis (PHA) on a representative hydrogen fueling system (Figure A-1) to better understand the relative risks of the pieces of the system. The following analysis gives a picture of the components of most concern in a hydrogen fueling system.

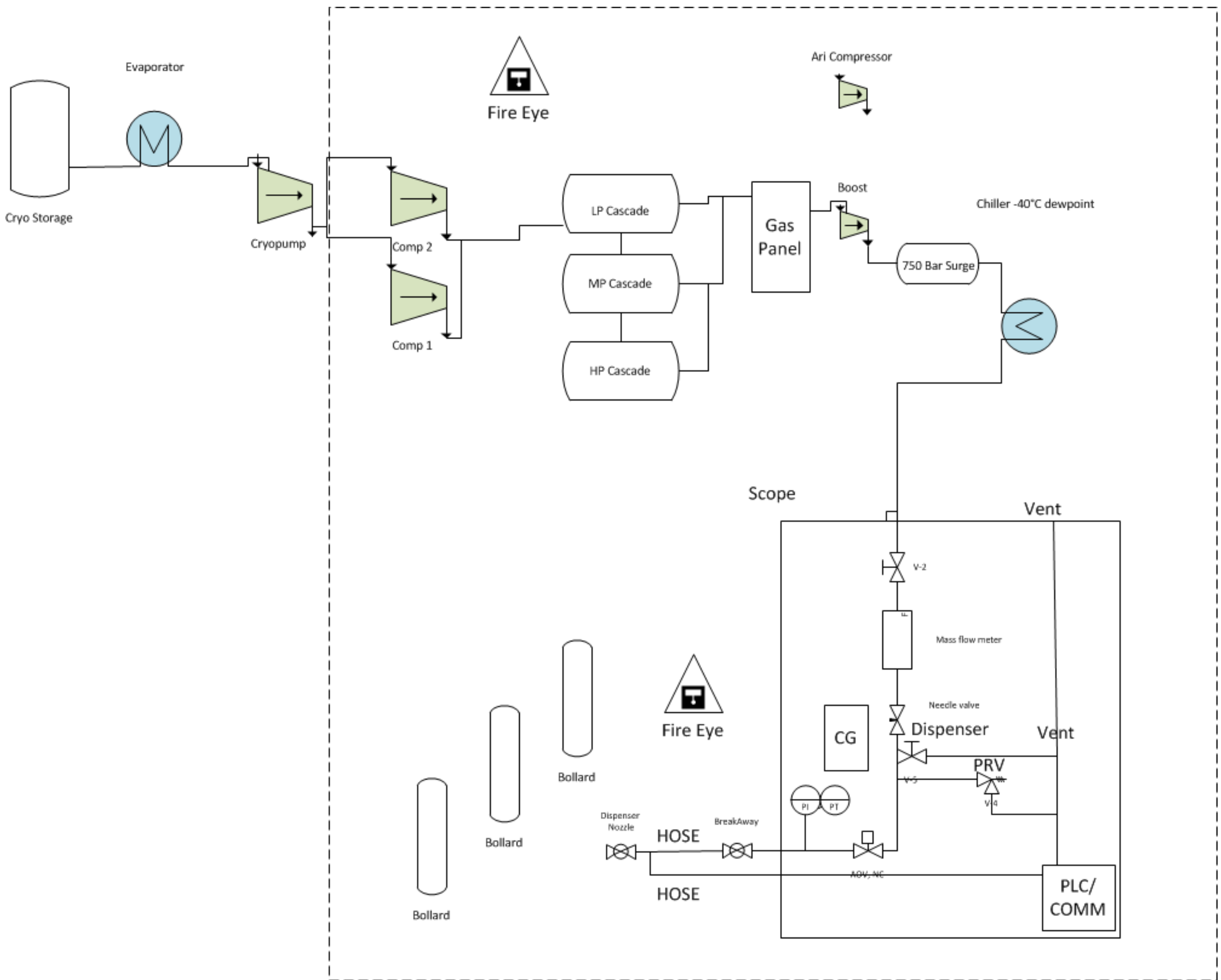


Figure A-1. Schematic of a representative hydrogen station

A PHA was conducted on the representative station shown in Figure A-1. The analysis was performed by NREL staff familiar with operating hydrogen fueling stations and component safety and performance issues. NREL employed PHAWorks 5, a spreadsheet software package designed to perform risk analyses.

The analysis was based on the assumption that the system complied with the requirements of codes and standards typically used in the United States. These documents include the following:

- NFPA 2 Hydrogen Technologies Code
- International Fire Code—addresses hydrogen applications
- International Building Code—general construction requirements
- ASME B31.12 Hydrogen Pipelines and Piping Code—hydrogen piping design
- ASME BPV Code Section XIII and X Pressure Vessels
- CGA S-1.1-3 Pressure Relief—hydrogen storage systems
- NFPA 70 National Electric Code—classified electrical areas.

Table A-1 shows the preliminary results of the PHA. Figure A-2 and Table A-2 show the hazard assessment and frequency categories used in the PHA. The system was broken down into the eight nodes shown in Table A-1. Undesirable outcomes were identified based on defining variations at nodes. Safety measures were identified for these undesired outcomes. The residual risk was then defined for each undesirable outcome. The residual risk is based on assigning a consequence and probability using the rating system shown in Table A-2. The combination of consequence and probability produces a risk rating as determined by the risk matrix.

Table A-1. Risk Value Frequencies

Node/Parameter	HR	MR	LR	RR	Sum
Node 1 Dispensing Nozzle	0	0	5	1	6
Flow	0	0	5	1	6
Temperature	0	0	0	0	0
Node 2 Dispensing Hose	0	2	3	0	5
Flow	0	2	3	0	5
Node 3 Dispenser Cabinet	0	0	0	0	0
Flow	0	0	0	0	0
Node 4 Cascade tanks to Dispenser	0	0	2	5	7
Flow	0	0	0	1	1
Temperature	0	0	2	4	6
Node 5 Compression to Cascade Tanks	0	0	7	9	16
Pressure	0	0	7	9	16
Node 6 Cryogenic Storage to Compressors	0	0	0	1	1
Temperature	0	0	0	1	1
Node 7 Air System	0	0	0	5	5
Flow	0	0	0	5	5
Node 8 Control Electronics	0	0	2	4	6
Level	0	0	2	4	6
PROJECT TOTAL	0	2	19	25	46

The PHA used the risk evaluation system shown in Figure A-2. This matrix integrates event severity and event frequency to produce four categories of risk. These categories are High Risk (HR), Medium Risk (MR), Low Risk (LR), and Routine Risk (RR).

			Probability					
Consequences	**Category**	**Descriptive Word**	**A Frequent**	**B Reasonably Probable**	**C Occasional**	**D Remote**	**E Extremely Remote**	**F Impossible**
	I	Catastrophic						Hose rupture
	II	Critical					Nozzle leak	
	III	Marginal					Compressor failure	
	IV	Negligible						

High Risk	**Moderate Risk**	**Low Risk**	**Routine Risk**

Figure A-2. NREL risk matrix

Table A-2. NREL Event Probability Classification Table

Probability (Probability that the potential consequence occurs)		
Level	**Annual Probability**	**Potential Consequences**
A	Frequent > 1.0	Likely to occur many times during the life cycle of the system (test/activity/operation)
B	Reasonably Probable 1.0 to 0.1	Likely to occur several times during the life cycle of the system
C	Occasional 0.01 to 0.1	Likely to occur sometime during the life cycle of the system
D	Remote 0.0001 to 0.01	Not likely to occur in the life cycle of the system, but possible
E	Extremely Remote 0.000001 to 0.0001	Probability of occurrence cannot be distinguished from zero
F	Impossible < 0.000001	Physically impossible to occur
Consequence		
Category	**Description (Est. $ Lost)**	**Potential Consequences**
I	Catastrophic (equipment loss > $1,000,000)	May cause death or system loss.
II	Critical ($100,000 to $1,000,000)	May cause severe injury or occupational illness, or minor system damage.
III	Marginal ($10,000 to $100,000)	May cause minor injury or occupational illness, or minor system damage.
IV	Negligible (< $10,000)	Will not result in injury, occupational illness, or system damage.

The preliminary results shown in Table A-1 were weighted on a 1 to 4 system with High Risk (HR) = 4 and Routine Risk (RR) = 1 to develop a total relative risk at each node. The results of this process are shown in Table A-3.

Table A-3. Total Risk at Node

Node	Node Description	HR	MR	LR	RR	Node Total Risk
5	Compressor to Cascade Tank	0	0	7	9	23
2	Hose	0	2	3	0	12
1	Nozzle	0	0	5	1	11
4	Cascade Tanks to Dispenser	0	0	2	5	9
8	Control Electronics	0	0	2	4	8
7	Air System	0	0	0	5	5
6	Cryo Storage to Compressor	0	0	0	1	1
3	Dispenser Cabinet (evaluated under control electronics)	0	0	0	0	0

HR - High Risk
MR - Medium Risk
LR - Low Risk
RR - Routine Risk

HYDROGEN SAFETY CHECKLIST

It is a common application of hydrogen technologies to have an outdoor hydrogen supply system providing for an indoor use. The Hydrogen Safety Panel developed a checklist to help both new and experienced hydrogen users identify considerations necessary to ensure a safe installation. The checklist is not intended to replace or provide guidance on compliance. Rather, it presents a concise table of critical safety measures compiled by some of the hydrogen industry's foremost safety experts. Figure B.1 illustrates the system considered by the Panel in developing the checklist. The general principles in the checklist apply to all types and sizes of hydrogen systems.

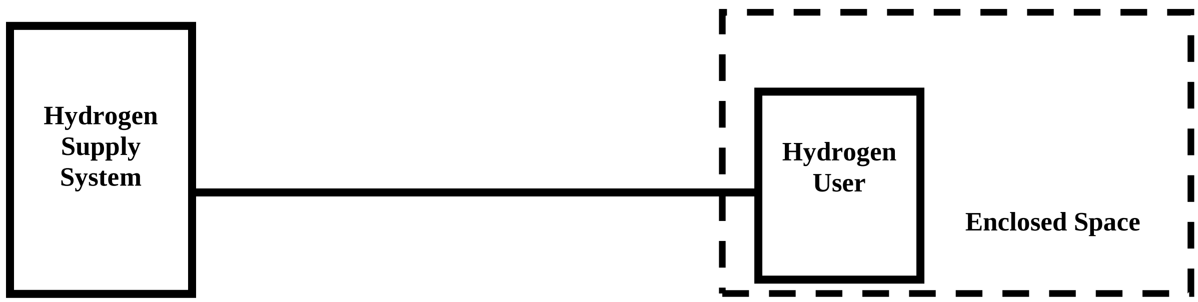


Figure B.1. Outdoor hydrogen supply system for indoor use

Hydrogen safety, much like all flammable gas safety, relies on five key considerations:

1. Recognize hazards and define mitigation measures (plan).
2. Ensure system integrity (keep the hydrogen in the system).
3. Provide proper ventilation to prevent accumulation (manage discharges).
4. Ensure that leaks are detected and isolated (detect and mitigate).
5. Train personnel and ensure that hazards and mitigations are understood and that established work instructions are followed (manage operations).

The checklist is organized using these key considerations. Examples are included to help users identify specific prevention techniques.

The checklist is intended to assist people developing designs for hydrogen systems as well as those involved with the risk assessment of hydrogen systems. While these considerations are fairly inclusive, it is not possible to include all variables that need to be considered. The hazard analysis process should therefore include personnel who are familiar with applicable codes and standards in addition to team members with expertise in the technical aspects of the specific project.

Useful References:

Hydrogen Incident Reporting and Lessons Learned Database: http://www.h2incidents.org

Hydrogen Safety Best Practices: http://h2bestpractices.org/default.asp

NFPA 2, "Hydrogen Technologies Code": http://www.nfpa.org

NFPA 52, "Vehicular Gaseous Fuel Systems Code": http://www.nfpa.org

DOE Hydrogen Safety Program: http://www.hydrogen.energy.gov/safety.html

Hydrogen Safety Checklist

	Approach	Examples of Actions
Plan the Work	**Recognize hazards and define mitigation measures**	☐ Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc. ☐ Identify potential hazards from adjacent facilities and nearby activities ☐ Address common failures of components such as fitting leaks, valve failure positions (open, closed, or last), valves leakage (through seat or external), instrumentation drifts or failures, control hardware and software failures, and power outages. ☐ Consider uncommon failures such as a check valve that does not check, relief valve stuck open, block valve stuck open or closed, and piping or equipment rupture. ☐ Consider excess flow valves/chokes to size of hydrogen leaks ☐ Define countermeasures to protect people and property. ☐ Follow applicable codes and standards.
	Isolate hazards	☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas. ☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials. ☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc.
	Provide adequate access and lighting	Provide adequate access for activities including: ☐ Operation, including deliveries ☐ Maintenance ☐ Emergency exit and response

	Approach	Examples of Actions
Keep the Hydrogen in the System	**Design systems to withstand worst-case conditions**	☐ Determine maximum credible pressure considering abnormal operation, mistakes made by operators, etc., then design the system to contain or relieve the pressure. ☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service. ☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions. ☐ Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections.
	Protect systems	☐ Design systems to safely contain maximum expected pressure or provide pressure relief devices to protect against burst. ☐ Mount vessels and bottled gas cylinders securely. ☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures. ☐ De-mobilize vehicles and carts before delivery transfers or operation. ☐ Protect against vehicle or accidental impact and vandalism. ☐ Post warning signs.
	Size the storage appropriately for the service	☐ Avoid excess number of deliveries/change-outs if too small. ☐ Avoid unnecessary risk of a large release from an oversized system.

	Approach	Examples of Actions
	Provide hydrogen shutoff(s) for isolation	☐ Locate automatic fail-closed shutoff valves at critical points in the system (such as storage exit, entry to buildings, inlets to test cells, etc.) to put the system in a safe state when a failure occurs. ☐ Consider redundant or backup controls. ☐ Install manual valves for maintenance and emergencies.
	Prevent cross-contamination	☐ Prevent back-flow to other gas systems with check valves, pressure differential, etc.
	Approach	**Examples of Actions**
Manage Discharges	**Safely discharge all process exhausts, relief valves, purges, and vents**	☐ Discharge hydrogen outdoors or into a laboratory ventilation system that assures proper dilution. ☐ Direct discharges away from personnel and other hazards. ☐ Secure/restrain discharge piping.
	Prevent build-up of combustible mixtures in enclosed spaces	☐ Do not locate equipment or piping joints/fittings in poorly ventilated rooms or enclosed spaces. Use only solid or welded tubing or piping in such areas. ☐ Provide sufficient ventilation and/or space for dilution. ☐ Avoid build-up of hydrogen under ceilings/roofs and other partly enclosed spaces.
	Remove potential ignition sources from flammable spaces/zones	☐ Proper bonding and grounding of equipment. ☐ No open flames. ☐ No arcing/sparking devices, e.g., properly classified electrical equipment.
	Approach	**Examples of Actions**
Detect and Mitigate	**Leak detection and mitigation**	☐ Provide detection and automatic shutdown/isolation if flammable mixtures present, particularly in enclosed spaces. ☐ Consider methods for manual or automatic in-process leak detection such as ability for isolated systems to hold pressure. ☐ Periodically check for leaks in the operating system.
	Loss of forced ventilation indoors	☐ Automatically shut off supply of hydrogen when ventilation is not working.
	Monitor the process and protect against faults	☐ Provide alarms for actions required by people, e.g., evacuation. ☐ Provide capability to automatically detect and mitigate safety-critical situations. ☐ Consider redundancy to detect and mitigate sensor or process control faults. ☐ Provide ability for the system to advance to a "safe state" if power failures or controller faults are experiences.
	Fire detection and mitigation	☐ Appropriate fire protection (extinguishers, sprinklers, etc.). ☐ Automatic shutdown and isolation if fire detected.
	Approach	**Examples of Actions**
Manage Operations	**Establish and document procedures**	☐ Responsibilities for each of the parties involved. ☐ Operating procedures. ☐ Emergency procedures. ☐ Preventive maintenance schedules for equipment services, sensor calibrations, leak checks, etc. ☐ Safe work practices such as lock-out/tag-out, hot work permits, and hydrogen line purging. ☐ Review and approval of design and procedural changes.
	Train personnel	☐ MSDS awareness for hydrogen and other hazardous materials. ☐ Applicable procedures and work instructions for bottle change-out, deliveries, operation, maintenance, emergencies, and safety work practices.
	Monitor	☐ Track incidents and near-misses, and establish corrective actions. ☐ Monitor compliance to all procedures and work instructions.

Safety Planning Guidance

for

Hydrogen and Fuel Cell Projects

April 2010

U.S. Department of Energy
Fuel Cell Technologies Program

Table of Contents

Safety Planning Guidance for Hydrogen and Fuel Cell Projects

A. Introduction

This guidance document provides applicants and recipients with information on safety requirements for hydrogen and fuel cell projects funded by the U. S. Department of Energy (DOE) Fuel Cell Technologies Program.

Safe practices in the production, storage, distribution, and use of hydrogen are essential for the widespread acceptance of hydrogen and fuel cell technologies. A catastrophic failure in any project could damage the public's perception of hydrogen and fuel cells. The project safety plan is meant to help identify and avoid potential hydrogen and related incidents. This guidance document aims to assist recipients in generating their safety plan, which will serve as a guide for the safe conduct of all project work.

In general, a good safety plan identifies immediate (primary) failure modes as well as secondary failure modes that may come about as a result of other failures. In effective safety planning, every conceivable failure is identified, from catastrophic failures to benign collateral failures. Identification and discussion of perceived benign failures may lead to the identification of more serious failures.

Potential hazards in any work, process or system should always be identified, analyzed and eliminated or mitigated as part of sound safety planning. Other safety aspects that may be adversely affected by a failure should be considered. These aspects include threats or impacts to:

- **Personnel.** Any hazards that pose a risk of injury or loss of life to personnel and the public at-large must be identified and eliminated or mitigated. A complete safety assessment considers not only those personnel who are directly involved in the work, but also others who are at risk due to these hazards.
- **Equipment.** Damage to or loss of equipment or facilities must be prevented or minimized. Damage to equipment can be both the cause of incidents and the result of incidents. An equipment failure can result in collateral damage to nearby equipment and property, which can trigger additional equipment failures or even present additional risks. Effective safety planning considers and minimizes serious risk of equipment and property damage.
- **Business Interruption.** The prevention of business interruption is important for commercial entities. Hazardous events may lead to interruption in providing service or product. A complete safety plan in these instances would also include a contingency plan for providing needed services or manufacturing.
- **Environment.** Damage to the environment must be prevented. Any aspect of a natural or built environment that can be harmed due to a failure should be identified and analyzed. A qualification of the failure modes resulting in environmental damage must be considered.

B. Requirements and Procedures

All projects funded by the DOE Fuel Cell Technologies Program will be required to submit a project safety plan with the exception of those projects relating to non-experimental computational or analytical work. Safety plans will be required to cover the work of the award recipient and any subcontractors. This guidance document, in addition to any example project safety plans provided by the DOE project officer, should provide sufficient background for preparing the safety plan. However, the responsibility of selecting and using a specific safety methodology falls upon the applicant or principal investigator and collaborating groups. A variety of practices exist for the identification and analysis of safety hazards and the team can choose an approach that is best suited for their project.

DOE will identify specific safety plan deliverable requirements at the time of award; the specific instructions will be stated on the "Federal Assistance Reporting Checklist" (Form DOE F 4600.2) within the award package. The specific procedure for each project may differ. Generally, though, the draft project safety plan will be required 90 days after the award has been signed. The safety plan should not contain any proprietary or confidential information since it will be reviewed by a panel external to DOE. Once submitted, the plan will be reviewed and specific comments and feedback will be provided to the recipient. In some cases, the recipient will then be required to address all necessary comments and submit a revised safety plan. For any project involving multiple phases, the updating and resubmitting of the safety plan may also be required.

A preliminary safety plan may be required during the submission of the application package as part of the Funding Opportunity Announcement (FOA) issued by DOE. If a preliminary safety plan is required, the FOA will provide further direction regarding specific requirements.

All project safety plan submissions and questions should be sent via e-mail to the project officer identified in Block 11 of the Notice of Financial Assistance Award.

C. The Safety Plan

A project safety plan addresses potential threats and impacts to personnel, equipment and the environment. As an integral part of any project, a safety plan should reflect that sound and thoughtful consideration is given to the identification and analysis of safety vulnerabilities, prevention of hazards, mitigation of risks and effective communications. Safety plans should be "living documents" that recognize the type of work being conducted, the factors of human error, the nature of equipment life and the inevitable changes that occur over the project life.

A project safety plan should be prepared using a graded approach based on level of risk and project complexity. The plan should cover all experimental/operational work being conducted with particular emphasis on the aspects involving hydrogen, hazardous materials handling and fuel cell systems. The elements of a good safety plan are described in Appendix IV and summarized as follows:

1. Scope of Work
2. Organizational Safety Information

- Organizational Policies and Procedures
    - Hydrogen and Fuel Cell Experience
3. Project Safety
    - Identification of Safety Vulnerabilities (ISV)
    - Risk Reduction Plan
    - Operating Procedures
        - Operating steps
        - Sample handling and transport
    - Equipment and Mechanical Integrity
    - Management of Change Procedures
    - Project Safety Documentation
4. Communication Plan
    - Employee Training
    - Safety Reviews
    - Safety Events and Lessons Learned
    - Emergency Response
    - Self-Audits
5. Safety Plan Approval
6. Other Comments or Concerns

Each element is briefly described in the following sections. The text boxes included in the following sections provide useful background information on good safety practices and should be thoughtfully considered in preparing your safety plan. Detailed documentation related to this background information does not need to be included in the safety plan itself. Project teams may also find H_2 Safety Best Practices (http://h2bestpractices.org) to be a useful reference for safety planning. This website captures the experience that already exists in a wide variety of industrial, aerospace and laboratory settings with topics covering safety practices, design and operations. An extensive reference list is also supplemented with lessons learned from incidents and near-misses.

1. Scope of Work. The plan should briefly describe the specific nature of the work being performed to set the context for the safety plan. It should distinguish between laboratory-scale research, bench-scale testing, engineering development, and prototype operation. All intended project phases should be described. In describing the work, it is valuable to quantify the amounts of hazardous materials generated, used and stored. Even laboratory-scale experiments may result in substantial risks when a quantity of hydrogen or other hazardous material is stored in or near the laboratory.

The plan should discuss the location of activities (description of facilities, types of personnel, other operations/testing performed at the facility, adjacent facilities) and describe how the activities will be coordinated across the total project. **Safety plans should cover the work of any subcontractors.** Any relevant permits that apply to current and planned operations should be listed.

2. Organizational Safety Information

Organizational Policies and Procedures. The plan should describe how the safety policies and procedures of the organization are implemented down to the project and staff member levels for the work being performed. Staff member involvement is important in the development and implementation of comprehensive project safety plans.

Hydrogen and Fuel Cell Experience. Knowledge gained over a period of time can be an important asset in effective safety planning. The plan should describe the types of previous operations, degree of experience of project personnel, and how previous organizational experience with hydrogen and fuel cells will be applied to the project.

3. Project Safety

Identification of Safety Vulnerabilities (ISV). Assessment of the potential hazards associated with work at any scale from laboratory to operations begins with the identification of an appropriate assessment technique. The ISV is the formal means by which potential safety issues associated with laboratory or process steps, materials, equipment, operations, facilities and personnel are identified. The plan should describe:

- The ISV method that is used for this project
- Who leads and stewards the use and results of the ISV process
- Significant accident scenarios identified (e.g. higher consequence, higher frequency)
- Significant vulnerabilities (risks) identified
- Safety critical equipment

Hazardous Materials. The plan should discuss the storage and handling of hazardous materials and related topics including possible ignition sources, explosion hazards, material interactions, possible leakage and accumulation, and detection. For hydrogen handling systems, the plan should describe the source and supply, storage and distribution systems including volumes, pressures and with estimated use rates.

Two other questions should be addressed in the ISV:

- What hazard associated with this project is most likely to occur?
- What hazard associated with this project has the potential to result in the worst consequence?

The plan should describe how the ISV will be updated as new information becomes available. Typical ISV methods are described in Appendix I.

Risk Reduction Plan. The purpose of a risk reduction plan is to reduce or eliminate significant risks. The plan should describe prevention and mitigation measures for the significant safety vulnerabilities previously identified. The development of prevention and mitigation measures is usually done in conjunction with the ISV which assesses the scenarios and identified hazards. Risk binning is one available analysis tool used to classify vulnerabilities, as shown in Appendix II.

Operating Procedures

Operating Steps. The plan should list existing and planned procedures that describe the operating steps for the system, apparatus, equipment, etc. It should also reference specific safe work practices used to control hazards during operations such as lockout; confined space entry; opening equipment or piping; and control over entrance into a facility by maintenance, contractor, laboratory, or other support personnel.

> *Background Information: Procedures should be developed for each process or laboratory-scale experiment with the active involvement of project personnel. These written procedures should provide clear instructions for conducting processes or experiments in a safe manner. The procedures should include:*
> - *Steps for each operating phase, such as startup, normal operation, normal shutdown, emergency shutdown*
> - *Operating limits*
> - *Safety considerations, such as precautions necessary to prevent exposure and measures to be taken if physical contact or airborne exposure occurs*
> - *Safety systems and their functions*
>
> *Operating procedures should be updated promptly to reflect changes to chemicals and other materials, equipment, technologies and facilities*

Sample handling and transport. The plan should discuss any anticipated transport of samples and materials and identify the relevant policies and procedures that are in place to ensure their proper handling.

Equipment and Mechanical Integrity. The plan should describe how the integrity of equipment, piping, tubing, and other devices associated with the hazardous material handling systems will be assured.

> *Background Information: Mechanical integrity generally involves*
> - *Written procedures*
> - *Proper design, testing and commissioning*
> - *Validation of materials compatibility*
> - *Preventative maintenance plan*
> - *Calibration for safety related devices – The frequency should be consistent with applicable manufacturers' recommendations, adjusted as indicated by operating experience.*
> - *Testing and inspection – The types and frequency of inspections and*

tests should be consistent with applicable manufacturers' recommendations, adjusted as indicated by operating experience.

- *Training for maintenance, calibration, testing and inspection personnel.*
- *Documentation – Each calibration, inspection and test should be recorded. Typical records include date, name of the person, identifier of the device, description of what was done, and results. Any deficiencies outside acceptable limits should be highlighted.*
- *Correcting deficiencies that are outside acceptable limits*

Management of Change Procedures. The plan should describe the method that will be used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities.

Background Information:[1] *For changes resulting in a change to the safety information such as to the ISV or an operating procedure, the applicable safety information should be updated accordingly. Employees whose job tasks will be affected by the change must be informed of the change and retrained prior to resumption of work.*

Scale-up of the process, modification of equipment and changes in materials are commonly encountered and should be considered as changes that may result in the need to update the safety plan. Change may also refer to new personnel involved in the work, necessitating training.

Project Safety Documentation. The plan should describe how safety documentation is maintained for the project, including who is responsible, where documents are kept, and how it is accessed by project personnel.

Background Information: Safety documentation includes

- *Information pertaining to the technology of the project*
  - *A block flow diagram or simplified process flow diagram*
  - *Process chemistry*
  - *Maximum intended inventory of materials*
  - *Safe upper and lower limits for such items as temperatures, pressures, flows and concentrations*
  - *An evaluation of the consequences of deviations, including those affecting the safety and health of employees*
- *Information pertaining to the equipment or apparatus*
  - *Materials of construction*
  - *Electrical classification*
  - *Pressure relief system design and design basis*
  - *Ventilation system design*

[1] *Management of Change*, U.S. Chemical Safety and Hazard Investigation Board, Safety Bulletin No. 2001-04-SB, August 2001.

- *Design codes and standards employed*
- *Material and energy balances*

- *Safety systems (e.g. alarms, interlocks, detection or suppression systems)*
- *Safety review documentation, including the ISV*
- *Operating procedures (including response to deviation during operation)*
- *Material Safety Data Sheets*
- *References such as handbooks and standards*

Safety documentation should be updated regularly to reflect changes to chemicals/other materials and their quantities, equipment, technologies, and facilities.

4. Communications Plan. The plan should describe how project safety information is communicated and made available to all project participants, including external partners.

Employee Training. The plan should describe formal programs and planned hazard-specific training related to the various hazards associated with the project. It should describe how the organization stewards training participation and verifies understanding.

Background Information: It is crucial to provide hydrogen and other safety training for all project personnel responsible for handling equipment and systems containing hazardous materials. The training program should include

- *Initial training that includes an overview of the process, a thorough understanding of the operating procedures, an emphasis on the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks.*
- *Refresher training that is provided to each employee involved in operating a process to assure that the employee understands and adheres to the current standard operating procedures.*
- *Training documentation that shows each employee involved in operating a process has received and understood the training.*
- *For people maintaining process equipment, performing calibrations, etc., training needs to ensure that the employee can perform the job tasks in a safe manner.*

Safety Reviews. The plan should describe safety reviews that will be conducted for the project during the design, development and operational phases. The involvement and responsibilities of individual project staff in such reviews and how the reviews will be documented should be included. The ISV is expected to be one of the safety reviews performed for the project. Other safety reviews may be needed during the life of the project, including those required by organizational policies and procedures.

Safety Events and Lessons Learned. The plan should describe how safety events (incidents and near-misses) will be handled by the project team. The description should include:

- The reporting procedure within the organization and to DOE
- The method and procedure used to investigate events
- How corrective measures will be implemented
- How lessons learned from incidents and near-misses are documented and disseminated

By learning about the likelihood, severity, causal factors, setting and relevant circumstances regarding safety events, project teams are better equipped to prevent similar, perhaps more serious, events in the future. To be effective, this process requires a good investigation, a good report, and a great deal of information sharing as openly and thoroughly as possible.

An **INCIDENT** is an event that results in:
- a lost-time accident and/or injury to personnel
- damage to project equipment, facilities or property
- impact to the public or environment
- an emergency response or should have resulted in an emergency response

A **NEAR-MISS** is an event that, under slightly different circumstances, could have become an incident. Examples include:
- any unintentional hydrogen release that ignites, or is sufficient to sustain a flame if ignited, and does not fit the definition for an incident
- any hydrogen release which accumulates above 25% of the lower flammability limits within an enclosed space and does not fit the definition of an incident

Note that the definitions do not include all possible events that should be reported. The definitions are indicative of events that should be reported. All incidents and near-misses must be reported to the appropriate DOE project officer as soon as possible after the safety event has occurred. For DOE national laboratory-led projects, all incidents and near-misses should be reported to the appropriate DOE technology development manager as soon as possible after the safety event has occurred.

> Background Information: *The investigation of an incident should be initiated as promptly as possible. An event investigation team should consist of at least one member who is independent from the project team, at least one person knowledgeable in the process chemistry and actual operation of the equipment and process, and other persons with the right knowledge and experience to thoroughly investigate and analyze the incident. The event report should include:*
> - *Date of incident*
> - *Date investigation began*
> - *A description of the incident*
> - *The factors that contributed to the incident*

- *Lessons learned from the incident*
- *Any recommendations resulting from the investigation*

The project team should promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions should be documented. The report should be reviewed with all affected personnel whose job tasks are relevant to the incident findings.

***Hydrogen Incident Reporting and Lessons Learned (**www.h2incidents.org), is a database which provides a voluntary mechanism for anyone to report an incident or near-miss and to benefit from the lessons learned from other reported incidents. All identifying information, including names of individuals, companies, organizations, vendors of equipment and locations are removed to ensure confidentiality and to encourage the unconstrained future reporting of events as they occur.*

Emergency Response. The plan should describe the emergency response procedures that are in place, including communication and interaction with neighboring occupancies and local emergency response officials.

Self-Audits. The plan should describe how the project team will verify that safety-related procedures and practices are being followed throughout the life of the project.

Background Information: Verification is usually accomplished via a compliance audit that is conducted by at least one person knowledgeable in the process who is external to the project. A report of the findings of the audit should be developed. The project team should promptly determine and document an appropriate response to each of the findings of the compliance audit with an appropriate action plan.

5. Safety Plan Approval. The review and approval process used for the project safety plan must be documented. It should be consistent with the organization's policies, and can be done by briefly describing the approval process used and/or completing an approval form. An example approval form is shown in Appendix III. In most cases, this approval process will include a review by the next management level and approved by the organization's safety representative.

6. Other Comments or Concerns. If appropriate, provide information on any topics not covered above, and any issues that may require assistance from DOE. Appendix IV – Safety Plan Checklist is also provided for use as a resource in preparing safety plans.

Appendix I – Acceptable ISV Methods

Background Information: Identification of Safety Vulnerabilities (ISV) can be done using any of several established industry methods. The ISV should be done at the project's earliest stages. The ISV helps the project team identify potential safety issues, discover ways to lower the probability of an occurrence, and minimize the associated consequences.

The ISV should address:

- The potential hazards of the operation
- Previous incidents and near misses
- Engineering and administrative controls applicable to the hazards and their interrelationships, e.g. the use of hydrogen detectors and emergency shutdown capability
- Mechanisms and consequences of failure of engineering and administrative controls
- A qualitative evaluation of a range of the possible safety and health effects resulting from failure of controls
- Facility location

The ISV should be performed by a team with sufficient expertise in all aspects of the work to be performed. At least one team member should have experience and knowledge specific to the set of processes, equipment and facilities being evaluated. Also, one member of the team needs to be knowledgeable in the specific ISV method being used.

Method	Description	References
FMEA Failure Modes and Effects Analysis	The FMEA process has these elements ○ Identify top level hazards and events ○ Identify related equipment, components, and processes ○ Identify potential failure modes and effects ○ Identify designs that provide inherent safety ○ Identify potential prevention and mitigation corrective action	○ **http://www.fmeainfocentre.com/** a non-commercial web-based inventory dedicated to the promotion of FMEA ○ Government documents, including MIL-STD-882C and MILSTD-1629A ○ NASA Scientific and Technical Information **http://www.sti.nasa.gov/** ○ A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
"What If" Analysis	A speculative process where questions of the form "What if … (hardware, software, instrumentation, or operators) (fail, breach, break, lose functionality, reverse, etc.)..?" are formulated and reviewed.	A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
HAZOP Hazard and Operability Analysis	Systematically evaluates the impact of deviations using project information. Method was developed to identify both hazards and operability problems at chemical process plants.	An extensive description and worked example of the HAZOP procedure can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.

Method	Description	References
Checklist Analysis	Method evaluates the project against existing guidelines using a series of checklists. This technique is most often used to evaluate a specific design, equipment or process for which an organization has a significant amount of experience.	○ A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992. ○ Risk-based decision-making guidelines, United States Coast Guard (http://www.uscg.mil/hq/g-m/risk/e-guidelines/RBDM/html/vol3/02/v3-02-cont.htm)
Fault Tree Analysis	Fault Tree Analysis is a deductive (top-down) method used for identification and analysis of conditions and factors that can result in the occurrence of a specific failure or undesirable event. This method addresses multiple failures, events, and conditions.	A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
Event Tree Analysis	This method is an inductive approach used to identify and quantify a set of possible outcomes. The analysis starts with an initiating event or initial condition and includes the identification of a set of success and failure events that are combined to produce various outcomes. This method identifies the spectrum and severity of possible outcomes and determines their likelihood.	A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
Probabilistic Risk Assessment	A Probabilistic Risk Assessment (PRA) is an organized process for answering the following three questions: 1. What can go wrong? 2. How likely is it to happen? 3. What are the consequences?	A detailed description of this method can be found in *Guidelines for Chemical Process Quantitative Risk Analysis*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2000.
Others	Other methods or combinations of methods, including those developed by the project team's organization, may be used.	See *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.

Appendix II – Risk Binning Matrix[2]

Risk binning is one analysis tool used to classify vulnerabilities. Each vulnerability can be assigned a qualitative risk using a frequency-consequence matrix, such as the one shown below. Highest consequences are generally assigned to events that could reasonably result in an unintended release of hazardous material, destruction of equipment and/or facilities, or injury to people.

Risk Binning Matrix: Frequency/Consequence Criteria

<table>
<tr><th colspan="2"></th><th colspan="4">Frequency</th></tr>
<tr><th colspan="2"></th><th>Beyond extremely unlikely</th><th>Extremely unlikely</th><th>Unlikely</th><th>Anticipated</th></tr>
<tr><td rowspan="3">Consequence</td><td>High</td><td rowspan="3">10</td><td>7</td><td>4</td><td>1</td></tr>
<tr><td>Moderate</td><td>8</td><td>5</td><td>2</td></tr>
<tr><td>Low</td><td>9</td><td>6</td><td>3</td></tr>
<tr><td></td><td>Negligible</td><td>12</td><td colspan="3">11</td></tr>
</table>

Higher risk: 1, 2, 4

Moderate risk: 3, 5, 7

Lower risk: 6, 8, 9

Negligible risk: 10, 11, 12

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[2] *Preliminary Safety Evaluation for Hydrogen-fueled Underground Mining Equipment*, DA. Coutts and J.K. Thomas, Westinghouse Safety Management Solutions, Aiken, SC, Publication WSRC-TR-98-00331, September 1998. (This reference includes information from *Preparation Guide for US Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports,* DOE-STD-3009-94, July 1994.)

Frequency criteria used for risk-binning

Acronym	Description	Frequency level
A	Anticipated, Expected	> 1E-2/yr
U	Unlikely	1E – 4 < f ≤ 1E – 2/yr
EU	Extremely Unlikely	1E – 6 < f ≤ 1E – 4/yr
BEU	Beyond Extremely Unlikely	≤ 1E – 6/yr

Consequence criteria used for risk-binning

Consequence Level	Impact on Populace	Impact on Property/Operations
High (H)	Prompt fatalities Acute injuries – immediately life threatening Permanent disability	Damage > $50 million Production loss in excess of 1 week
Moderate (M)	Serious injuries Non-permanent disability Hospitalization required	$100,000 < damage ≤ $50 million Equipment destroyed Critical equipment damaged Production loss less than 1 week
Low (L)	Minor injuries No hospitalization	Damage ≤ $100,000 Repairable damage to equipment Significant operational down-time Minor impact on surroundings
Negligible (N)	Negligible injuries	Minor repairs to equipment required Minimal operational down-time No impact on surroundings

Appendix III – Example Project Safety Plan Approval Form

DOE Award Number: ______________________________

Project Title: ______________________________

Organization: ______________________________

Safety Plan submitted by: ______________________________

The attached safety plan is being submitted to the U.S. Department of Energy in compliance with the Fuel Cell Technologies Program requirement under the terms of the above-referenced award. The completed approvals noted below are consistent with organization's policy for such submittals.

Project safety plan prepared by: (**EXAMPLE:** Primary Author/PI)
Name
Title
Department/Division

Project safety plan reviewed by: (**EXAMPLE:** Next Level of Management Above PI)
Name
Title
Department/Division

Project safety plan approved by: (**EXAMPLE:** Organization's Safety Representative)
Name
Title
Department/Division

Appendix IV – Safety Plan Checklist

This checklist is a summary of desired elements for safety plans. The checklist, referring to page numbers in this document, is intended to help project teams verify that their safety plan is complete and can be a valuable tool over the life of the project.

Page	Element	The Safety Plan Should Describe
1	**Scope of Work**	• Nature of the work being performed
3	**Organizational Policies and Procedures**	• Application of organizational safety-related policies and procedures to the work being performed
3	**Hydrogen and Fuel Cell Experience**	• How previous organizational experience with hydrogen, fuel cell and related work is applied to this project
4	**Identification of Safety Vulnerabilities (ISV)**	• What is the ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method • Who leads and stewards the use of the ISV methodology • Significant accident scenarios identified • Significant vulnerabilities identified • Safety critical equipment • Storage and Handling of Hazardous Materials and related topics o ignition sources; explosion hazards o materials interactions o possible leakage and accumulation o detection • Hydrogen Handling Systems o supply, storage and distribution systems o volumes, pressures, estimated use rates
4	**Risk Reduction Plan**	• Prevention and mitigation measures for significant vulnerabilities

Page	Element	The Safety Plan Should Describe
4	**Operating Procedures**	• Operational procedures applicable for the location and performance of the work including sample handling and transport • Operating steps that need to be written for the particular project: critical variables, their acceptable ranges and responses to deviations from them
5	**Equipment and Mechanical Integrity**	• Initial testing and commissioning • Preventative maintenance plan • Calibration of sensors • Test/inspection frequency basis • Documentation
6	**Management of Change Procedures**	• The system and/or procedures used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities
6	**Project Safety Documentation**	• How needed safety information is communicated and made available to all project participants, including partners. Safety information includes the ISV documentation, procedures, references such as handbooks and standards, and safety review reports.
7	**Employee Training**	• Required general safety training - initial and refresher • Hydrogen-specific and hazardous material training - initial and refresher • How the organization stewards training participation and verifies understanding
7	**Safety Reviews**	• Applicable safety reviews beyond the ISV described above

Page	Element	The Safety Plan Should Describe
7	**Safety Events and Lessons Learned**	• The reporting procedure within the organization and to DOE • The system and/or procedure used to investigate events • How corrective measures will be implemented • How lessons learned from incidents and near-misses are documented and disseminated
9	**Emergency Response**	• The plan/procedures for responses to emergencies • Communication and interaction with local emergency response officials
9	**Self-Audits**	• How the project will verify that safety related procedures and practices are being followed throughout the life of the project
9	**Safety Plan Approval**	• Safety plan review and approval process
9	**Other Comments or Concerns**	• Any information on topics not covered above • Issues that may require assistance from DOE

Safety, Codes, and Standards

Hydrogen and fuel cell technologies are poised to play an integral role in our energy future. Hydrogen, a versatile fuel with a history of safe use in industrial applications, can be produced from diverse domestic resources including renewable, nuclear, natural gas, and coal with carbon sequestration. Fuel cells provide a highly efficient means for producing electricity from hydrogen. They can be built to a variety of scales to provide power for distributed power systems, utility-scale generation, specialty vehicles (e.g., forklifts and airport baggage tugs), automobiles, buses, auxiliary power applications, and portable electronic equipment.

Like natural gas vehicles, hydrogen vehicles and hydrogen fuel cell material handling equipment are refueled using a closed-loop system that helps to ensure safe operation.

Hydrogen Safety Facts

Hydrogen has unique physical and chemical properties which present benefits and challenges to its successful widespread adoption as a fuel. Hydrogen is the lightest and smallest element in the universe. Hydrogen is 14 times lighter than air and rises at a speed of almost 20 m/s, 6 times faster than natural gas which means that when released, it rises and disperses quickly. Hydrogen is also odorless, colorless, and tasteless making it undetectable by human senses. For these reasons, hydrogen systems are designed with ventilation and leak detection. Natural gas is also odorless, colorless, and tasteless, but a sulfur-containing odorant is added so people can detect it. There is no known odorant light enough to "travel with" hydrogen at an equal dispersion rate, so odorants are not used to provide a detection method. Many odorants can also contaminate fuel cells.

Hydrogen burns very quickly. Under optimal combustion conditions, the energy required to initiate hydrogen combustion is significantly lower than that required for combustion of other common fuels, such as natural gas or gasoline. The energy required to initiate combustion of low concentrations of hydrogen in the air is similar to that of other fuels. Combustion cannot occur in a hydrogen vessel or any contained location that contains only hydrogen – an oxidizer, such as oxygen, is required. Hydrogen flames have low radiant heat. A hydrogen fire has significantly less radiant heat than a hydrocarbon fire (a fire fueled by hydrocarbon products such as petroleum and natural gas). Although a hydrogen flame is just as hot as a hydrocarbon flame, the levels of heat emitted from the flame are lower. This decreases the risk of secondary fires.

Hydrogen is unlikely to cause asphyxiation. With the exception of oxygen, any gas can cause asphyxiation in high enough concentrations. Because hydrogen rises and disperses so rapidly, it is unlikely to cause asphyxiation. Hydrogen is non-toxic and non-poisonous. It will not contaminate groundwater. It is a gas under normal atmospheric conditions, and a release of hydrogen does not contribute to atmospheric or water pollution. Hydrogen can be used as safely as other common fuels we use today when guidelines are observed and users understand its behavior.

A Record of Safety

The U.S. currently produces and safely uses more than 9 million tons of hydrogen each year. Fuel cells continue to enter the market for diverse applications including specialty vehicles, combined heat and power (CHP), stationary, backup, and portable power. The number of fuel cell deployments continues to grow each year.

To ensure the safe use of these technologies, industry considers the unique properties of hydrogen when designing structures where it will be used and stored. Components are built to meet strict manufacturer and published

Hydrogen fuels stationary fuel cells providing primary power.

Safety Information Resources
http://hydrogen.energy.gov/safety.html

H_2 Safety Snapshot
http://www1.eere.energy.gov/hydrogenandfuelcells/codes/snapshot.html

Hydrogen Safety Best Practices Manual
http://h2bestpractices.org/

Hydrogen Safety Bibliographic Database
http://www.hydrogen.energy.gov/biblio_database.html

Hydrogen Incident Reporting Database
http://www.h2incidents.org/

Introduction to Hydrogen Safety for First Responders
http://www.hydrogen.energy.gov/firstresponders.html

guidelines and undergo third-party testing for safety and structural integrity.

As the technology develops and the number of installations increases, education and training becomes even more critical. Emergency personnel must be prepared to handle potential incidents, and public education must be provided to familiarize users with simple hydrogen safety practices to help to ensure a continued record of safety.

Safety Research

The U.S. Department of Energy (DOE) Fuel Cell Technologies Safety, Codes & Standards sub-program supports research and development (R&D) that provides critical data and information needed to define requirements for the development of technically sound codes and standards to enable the widespread commercialization and safe deployment of hydrogen and fuel cell technologies. Researchers in government, industry, and academia are working to further analyze critical hydrogen behavior data; develop reliable, inexpensive hydrogen sensor and leak detection technologies; and identify tools and methodologies to support the development of hydrogen codes and standards.

Hydrogen safety information resources and best practices are being developed, based on safety R&D and as well as external stakeholder input from the fire-protection community, academia, automobile manufacturers, and the energy, insurance, and aerospace sectors, to create and enhance safety knowledge tools for emergency responders and authorities having jurisdiction. DOE develops safety knowledge tools in order to reach the largest number of safety personnel possible to ensure continued safe use of hydrogen.

Codes and Standards

Hydrogen codes and standards are being developed to provide the information needed to safely build, maintain, and operate hydrogen applications and fuel cell systems. Federal and state agencies are working to ensure uniformity of safety requirements and to provide local officials and safety inspectors with the information needed to certify these technologies. DOE promotes collaboration among government, industry, standards development organizations, universities, and national laboratories in an effort to harmonize regulations, codes, and standards internationally and domestically. This work is critical to global competitiveness and the successful early market introduction of hydrogen and fuel cell technologies.

For More Information

More information on the Fuel Cell Technologies Program is available at *http://www.hydrogenandfuelcells.energy.gov*.

First responders learn the basics of hydrogen and fuel cell safety.

Codes and Standards Information Resources
http://hydrogen.energy.gov/codes_standards.html

Permitting Hydrogen Facilities
http://www.hydrogen.energy.gov/permitting/

Introduction to Hydrogen for Code Officials
http://www.hydrogen.energy.gov/training/code_official_training/

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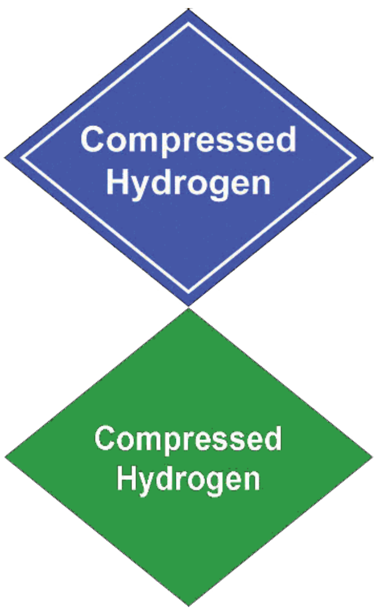
FIRST RESPONDER SAFETY: HYDROGEN AND HYDROGEN-POWERED VEHICLES

HYDROGEN

Hydrogen is colorless, odorless, tasteless, non-toxic, and non-corrosive. This excellent source of energy is the most abundant element on Earth. Hydrogen easily combines with almost every other element (e.g., oxygen). Most hydrogen is locked up in enormous quantities in water, hydrocarbons, and other organic matter. Efficiently producing hydrogen from these compounds is one of the challenges of using hydrogen as a fuel. Currently, steam reforming of methane (natural gas) accounts for about 95% of the hydrogen produced in the United States.



Hydrogen Labels. *Source: NAFTC*

Like natural gas, hydrogen can be stored in two forms:

Gaseous. Gaseous hydrogen is compressed to store sufficient quantities.

Liquid. Liquid hydrogen is typically used as a concentrated form of hydrogen storage. To exist as a liquid, H2 must be pressurized and cooled to a very low temperature, –423.17 °F/–252.87°C. As with any gas, storing it as liquid takes less space than storing it as a gas at normal temperature and pressure.

HYDROGEN-POWERED VEHICLES

Hydrogen vehicles are still largely in development with a limited number of vehicles in use by select organizations and consumers in certain areas. Hydrogen can be used to power vehicles in two ways: (1) in an internal combustion engine (ICE) hydrogen-powered vehicle by igniting the hydrogen to release its energy or (2) in a fuel cell electric vehicle (FCEV) electrochemically, by passing molecules through a fuel cell.

ICE Hydrogen-Powered Vehicles. In an ICE hydrogen-powered vehicle, hydrogen is stored in fuel tanks and burned by the ICE, converting the hydrogen into mechanical energy. The functions of the transmission and drive train are identical to those of a conventional vehicle, though using hydrogen to power an ICE requires modification to the engine calibration and fuel management systems.

Fuel Cell Electric Vehicles. FCEVs use electricity to power motors located near the vehicle's wheels. In contrast to electric vehicles, fuel cell vehicles produce their primary electricity using a fuel cell. The fuel cell is powered by filling the fuel tank with hydrogen. FCEVs may differ from one to another, but usually have several basic components in common: an electric motor, a battery pack, a hydrogen fuel tank, and a fuel cell stack. Electricity is generated by fuel cells to power an electric motor and accessories. The main byproducts of the fuel cell reaction are water and heat.

Hydrogen fuel cell bus. *Source: National Renewable Energy Laboratory (NREL) Photographic Information eXchange (PIX)#16143*

VEHICLE SAFETY

Hydrogen vehicles undergo the same rigorous testing as conventional vehicles and will be required to meet all the same standards for safety, including crash and airbag testing. First responders must understand the different components that make these vehicles unique in an emergency situation. Hydrogen has the widest range of flammability compared to other fuels. Under optimal combustion conditions, the energy required to initiate a hydrogen combustion is much lower than other common fuels. The automotive industry has taken this into consideration when the vehicles are built to include many safety systems. These include sampling of the air for hydrogen concentrations, monitoring pressure levels and stratgic use of pressure release devices to name a few. The high voltage battery pack is no more of a concern on a FCEV than that of a HEV.

U.S. STATISTICS

- Though they are not commercially available on a national scale, there were approximately 313 hydrogen vehicles in use in the United States as of 2008.[1]
- In 2008, approximately 117,000 gasoline gallon equivalents (GGEs) of hydrogen were used in vehicles.[1]
- As of May 2010, there were approximately 56 hydrogen fueling stations in the United States.[2]

[1] U.S. Energy Information Administration, Alternatives to Traditional Transportation Fuels 2008.
[2] U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center (AFDC).

FIRST RESPONDER INFORMATION

Important considerations when responding to an incident involving a hydrogen-powered vehicle:

- Approach the vehicle with caution and only with the appropriate training.
- Eliminate all ignition sources.
- Stay upwind and away from vapors and leaks.
- Look, smell, feel and/or use sensors to detect leaking fuel or a fire.
    - o If the vehicle is on fire or a leak is detected, do not approach the vehicle.
    - o If no fire or leak is detected, isolate the fuel system.

In the case of a vehicle fire:

- Isolate the fire, if possible.
- Extinguish the fire.
- Be aware that, if the flame is extinguished without stopping fuel flow, the fire may reignite.

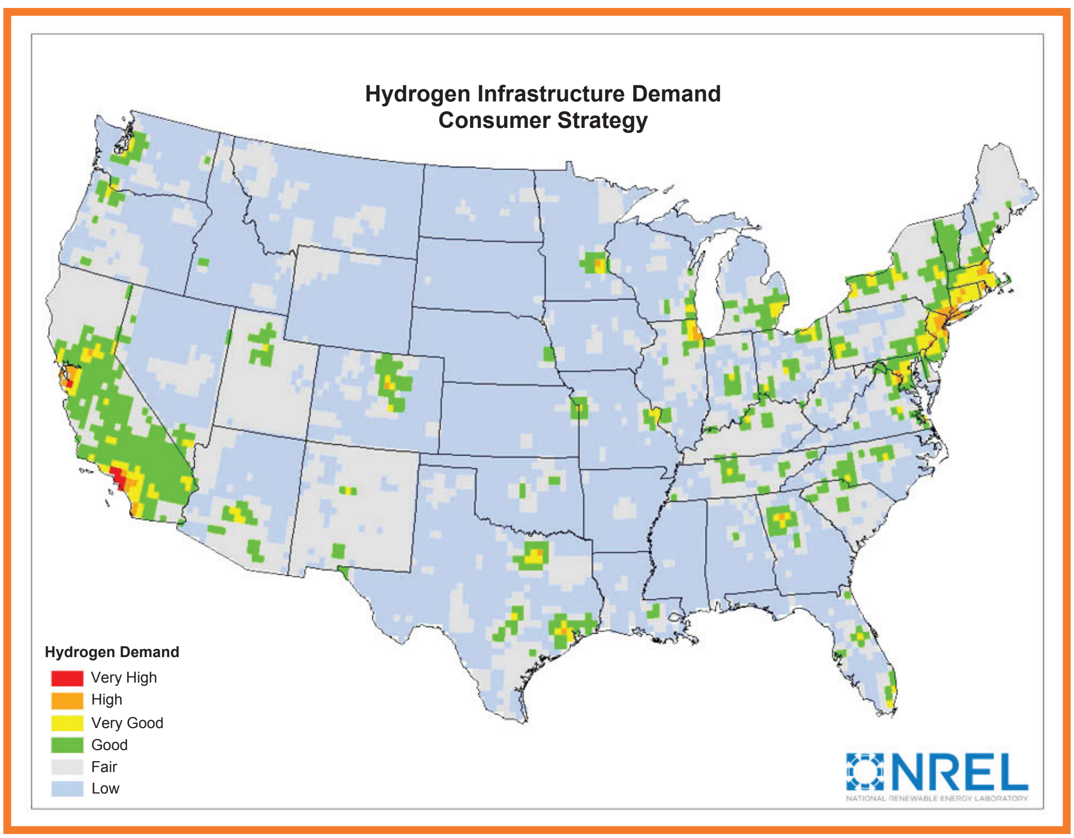
In the case of hydrogen spill or leak, isolate the area until the gas has dispersed and use water spray to reduce vapors or divert vapor cloud drift.

If extrication is necessary:

- Be sure there are no vapors or fuel leaks that could ignite.
- Know cribbing points and cut zones before cutting into a vehicle.
- Avoid cutting critical components.

ADDITIONAL RESOURCES

- U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/
- National Hydrogen Association: http://www.hydrogenassociation.org/
- National Fire Protection Association: http://www.nfpa.org/



Hydrogen demand map. *Source: NREL In this map, the National Renewable Energy Laboratory (NREL) analyzed demographic, socio-economic, transportation, and policy data that influence hydrogen demand. The demand scenarios were further used to estimate infrastructure needs and usage throughout the country and to predict transition infrastructure costs.*

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