Safety Considerations for Hydrogen Installations

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Hydrogen Properties and Behavior

- A gas at ambient conditions

- Hydrogen is a cryogen: exists as a liquid at -423°F (-253°C).
  - Compressing the gas does not liquefy it
  - No liquid phase in a compressed gaseous hydrogen storage tanks

- LH2 storage at relatively low pressure (50 psi)

- Double walled, vacuum insulated tanks with burst disks, vents, and PRDs

- Volumetric ratio of liquid to gas is 1:848
  - Compare water to steam (1:1700)

- Energy content of 1kg of H₂ is approximately equal to 1 gal of gasoline (in BTUs)

Codes and Standards: IFGC Chapter 7, ASME B31.12, CGA G5.5
Gaseous hydrogen:
- has a flammable range of 4-75% in air
- will typically rise and disperse rapidly (14x lighter than air)
- diffuses through materials not normally considered porous
- requires only a small amount of energy for ignition (0.02 mJ)
- burns with a pale blue, almost invisible flame
- can embrittle some metals
## Hydrogen Properties: A Comparison

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen</th>
<th>Natural Gas</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Toxicity</strong></td>
<td>None</td>
<td>Some</td>
<td>High</td>
</tr>
<tr>
<td><strong>Odor</strong></td>
<td>Odorless</td>
<td>Mercaptan</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Buoyancy</strong></td>
<td>14X Lighter</td>
<td>2X Lighter</td>
<td>3.75X Heavier</td>
</tr>
<tr>
<td><strong>Energy by Weight</strong></td>
<td>2.8X &gt; Gasoline</td>
<td>~1.2X &gt; Gasoline</td>
<td>43 MJ/kg</td>
</tr>
<tr>
<td><strong>Energy by Volume</strong></td>
<td>4X &lt; Gasoline</td>
<td>1.5X &lt; Gasoline</td>
<td>120 MJ/Gallon</td>
</tr>
</tbody>
</table>

Source: California Fuel Cell Partnership
Comparing Hydrogen and Propane Flames

Video URL: https://h2tools.org/content/hydrogen-propane-flame-comparison
Hydrogen safety, much like all flammable gas safety, relies on five key considerations:

▶ Recognize hazards and define mitigation measures
▶ Ensure system integrity
▶ Provide proper ventilation to prevent accumulation (manage discharges)
▶ Ensure that leaks are detected and isolated
▶ Train personnel
General Considerations

Hydrogen cylinders and storage tanks should be stored outside at a safe distance from structures, ventilation intakes, and vehicle routes. This applies even while in use. Best practices call for compressed hydrogen bottles supplying a manifold to be located outside, with welded lines to connect to indoor equipment. Safety considerations for indoor storage or use of bulk gaseous hydrogen include:

▶ Buildings should be constructed of noncombustible materials.
▶ Mechanical ventilation systems should have inlets low to the ground and exhausts at the highest point of the room in the exterior wall or roof. Consideration should be given to providing venting for both normal conditions and emergency situations.
▶ Hydrogen sensors should be installed at the exhaust within the enclosure.
▶ Automatic shutoff that activates if a leak or fire is detected in the facility that is being supplied with hydrogen.
▶ Ignition sources in storage areas should be avoided.
▶ Classified electrical equipment should be used in close proximity to storage systems.
▶ Gaseous hydrogen system components should be electrically bonded and grounded.

Code and Standards: IFC, IBC, IFGC, NFPA 2, NFPA 70
Proper ventilation can reduce the likelihood of a flammable mixture of hydrogen forming in an enclosure following a release or leak.

- At a minimum, ventilation rates should be sufficient to dilute a potential hydrogen leak to 25% of the lower flammability limit (LFL) for all operations and credible accident scenarios.

Passive ventilation features such as roof or eave vents can prevent the buildup of hydrogen in the event of a leak or discharge, but passive ventilation works best for outdoor installations.

- In designing passive ventilation, ceiling and roof configurations should be thoroughly evaluated to ensure that a hydrogen leak will be able to dissipate safely. Inlet openings should be located at floor level in exterior walls, and outlet openings should be located at the highest point of the room in exterior walls or the roof.

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.1, NFPA 2-6.17
Active Ventilation

- If passive ventilation is insufficient, active (mechanical, forced) ventilation can be used to prevent the accumulation of flammable mixtures.
  - Equipment used in active ventilation systems (e.g., fan motors, actuators for vents and valves) should have the applicable electrical classification and be approved for hydrogen use.
  - If active ventilation systems are relied upon to mitigate gas accumulation hazards, procedures and operational practices should ensure that the system is operational at all times when hydrogen is present or could be accidentally released.
  - Hydrogen equipment and systems should be shut down if there is an outage or loss of the ventilation system if LFL quantities of hydrogen could accumulate due to the loss of ventilation. If the hazard is substantial, an automatic shutdown feature may be appropriate.
- Ventilation (passive or active) should be at a rate not less than 1 scf/min/ft² (0.3048 Nm³/min/m²) of floor area over the area of storage or use.

Be aware that no practical indoor ventilation features can quickly disperse hydrogen from a massive release by a pressurized vessel, pipe rupture, or blowdown.

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.2, NFPA 2-6.17
Hydrogen leak detection systems may be required by the AHJ or may be installed as a means for enhancing safety of the operation. Leak detection can be achieved by:

- **Providing hydrogen (or flammable gas) detectors in a room or enclosure, or**
- **By monitoring the internal piping pressures and/or flow rates for changes that would suggest a leak is present in the system.**
- **Other methods include providing detectors in close proximity to the exterior piping or locating hydrogen piping within another pipe and monitoring the annulus for leaks.**

Regardless of the method used, leak detection systems should, at a minimum, incorporate automatic shutoff of the hydrogen source (and startup of a properly-configured active ventilation system, if present) when hydrogen is detected. For systems designed to monitor hydrogen concentrations in rooms or areas, the leak detection system should also warn personnel with visual and audible warnings when the environment is becoming unsafe. Remote notification should also be considered.
Hydrogen flames are almost invisible to humans, so thermal and optical sensors are used to detect burning hydrogen.

- To cover a large area or volume, many thermal detectors are needed and should be located at or near the site of a potential fire.
- Optical sensors for detecting hydrogen flames can operate in the ultraviolet or infrared spectral region.

Flame detectors should be installed in certain applications (e.g., NFPA 2 requires them near hydrogen dispensers in hydrogen fueling stations). Detectors should provide a rapid and reliable indication of the existence of a hydrogen flame. The system should also:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down the system to a safe mode
- Control active ventilation
- Activate audible and visual alarms
- Control access to areas with high concentrations of hydrogen or active fires
Specific considerations:

- Fans for active ventilation systems should be provided with a rotating element of nonferrous or spark-resistant construction.
- Equipment or devices should be designed for use in hydrogen service.
- The gaseous hydrogen system should be electrically bonded and grounded.
- Equipment not conforming to NEC requirements must be located outside the area classified as hazardous.

Electrical Equipment Requirements for Bulk Systems

<table>
<thead>
<tr>
<th>Location</th>
<th>Classification*</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area containing gaseous hydrogen storage, compression or ancillary equipment</td>
<td>Class 1, Division 2</td>
<td>Up to 15 ft from storage/equipment</td>
</tr>
<tr>
<td>Area containing liquefied hydrogen storage</td>
<td>Class 1, Division 2</td>
<td>Up to 25 ft from the storage equipment, excluding the piping system, downstream of the source valve</td>
</tr>
<tr>
<td></td>
<td>Class 1, Division 1</td>
<td>Within 3 ft from points where connections are regularly made and disconnected</td>
</tr>
<tr>
<td>Interior of dispensing equipment</td>
<td>Class 1, Division 2</td>
<td>Up to the support mechanism (anchoring the dispenser) or connection to the ground level</td>
</tr>
<tr>
<td>Exterior of outdoor dispensing equipment</td>
<td>Class 1, Division 2</td>
<td>Up to 5 ft from dispenser</td>
</tr>
<tr>
<td>Exterior of indoor dispensing equipment</td>
<td>Class 1, Division 2</td>
<td>Up to 15 ft from the point of transfer from floor to ceiling</td>
</tr>
<tr>
<td>Outdoor discharge from relief vents</td>
<td>Class 1, Division 1</td>
<td>Up to 5 ft from the source</td>
</tr>
<tr>
<td>Discharge from relief vents within 15 degrees of the line of discharge</td>
<td>Class 1, Division 1</td>
<td>5-15 ft from the source</td>
</tr>
<tr>
<td></td>
<td>Class 1, Division 2</td>
<td>Within 15 ft from source</td>
</tr>
</tbody>
</table>

* All equipment shall be rated for Group B applications (NFPA 70-500.6).
The Certification Challenge

The scarcity of listed hydrogen equipment places an extraordinary burden on code officials to ensure (approve) that products include the appropriate inherent or automatic safety measures.

Certification presents significant challenges.

- Few systems or equipment that are listed, labeled or certified
- Significant costs since the technology and products are still rapidly changing and each new iteration would require recertification

Development of a Certification Guide

The Hydrogen Safety Panel is developing a guide to assist code officials, designers, owners, evaluators and others with the application of requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes. The scope of the Guideline will be limited to those requirements where the terms approved, certified, listed and/or labeled are used.

Selection of Materials

- Materials of construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen at the intended operating conditions.

- The mechanical properties of metals, including steels, aluminum and aluminum alloys, titanium and titanium alloys, and nickel and nickel alloys are detrimentally affected by hydrogen.

- Exposure of metals to hydrogen can lead to embrittlement, cracking and/or significant losses in tensile strength, ductility, and fracture toughness. This can result in premature failure in load-carrying components.

- Additionally, hydrogen diffuses through many materials, particularly nonmetals, due to its small molecular size.


Preferred
- Generally acceptable materials include austenitic stainless steels, copper, and copper alloys.

Avoid
- Nickel and most nickel alloys should not be used since they are subject to severe hydrogen embrittlement.

- Gray, ductile, and malleable cast irons should generally not be used for hydrogen service.

Codes and Standards: IFGC 5003.2.2.1, IFGC 704.1.2.3, NFPA 2-10.3.1.3
Hydrogen piping systems should be designed in accordance with the applicable codes and standards and to:

- Minimize leaks through the use of welded joints where possible
- Piping should not be concealed and arranged to ensure that personnel will be able to easily reach joints and fittings (to check for leaks).
- Prevent or reduce the chance of personal injury (i.e., contact with cold surfaces, head impact, tripping hazards, etc.)
- Minimize stresses (structural and thermal) in piping components and connected equipment
- Provide proper sizes and settings of pressure relief devices
- Include properly labeled shutoff valves at safe locations

Flow restrictors, such as orifice meters, in the supply line are an effective means of limiting the supply flow rate and controlling leakage rate.

Piping should be labeled to indicate content, flow direction, and design and test pressures.

Vent Lines
Vent lines for hydrogen (including pressure relief lines and boil-off from cryogenic systems) should be vented to a safe outside location. The vent should be designed to prevent moisture or ice from accumulating in the line. The vent system should:

- be leak tight
- avoid air intrusion or be designed to handle the possibility of an explosion inside the piping
- be unobstructed and protected from the weather
- safely release the unused hydrogen above the facility roof or at a remote location
- be designed to carry the excess flow of the venting gas or liquid

Codes and Standards: IFGC 704.1.2.3, ASME B31.12, CGA G5.5
This presentation was primarily focused **gaseous hydrogen systems and equipment**. Cryogenic liquid hydrogen storage and supply systems offer additional hazards. General safety considerations for the use of cryogenic liquid are listed below.

- Due to its extremely low boiling point, liquid hydrogen can cause serious frostbite and hypothermia.
- Ice formation on vents and valves could cause them to malfunction.
- Condensed air could result in oxygen enrichment and explosive conditions near a liquid hydrogen storage system.
- Accidental air leakage into a liquid hydrogen storage vessel (e.g., from inadequate purging) will result in the introduction of moisture. The water will form ice, which may plug lines or cause instruments to malfunction.
- Continuous evaporation generates gaseous hydrogen and an increase in pressure inside a liquid hydrogen storage vessel if not properly released.
- If a liquid hydrogen leak or spill occurs, a hydrogen cloud could flow horizontally for some distance or even downward, depending on the terrain and weather conditions.

A liquid hydrogen release will look similar to this liquid nitrogen release. (Photo courtesy of Scott Stookey)
For additional information…

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