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TRAINING FOR COST-EFFECTIVE, CODE-COMPLIANT MAINTENANCE FACILITIES

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CODE REQUIREMENTS AND BEST PRACTICES: HYDROGEN

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Prepared For:
Trevelyn Hall
Program Manager
U.S. DOE/NETL

National Energy Technology Laboratory
626 Cochrans Mill Road
PO Box 10940
Pittsburgh, PA 15236
304-205-2490
Trevelyn.Hall@netl.doe.gov

GTI Technical Contact:
Tyler Manley
Principal Engineer
847-768-0697
Tyler.Manley@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

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Acknowledgement

Gas Technology Institute would like to emphasize that the goal of this project was to compile existing educational materials and expand upon them. In doing so, GTI would like to acknowledge that the following work has been instrumental to the development of this report:

Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook. Authored by Kay Kelly and Margot Melendez, United States Department of Energy, Office of Energy Efficiency and Renewable Energy, and Co-Authored by John Gonzales and Lauren Lynch, National Renewable Energy Laboratory; Bob Coale and Jarrod Kohout, Gladstein, Neandross & Associates, 2017.

Gas Technology Institute would like would also like to recognize the significant contributions of subject matter experts in the area of hydrogen vehicle maintenance facility modification at Frontier Energy. In addition, Gas Technology Institute would like to recognize Sierra Monitor Corporation and Clean Energy for their support and contribution.

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Background

Hydrogen fuel cell electric vehicles (FCEVs) are available to consumers, either as a lease or for purchase. As such, dealership maintenance facilities are being retrofitted to accommodate for repair. In addition, transit agencies are beginning to utilize hydrogen fuel cell buses, and heavy duty fuel cell trucks will soon be available commercially. The potential cost of maintenance facility modifications for vehicle repairs is a factor in the decision to own and/or service FCEVs. While most routine FCEV maintenance does not require facility modifications over and above what already exists for any other vehicle, some garages will need some facility modifications in order to comply with locally adopted codes for maintenance garages. Additionally, those not yet experienced with hydrogen-related codes and standards may provide designs for unnecessarily high cost construction quotes for modifying or building a facility.

The objective of this project, supported by a competitively awarded, cost-shared agreement from the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under Award Number DE-EE0007815, is to develop and provide training and other resources for Authorities Having Jurisdiction (AHJs), designers, and other stakeholders regarding the aforementioned garage modifications. Best practices for FCEV maintenance and repair facilities will also be a highlight for project developers.

The project will accomplish these objectives using multiple outreach and training tools – in-person training seminars, facility tours, reports, and online resources. This consortium of tools will cover three fuels – natural gas, propane, and hydrogen. This report will focus on requirements for garages that service hydrogen fuel cell vehicles and best practices that a facility can implement to become code compliant. The final say, however is with the AHJ who can and may have jurisdictional-specific requirements.

Vehicle Safety

The engineering and design of FCEV compressed hydrogen storage systems (CHSS) ensure containment of the hydrogen fuel and prevention of accidental release. These designs follow component and system industry standards and include elements such as integration of hydrogen compatible materials and rigorous testing of those components and systems to prevent failure. It is important to have some understanding of the vehicle system(s) and the properties of hydrogen, when discussing an ‘accidental release’.

SAE International J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles is an industry standard for FCEV safety, and has been harmonized with international vehicle standards. One test in that document, for example, defines the maximum allowable leakage rate from the CHSS during holds at maximum full-fill static pressure. The document covers a battery of design requirements and functionality tests which promote the safe storage of compressed hydrogen on board the vehicles.

Hydrogen fuel cell buses and light duty passenger vehicles store gaseous hydrogen on board at 35 or 70 Megapascals (MPa), respectively (approximately 5,000 or 10,000 psi). The CHSS are comprised of Type III (metal liner) or Type IV (polymer liner) high pressure cylinders that are composite-wrapped. These cylinders are built to industry standards (SAE J2579, ANSI HGV 2) and tested rigorously to ensure robustness. The fuel lines and all associated components are made of hydrogen-compatible materials. The pressure of the gas is isolated to the storage cylinders; the fuel lines deliver hydrogen fuel to the fuel cell stack at much lower pressure and the system is designed to prevent leaks.

Vehicles are also equipped with on board hydrogen gas sensors, per the Global Technical Regulation (GTR) 13, Hydrogen and Fuel Cell Vehicle Safety. This system is designed to detect a hydrogen leak and alert the driver, beginning at very low concentrations of hydrogen (around 0.4% hydrogen in air, or 10% of the Lower Flammability Limit (LFL) of hydrogen, 4.1%). Should the leak continue, and the concentration of hydrogen reach one quarter to one half of the LFL (1-2%), the vehicle will isolate the fuel into the CHSS by closing in-tank solenoid(s), providing enough battery power to get to safety. The vehicle is designed to then shut off, and is unable to be restarted. The fuel is also isolated in a collision where the air bags are deployed. Collision sensors activate to shut off the hydrogen supply in the same way as the gas sensors. The vehicles also constantly monitor pressure as a part of the onboard diagnostics. Even with "normal" operation of the vehicle- startup and shutdown, the fuel and high voltage are isolated when the 12 volt signal is removed.

Hydrogen Properties

Hydrogen has properties which make it unique from other motor fuels, however just like any fuel, proper handling promotes safety. With proper procedures and understanding, hydrogen is no more dangerous than other motor fuels. At ambient conditions hydrogen is a colorless odorless gas. If modifications for hydrogen are warranted, the means of ensuring safety are different from those employed for liquid fuels because of the gaseous nature of hydrogen and the fact that it is 14 times lighter than air. Because of hydrogen's buoyancy, an accidental release will most likely rise to the highest point of the maintenance facility and dissipate quickly rather than remaining at or near floor level like liquid fuel vapors. The specific properties of hydrogen as well as other vehicle fuels are presented below.

Hydrogen Properties: A Comparison

	Hydrogen	Natural Gas	Gasoline
Color	No	No	Yes
Toxicity	None	Some	High
Odor	Odorless	Mercaptan	Yes
Buoyancy Relative to Air	**14X** Lighter	**2X** Lighter	**3.75X** Heavier
Energy by Weight	**2.8X** > Gasoline	**~1.2X** > Gasoline	**43** MJ/kg
Energy by Volume	**4X** < Gasoline	**1.5X** < Gasoline	**120** MJ/Gallon

Source: California Fuel Cell Partnership

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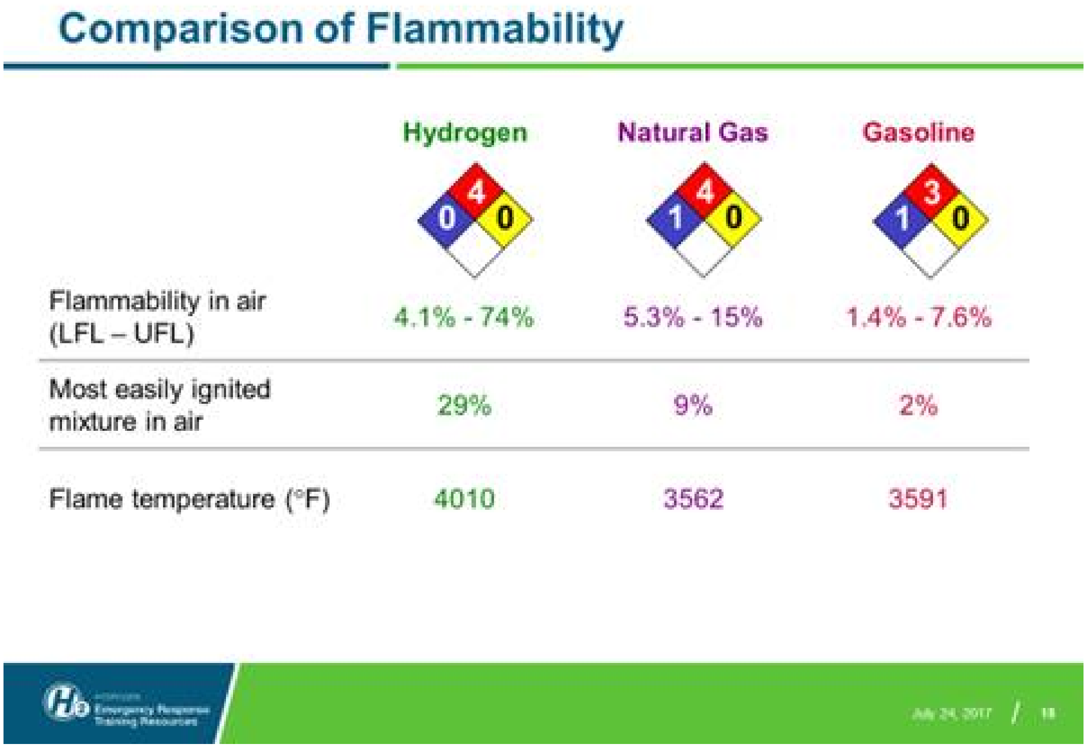
Figure 1: A comparison of hydrogen properties to those of other alternative fuels.



Comparison of Flammability

	Hydrogen	Natural Gas	Gasoline
NFPA diamond (health / flammability / reactivity)	0 / 4 / 0	1 / 4 / 0	1 / 3 / 0
Flammability in air (LFL – UFL)	4.1% - 74%	5.3% - 15%	1.4% - 7.6%
Most easily ignited mixture in air	29%	9%	2%
Flame temperature (°F)	4010	3562	3591

Figure 2: A comparison of hydrogen flammability characteristics to those of other fuels.

A key difference between hydrogen and other transportation fuels is the flammability range; the flammability range for hydrogen is 4%–74% hydrogen in air. The most easily ignited mixture is 29%. This is much greater than the 2% gas-to-air ratio for gasoline vapor. As such, much less gasoline needs to be present to create an unsafe condition. As with gasoline or any other fuel, proper procedures will enable safe environments.

Unlike natural gas and propane, which are odorized with a sulfur containing compound called mercaptan, hydrogen is not odorized. Due to its small molecular weight and buoyancy, an odorant would likely not stay with the hydrogen as it rises. Perhaps more importantly, the fuel cell will not tolerate contaminants such as odorant. The fuel quality specification for hydrogen used in fuel cells (SAE J2719 and ISO 14687) is 99.99%. Because there is no odor, it is only detectable in air with hydrogen gas sensors.

Hydrogen Behavior

It is generally unlikely for flammable concentrations of hydrogen to result from minor leaks that occur over time, as these types of leaks will dissipate rather quickly. However, if a gas detection system is installed, it will detect and alarm at conservative concentrations of hydrogen to prevent a flammable situation. While a hydrogen vehicle maintenance facility is designed to safely handle all types of releases, an uncontrolled release presents the greatest danger. Although this type of event is extremely rare, a maintenance facility must be prepared to protect against it.

Hydrogen is fourteen times lighter than air and tends to rise and dissipate if released into an open space. Although industry has gone to great lengths to prevent leaks, there could be an inadvertent release of hydrogen. For example, a damaged vehicle located within a facility could develop a slow leak due to an improperly sealed fuel system component (see Appendix A).

Pure hydrogen is not flammable, but as an unintended release begins to mix with air, the concentration begins to enter the flammability range. It is prudent for a maintenance facility to consider all potential ignition sources should a release reach a flammable mixture. Additionally, ventilation is often the primary defense in the event of a gaseous hydrogen leak.

Hydrogen behavior and paths of migration are also affected by air movement within the maintenance facility. For this reason, a maintenance facility should be designed to prevent the release from rising into unprotected areas that prevent or inhibit dispersion. This is accomplished by installing barriers, pressurizing adjacent areas, and sealing gaps in the structure to prevent the migration of hydrogen gas into unprotected areas.

Examples of potential paths of migration resulting from the structural characteristics of a facility are shown in the figures below. These potential paths of migration can be eliminated by installing sealing material around the wall penetrations and at the ceiling level, orange sealant can be seen in Figure 6.

Figure 3: Electrical conduit going into the wall of an all hydrogen service bay is sealed to prevent hydrogen from entering. Photo courtesy of Gladstein, Neandross & Associates, NREL

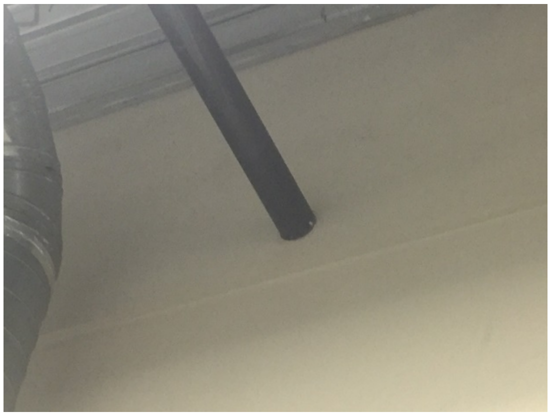


Figure 4: The fire sprinkler main runs perpendicular to adjoining bays. There is no gap; the wall is flush up to the pipe. Photo courtesy of Gladstein, Neandross & Associates, NREL

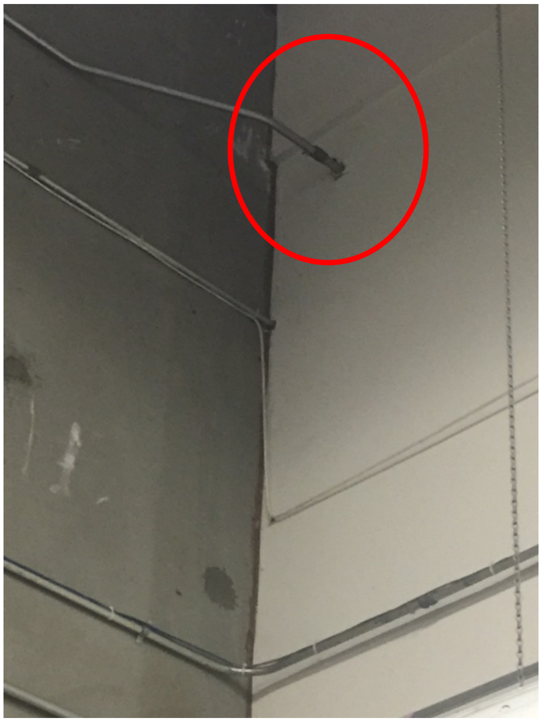


Figure 5: Another example of electrical conduit going into a wall; the wall is flush with the pipe. Photo courtesy of Gladstein, Neandross & Associates, NREL

Figure 6: Wall penetrations properly sealed to prevent migration. *Photo courtesy of Gladstein, Neandross & Associates, NREL*

Figure 7 shows an open passage to an adjacent non-maintenance area through which hydrogen gas migration could occur. The two areas must be isolated by installing a door between the areas to isolate the two rooms.

Figure 7: A potential path of migration created by an open passageway. *Photo courtesy of Gladstein, Neandross & Associates, NREL*

Stairways accessing an upper level could accentuate the upward gas flow. In these cases, the potential path of migration should be intercepted by installing a door that would prevent upward gas flow. The door must be fitted with a self-closing mechanism to keep it closed except when in use. Operating protocols and signage should also be used to ensure that the door is not propped open. Doors should not be fitted with louvers.

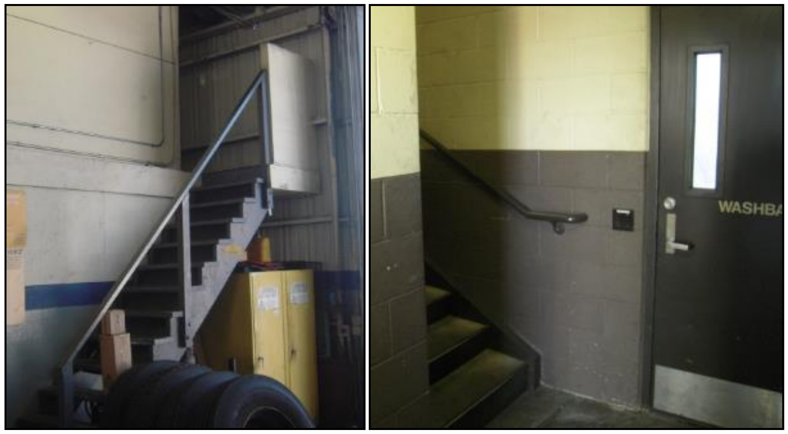


Figure 8: Examples of stairways to upper levels that are a potential path of migration. Photo courtesy of Gladstein, Neandross & Associates, NREL

Figure 9 shows a storage area for vehicle parts adjacent to a workshop that is serviced with a pass-through window. Open windows present a potential path of migration for the transmission of hydrogen gas to an unprotected area. This condition can be eliminated to the satisfaction of the AHJ by permanently sealing the window, adopting strict operating protocols ensuring that it is only open during active use, or installing a pressurizing fan in the parts room to prevent the inward flow of gas from the maintenance area.

Figure 9: A pass-through window presents a potential path of migration. Photo courtesy of Gladstein, Neandross & Associates, NREL

Applicable Codes and Standards

The hydrogen community has come together to contribute valuable information for the codes in recent code cycles, and continues as the industry learns more. The International Code Council and the National Fire Protection Association (NFPA) codes have been harmonized, removing conflicting requirements in the two documents. Thus, there are now a select number of codes dealing with hydrogen. Some of the 'usual' codes for maintenance garages, such as the IFC, NFPA 1, and NFPA 30 A still apply to FCEV maintenance facilities. These codes are further clarified by specific sections or separate codes for hydrogen and other lighter-than-air fuels.

One of two primary documents for hydrogen maintenance facilities is NFPA 2, the Hydrogen Technologies Code. While Chapter 4, General Fire Safety Requirements and Chapter 6, General Hydrogen Requirements, are applicable in general, Chapter 18 is specifically on repair garages. The other primary document is the International Fire Code (IFC) which has been, and continues to be harmonized for hydrogen applications. Certain states and jurisdictions do not adopt the IFC but instead use NFPA 1, which also points to NFPA 2. Adopting and applying the most recent versions of the following documents should address hydrogen vehicle maintenance garages. Future revisions will likely be better harmonized with each other, and will include further modifications/improvements for hydrogen applications which are based on data to back up that experience.

In addition to the documents listed above, many states and local authorities have their own codes or modifications to the model codes. It is essential to recognize that, while all of these documents provide valid and safe methods for facility design, it is the AHJ that has the final say in approving a plan. For an exhaustive list of all codes & standards pertaining to hydrogen infrastructure, visit h2tools.org.

Minor and Major Repair Facilities

NFPA 1, 2, and 30A and the International Fire Code (IFC) cover hydrogen vehicle maintenance facilities. NFPA classifies maintenance garages into one of two categories: major repair garages and minor repair garages whereas the IFC uses "exceptions". The language and intent in these two documents have been harmonized so as to not conflict with each other. The following are excerpts containing the definitions and exceptions concerning major and minor repair garages as presented in the 2016 version of NFPA 2, the 2018 version of 30A, and the 2018 version of the IFC:

> A major repair garage is defined by NFPA 2, Section 3.3.101.1 as:
>
> *A building or portions of a building for major repairs, such as work on the hydrogen storage system, the fuel cell system, the propulsion system, and repairs that require defueling of the hydrogen fuel cell vehicle, and maintenance or repairs that require open-flame cutting or welding.*
>
> A minor repair garage is defined by NFPA 2, Section 3.3.101.2 as:
>
> *A building or portions of a building not used for work required to be performed in a major repair garage, such as lubrication, inspection, and minor automotive maintenance work, fluid changes (e.g., brake fluid, air conditioning refrigerants), brake system repairs, tire rotation, and similar routine maintenance work.*

Generally, if fuel system work, painting, welding, or other open-flame work is done in a facility, it is a major repair facility, otherwise it is a minor repair facility. There are certain exceptions for some alternative fuels, including hydrogen.

> NFPA 2, 18.3.1.1 - *The discharge or defueling of hydrogen from fuel supply containers shall be required for the purpose of fuel storage system modification or repair or when welding or open flame activities occur within 18 in of the vehicle fuel supply container.*
>
> NFPA 2, 18.3.1.2 - *Other than for those repairs listed in 18.3.1.1, repairs that would be required to be performed in a major repair garage shall be permitted to be performed in a minor repair garage if the vehicle is defueled in accordance with Section 18.7 to less than 200 scf* [1] *and the fuel supply container is sealed.*

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1. A standard cubic foot (scf) is a unit of volume equivalent to one cubic foot of gas at 70 º F (15 C) and one atmosphere of pressure (14.7 PSI). An actual cubic foot (ACF) of gas at elevated pressure may contain many standard cubic feet of gas. It is often used as a proxy for mass, because mass does not change with pressure or temperature.

The IFC implies essentially the same classification requirements, but it does so through an exception that is specific to hydrogen-fueled vehicle repairs. Certain repairs that would otherwise be classified as major are classified as minor repairs if the fuel storage system contains less than 200 standard cubic feet of hydrogen. IFC Section 2311.7, Repair garages for vehicles fueled by lighter-than-air fuels, states:

> *Repair garages for the conversion and repair of vehicles that use CNG, Liquefied natural gas (LNG), hydrogen or other lighter-than-air motor fuels shall be in accordance with Sections 2311.7 through 2311.7.2.3 in addition to the other requirements of Section 2311.*
>
> ***Exceptions:***
>
> ***1.*** *Repair garages where work is not performed on the fuel system and is limited to exchange of parts and maintenance not requiring open flame or welding on the CNG, LNG-, hydrogen- or other lighter-than-air fueled motor vehicle.*

Repair garages for hydrogen-fueled vehicles where work is not performed on the hydrogen storage tank and is limited to the exchange of parts and maintenance not requiring open flame or welding on the hydrogen-fueled vehicle are allowed under the exemption. During the work, the entire hydrogen fuel system shall contain a quantity that is less than 200 standard cubic feet ($5.6sm^3$) of hydrogen.

NFPA 2, Section 18.2.1 states that major repair facilities that repair FCEVs and also repair traditional liquid-fueled vehicles are not exempt from liquid-fueled vehicle garage codes and still need to meet the requirements of NFPA 30A.

In general, the classification of a garage as major or minor becomes important when assessing the costs of code compliance. Major repair garages have requirements that minor repair garages do not.

Requirements for Minor Repair Facilities

This section applies to garages that perform minor repairs, including, but not limited to:

- Tire replacement, rotation, or balancing
- Washing
- Headlight replacement
- Oil changes
- Fluid replacements
- Brake work or pad replacement
- Dent Repair (without any hot work/welding)
- Windshield Replacement
- Interior work

These facilities are considered minor garages under the NFPA codes and are considered garages with exceptions under IFC. The work performed in such a facility may include minor repairs performed on gasoline or diesel vehicles as well. These facilities may perform minor maintenance and repair on hydrogen vehicles if a few simple requirements are met.

Sprinklers

NFPA 2 Section 18.3.2 specifies that automatic sprinkler systems should be installed in accordance with the building code and the fire code adopted by the AHJ. If a garage is up to code to service liquid fuel vehicles, no modifications to the existing sprinkler system will be necessary.

Heating

Heat-producing appliances should be installed in a way that meets the requirements in NFPA 31, NFPA 54, NFPA 82, NFPA 90A, and NFPA 211. These requirements are identical to the requirements in NFPA 30A. Garages that already do minor repairs on gasoline or diesel vehicles should already employ heating devices that are in compliance with NFPA 30A, and will not need to make further modifications in order to service hydrogen vehicles.

It is important to note that hydrogen is a gas that readily disperses, and careful attention should be given to any appliance that may be a source of ignition. Open-flame heaters and electric heating elements can ignite a dissipating hydrogen release, so care should be taken to ensure devices like this are moved out of hydrogen service areas.

Major Garages with Defueling Procedures

If a garage performs major repairs, but does not perform fuel storage system modification or welding near the fuel system, it can be classified as a minor garage under NFPA codes and can be considered a garage with exception under IFC if there are procedures for defueling to the prescribed 200 standard cubic feet prior to vehicle service. Guidelines for defueling are found in Section 18.7 of NFPA 2 and in Section 2311 of the IFC.

If an AHJ has adopted the latest version of NFPA 30A, it will refer entirely to NFPA 2 for hydrogen maintenance facilities. If an AHJ has not adopted the latest version of NFPA 30A, they may not recognize any exception and will consider such a facility a major facility. Please see the section of this report for strategies to work with your AHJ to use the most recent information for hydrogen facilities.

NFPA 2, Section 18.7.1 specifies that the discharge of hydrogen from motor vehicle fuel storage tanks shall be through a method called atmospheric venting. This safely vents the fuel that was in the fuel tank to an area where the fuel can dissipate away from ventilation intakes and ignition sources (in accordance with CGA-G-5.5, Hydrogen Vent Systems).

In any garage with defueling equipment, the current requirement is for the equipment to be listed and labeled for this use, however no such listing exists at this time. As such, the project proponent will have to work with the AHJ for approval. The defueling equipment should be isolated from other uses, and should not connect with another venting system before discharging to the atmosphere. In addition the defueling system needs to include a method of grounding to prevent any static discharge while defueling. The defueling nozzle needs to be electrically bonded to ground during defueling as well. Equipment supplied by the vehicle manufacturer shall be used to connect to the vehicle fuel supply containers to be defueled.

If the AHJ has chosen to adopt the IFC, per Section 2311.8 defueling must be performed as specified in IFC Section 2309.6.1 through 2309.6.1.2.4. Unlike the current NFPA 2, the 2015 IFC allows for listed, labeled or approved equipment. A helpful resource for approval is the Hydrogen Equipment Certification Guide; Listing, Labeling, and Approval Considerations located on h2tools.org[2]. Otherwise, many of the requirements are harmonized. One specific requirement in the IFC states that vent pipes must have an inner diameter of at least one inch, and the flow through the pipe is limited to 1,000 standard cubic feet per minute.

2 https://h2tools.org/hsp/safety-resources

Major Garages that Modify Fuel Storage Systems or Weld Near Onboard Storage

Major repair facilities that perform modifications to the fuel storage system or carry out open flame operations within 18 inches of the fuel storage system are a major garage under NFPA 2 and will not receive an exception under the IFC.[3] If an AHJ has not recognized any exception for defueling, a major garage may have to consider the modifications outlined in this section. Automatic sprinkler system and defueling guidelines for minor garages also apply to major garages.

Gas Detection & Alarms

NFPA 2, Section 18.3.3 specifies that major repair garages need to be outfitted with a hydrogen gas detection system. This detection system should provide coverage of the vehicle service area, and should have sensors at inlets to exhaust systems, high points in service bays, and inlets to mechanical ventilation systems. This system is to activate when hydrogen levels are above 25% of the lower flammable limit, essentially at 1% hydrogen in air. When the system activates, audio and visual alarms should begin, heating systems should be shut off automatically, and an exhaust system should be activated unless a form of continuously operational exhaust system is already operating. A failure in the gas detection system should initiate all of the aforementioned preventative measures.

Hydrogen gas detection systems may have two alarm levels: one that is a warning, at around 10% of the LFL (0.4% hydrogen in air), and one that is a shutdown and potential evacuation alarm, at anywhere from 25-50% of the LFL (1-2% hydrogen in air). Note that these concentrations are well below the LFL. This strategy help to reduce the number of serious alarms and evacuations if steps can be taken to quickly address the warning alarm. A local AHJ may request that other alarm scenarios, such as fire or carbon monoxide, trigger unique alarm systems so that first responders will know what actions to take to address any safety concerns in the event of an alarm.

Although it is not required by NFPA 2, selected electrical circuits in the hydrogen maintenance area may be modified during a retrofit so that shunt trips are activated on all non-critical electrical circuitry during an alarm. Shunt tripping involves an interface between the gas detection controls and the circuits within the facility electrical panel. When gas is detected, selected circuits can be instantaneously deactivated. It is important to ensure that gas detectors are on circuits that are not shunt tripped during an alarm.

3 Open flame operations such as welding should be done with extra caution around fuel cell vehicles, even if the tank is nearly empty. Flying sparks can damage carbon fiber tanks, and even small amounts of gas can ignite.

Many alternative fuel facilities that employ gas detection implement an early-warning alarm at the 10% of LFL. If installed, shunt trips should not activate until the most serious hydrogen alarm is activated. Circuits with the following equipment should not be equipped with shunt trips:

- Electrical controls to the overhead doors that are selected to automatically open for the purpose of providing makeup air upon activation of the gas detection system
- Ventilation fans
- Gas detection and alarm systems and controls
- Emergency lighting
- Critical data collection or storage functions (computers, servers, etc.).

Exhaust and Ventilation Systems

Most garages already have some form of exhaust system to handle liquid fuel vapors. Proper ventilation can be achieved by mechanical means (i.e. powered fans) or by convection to provide air flow. In some rare cases, natural ventilation alone may be approved because it can provide sufficient air flow. There are several reasons for ventilating a maintenance facility. Sufficient ventilation is necessary to quickly and effectively dilute a hydrogen release so that the concentration is below the flammable level. Ventilation may help drive air flow that will direct gas to the detection and alarm system that will alert occupants to safely evacuate the facility. Lastly, ventilation may aid in preventing a release from accumulating near potential ignition sources.

NFPA 2, Section 18.4 specifies that the part of the ventilation system that removes air from the building should have intake openings where hydrogen accumulations occur, typically near the ceiling. This system should be designed in accordance with the mechanical code adopted by the local AHJ.

Electrical Equipment

Electrical equipment represents a potential source of ignition, and must be certified to the appropriate electrical classification and must be suitable for hydrogen service. Fans for active ventilation systems should be provided with a rotating element of nonferrous or spark-resistant construction, or be constructed of, or lined with, such material.

Other equipment or devices should be constructed in a similar manner and designed for use in hydrogen service. Motors and their controls not approved for hydrogen service should be located outside the location where hydrogen is generated or conveyed. Other equipment not conforming to the National Electrical Code requirements must be located outside the area classified as hazardous.

Heat Producing Appliances

Forced air and space heaters pose an ignition risk in the event of an unlikely leak. Solid-fuel stoves, space heaters, salamanders, or other improvised heating devices are not permitted in hydrogen service areas. Heat producing appliances using gas or oil as fuel are permitted as long as they are not within 18 inches of the ceiling. Open-flame heating, or heating that relies on surfaces that are in excess of 750 F are not permitted in areas that hydrogen may be present.

Heat producing appliances with open flames or surfaces over 750 F may be installed in a separate room that is properly sealed off from hydrogen service areas. The partitions to this area should be constructed from 1-hour fire rated materials, and any small openings for wiring or conduit must be filled with fire-resistant material to seal out hydrogen. Input air for this system must be taken from outdoors. All air for combustion purposes shall be taken from outside the building.

Welding and Open Flames

Operations that require open flames or electric arcs or procedures that require cutting that may produce sparks may be sources of ignition in the unlikely event of a leak. This type of work should take place in specific areas dedicated to these operations. The fire protection precautions should comply with NFPA 51B, but if the garage already complies with NFPA 30A requirements, no modifications should be necessary.

Additional Resources for Major Garages

Garages with Multiple Fuels

Some maintenance facilities that service hydrogen vehicles will also service vehicles that use conventional liquid fuels such as gasoline and diesel, and may also service vehicles fueled by natural gas or propane. The requirements for garages that handle multiple fuels are additive, and careful consideration must be given to adhere to multiple codes. More details on natural gas and propane requirements can be found in similar reports at altfuelgarage.org.

Code Adoption Issues for Hydrogen-Only Garages

As previously mentioned, some jurisdictions have not adopted the latest version of NFPA 30A. Previous versions do not explicitly refer to NFPA 2 in the case of a hydrogen-only major garage. This results in an AHJ requiring compliance with NFPA 30A or IFC. Guidelines for working with outdated codes are available in a separate report available on altfuelgarage.org.

Best Practices

This section provides information on how to comply with the codes in innovative and cost-effective ways. Best practices based on case studies may be cited when working with a local AHJ during the garage modification process, however, major changes to compliance with the code need to be verifiable by a third party.

Working with Outdated Codes

Your local AHJ may not have adopted the latest versions of NFPA 30A or IFC. Over the past two to three code cycles, the hydrogen industry and stakeholders have been working to improve code requirements for hydrogen, and to harmonize those requirements across the codes. While the most recent version of the International Fire Code refers to the Hydrogen Technologies Code, NFPA 2 for the installation of fueling stations, it does not yet reference NFPA 2 for repair garages. However, the code language for repair garages in both documents been harmonized.

In recent versions, work that does not involve the fuel tank or hot work (i.e. welding), no modifications over and above what exist for liquid fuels (i.e. gasoline) are required. Further, should work need to be done on the fuel system, again without welding, that work can be carried out in a facility without upgrades (i.e. a minor repair facility) given that the fuel supply container is defueled to 200 scf and the fuel system is sealed.

If the jurisdiction has not adopted the most recent version of NFPA 30A or the IFC, there is usually a provision for using alternate means and methods (AMM). This, of course, is up to the AHJ to allow, and up to the project proponent to have justifiable and verifiable changes based on the most recent version of said code. For example, some strategies for getting approval for alternate means and methods are:

- Work with the AHJ(s) early; have them be a part of the process.
- Do a pre-submittal meeting with the jurisdiction (while it's not a requirement, it is usually an option).
- Completely justify compliance of the plan by documenting how you meet latest codes and submit a complete permitting package (the pre-submittal meeting will aid in this, as well).

Placement of Gas Detectors

Neither NFPA 30A, NFPA 2, nor IFC specify exactly where gas detectors should be located within a facility. The up-front cost of such a system will rely in part on the number of gas detectors, and on-going maintenance costs should be considered as well. Careful consideration during the specification of the location of individual gas detectors will keep these costs to a minimum. If a gas detection system is deemed necessary, a number of factors should be considered so that placement allows maximum coverage with minimum numbers of detectors: hydrogen behavior, detector maintenance, and potential hydrogen sources.

Hydrogen will rise unless disturbed by air currents or other obstacles. If placing sensors in an entire facility, it is recommended that gas sensors be placed near the ceiling in a place that is approximately above a hydrogen source. They should be placed away from corners or walls, so that gas can easily be sampled.

It is wise to place above but in between individual vehicle service areas, or in between rows of service areas in larger garages. This avoids placement in walls and corners but still places sensors approximately above the vehicles while they are in the service area, right in the path of migration.

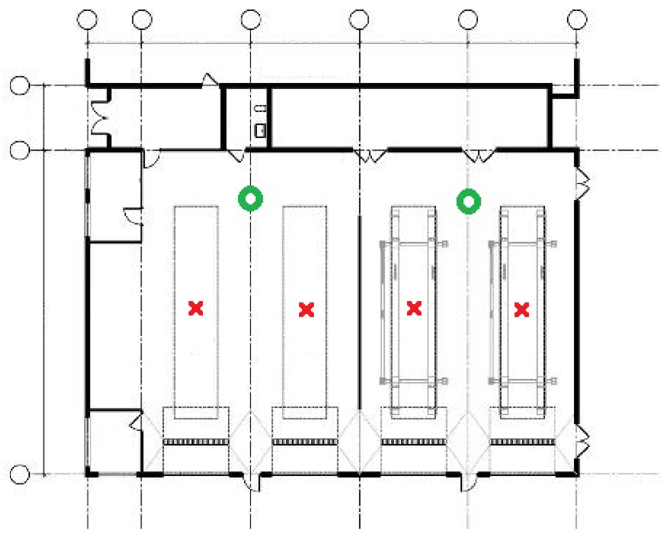

Figure 10: Diagram of recommended gas detector placement between vehicle bays.

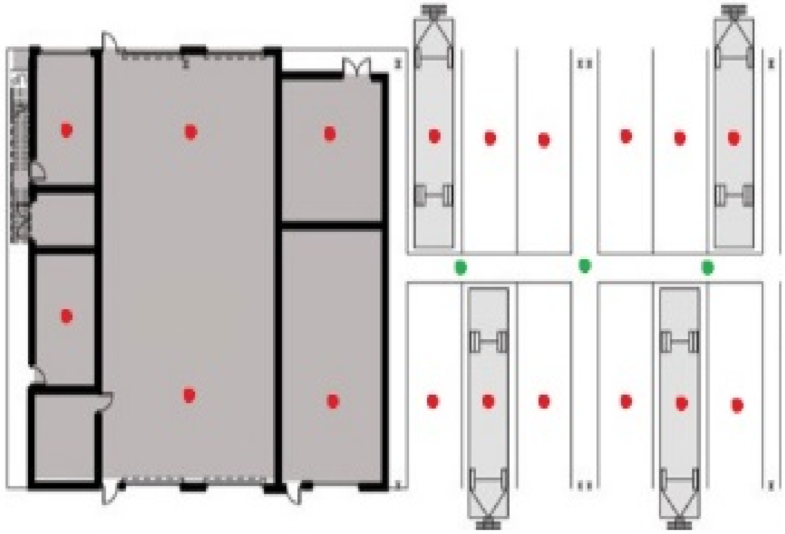

Figure 11: Diagram of recommended gas detector placement between rows of vehicle bays.

Placing detectors in between individual service areas allows one detector to protect two service areas, reducing the number of detectors by half, and therefore reducing cost. Placing one detector in the middle of four individual service areas reduces the number of detectors by four. This placement also allows for maintenance of the sensors without moving or interrupting vehicle service, as ladders, scissor lifts, or other means of access can fit in between service areas.

When developing a facility that includes flammable gas detectors, the manufacturer’s design recommendations should always be reviewed with the manufacturer’s technical staff. A review of the manufacturer’s recommended detection area of influence, combined with considering the ceiling, will optimize placement.

Marathon Hydrogen Service Bay (H2SB)

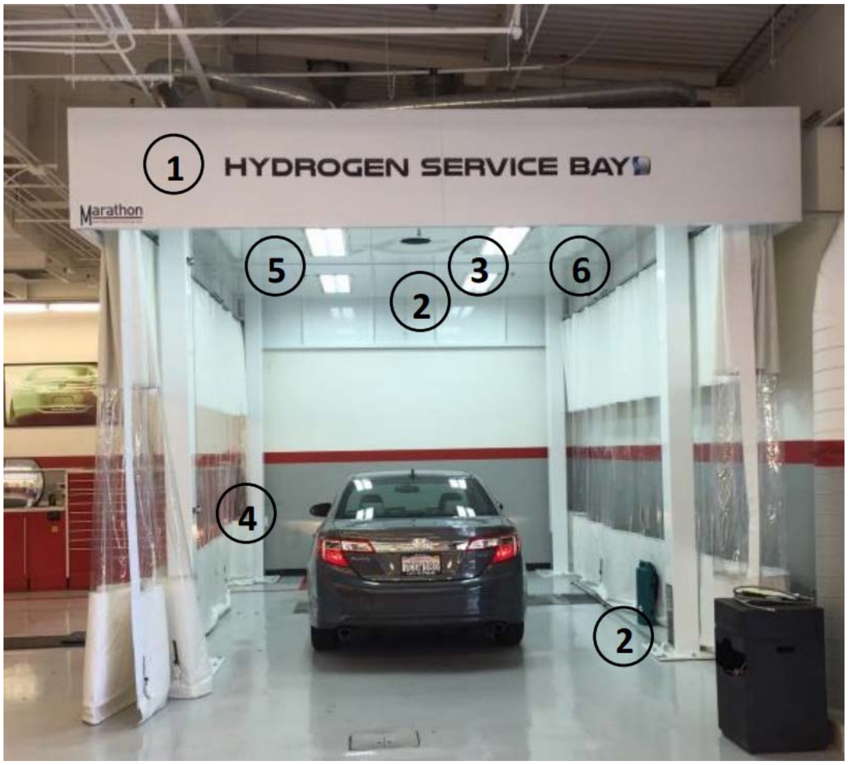

Figure 12: Hydrogen Service Bay, Annotation descriptions below. MarathonSprayBooths.com

One strategy for code compliance in a major hydrogen garage is the Hydrogen Service Bay, a product offered by Marathon Finishing Systems. The service bay separates the bulk of a garage volume into an encapsulated service environment through the use fire retardant, retractable vinyl curtains. Each bay is vented independently, with designated air intake and exhaust. For minor repairs, some of the features typically included may not be required by code, but many installations that utilize this system were designed with an abundance of caution.

1. Enclosed space:
    a. Freestanding hood/valence supported by four posts
    b. Retractable vinyl curtains (NFPA 701 fire retardant)
2. Ventilation system with exhaust at ceiling and with make-up air intakes at lower 4 corners
3. Hydrogen sensing with audible and visual alarms
4. Atmospheric hydrogen defueling system coupling
5. Classified electrical appliances within 18” of ceiling (NFPA 30A compliant)
    a. Above ground lift requires Class I, Division 2 limit switch or switch must be located outside of upper 18” zone
    b. Overhead lights; sealed, tempered glass (Class I, Division 2)
6. Fire sprinklers

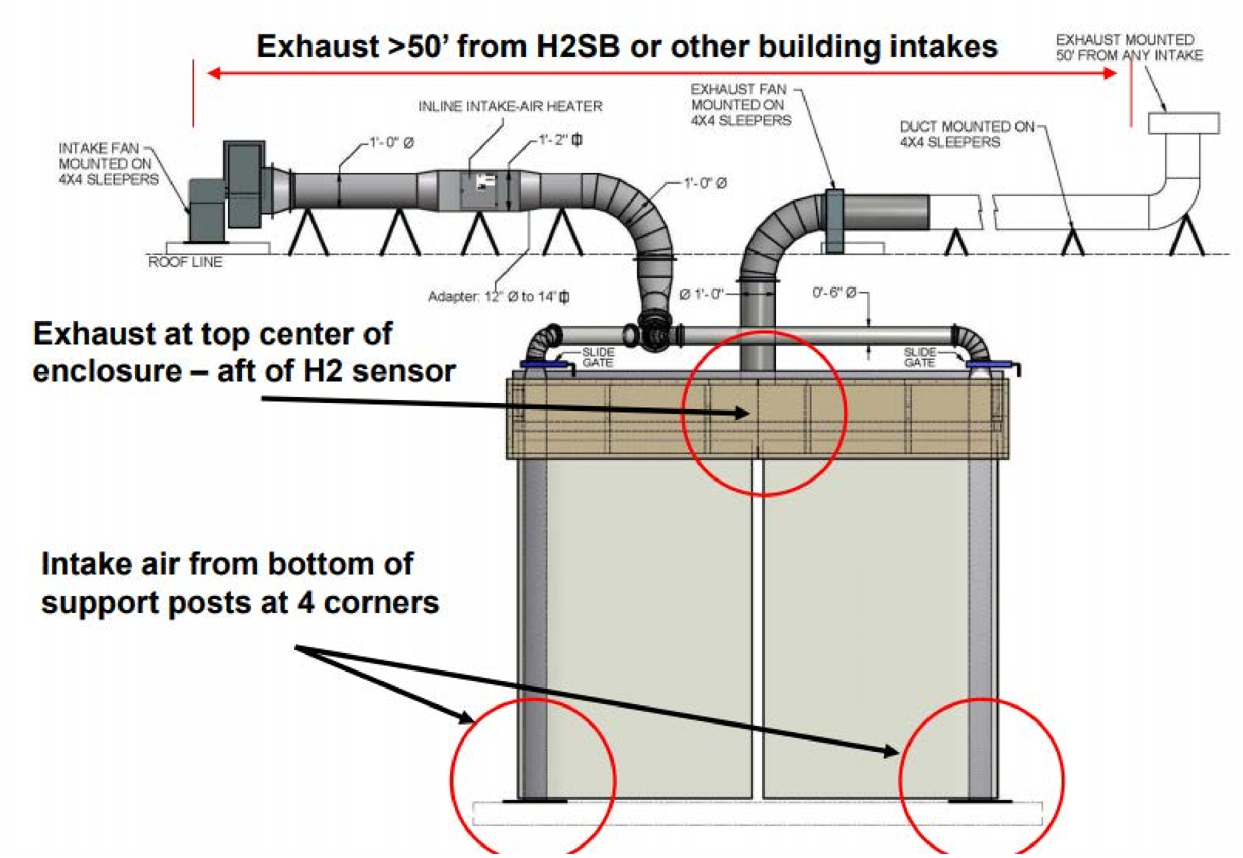

Figure 13: Exhaust considerations with the Hydrogen Service Bay. MarathonSprayBooths.com

The graphic above illustrates the ventilation strategy for the service bay. During normal operation, air exchange is continuous; an intake takes outside air and introduces it near the floor of the enclosed area. In the event of a hydrogen alarm, the rate of air exchange is increased dramatically in order to dilute and extract any hydrogen through the exhaust of the enclosure. The exhaust vent is located at least 50 feet away from the ventilation system intake.

In addition to the items outlined in the graphics above, the hydrogen service bay has an alarm system. The table below gives an example of which scenarios will trigger alarms and what actions to take. Signage in the garage should briefly indicate the necessary actions in a clear, easy to read format, similar to that shown below. Note that this signage lacks any explicit instruction for personnel to evacuate. Evacuation may be included in response plans, and may or may not be for a hydrogen-specific event.

ALARM CONDITIONS		
Condition	**Indicator**	**Action**
System, Intake Fan or Exhaust Fan in "OFF"	1) Red panel light, red flashing remote light & siren	Turn System, Intake Fan and Exhaust Fan to "ON"
Curtain is Open	1) Solid Red remote panel light	Close Curtain
Curtain is Open for > 3 min	1) Flashing Red remote Light & siren	Close Curtain
10% LEL Hydrogen reached	1) Fan speed increases to 2,000+ cfm 2) LEL alarm # 1 – **Yellow light & buzzer on Beacon H2 Sensor**	Warning Only upon exit do not re-enter until **yellow light** turns off.
25% LEL Hydrogen reached	1) **Alarm horn** 2) **Red flashing light & siren**	Stop Work, Evacuate Hydrogen Service Bay and surrounding area. Do not re-enter until alarms are silenced and **yellow light** turns off.
LEL System Failure (Hydrogen Detection System Failure)	1) **Alarm bell** 2) **Amber light top of panel** 3) **Remote solid red light** 4) **Fans activate at 2000+ cfm**	Stop work, cease use of Hydrogen Service Bay until repairs can be made.

Figure 14: Example of alarm conditions, indications, and actions. MarathonSprayBooths.com

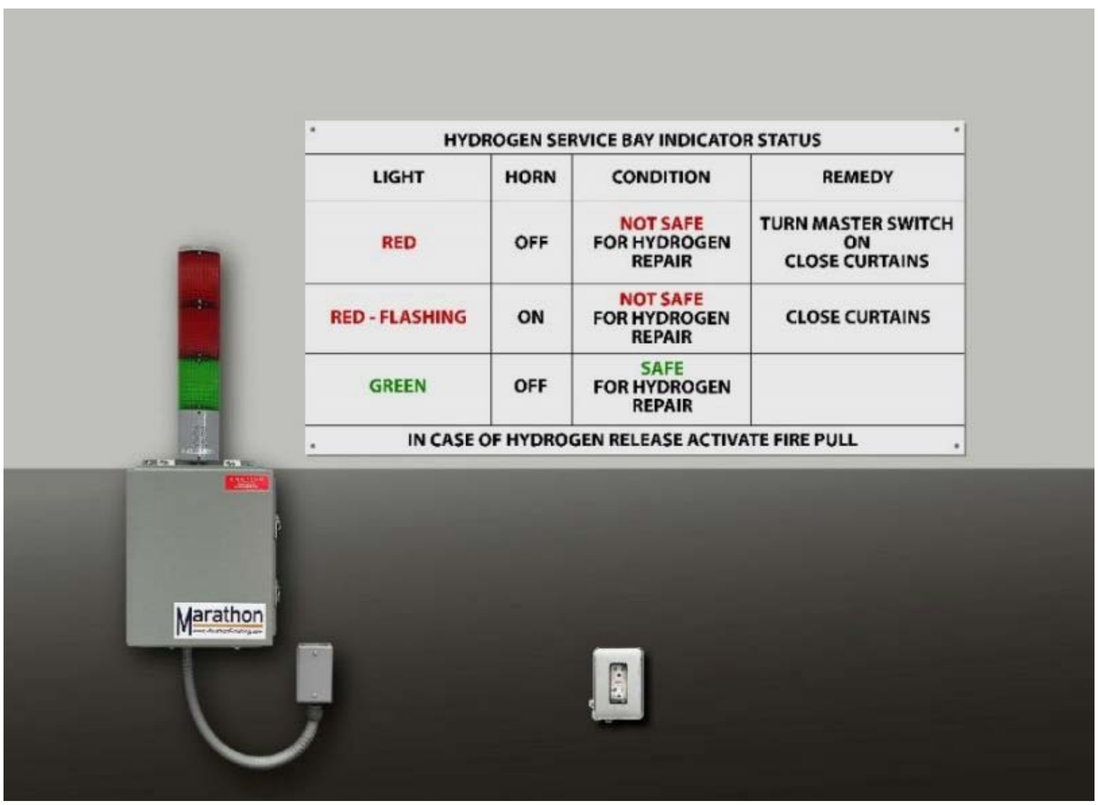

Figure 15: Visualization of an alarm display with adequate signage. MarathonSprayBooths.com

Training Programs

Facility modifications to improve safety in alternative fuel garages require considerable effort, and this effort will be wasted if the personnel who work in the facility are not aware of their role in safety. Physical modifications to the maintenance facility will help mitigate any potential hazard from adding CNG and LNG vehicles to facility operations, but proper training of personnel is critical to maintaining a safe work environment.

Employees, contractors, and visitors to the facility each need specific guidance on how to respond to emergencies. For new employees, gas properties, risk mitigation basics, and specific aspects of any installed alarm systems should be covered. For permanent employees, consider holding ongoing training as often as gas detection systems are calibrated – this is typically every six months. This training should serve as a refresher, and doesn’t need to include every aspect.

Consider having contractors and visitors go through an abbreviated training as part of an orientation program or a welcome presentation. This should at minimum cover evacuation procedures and guide them against doing anything that actively works against safety procedures. Consider teaming visitors with a trusted employee that can guide them in case of emergency.

The training program may include any of the topics below:

- The physical properties of hydrogen and any other fuels used.
- Hazards associated with compressed hydrogen and any other fuels used.
- Review gas detection alarm scenarios and what actions should be taken in each case.
- Procedure if a leak is identified but the alarm system hasn’t activated.
- Why it is important to follow safety procedures and not circumvent safety equipment.
- Building evacuation drills or training in conjunction with alarm scenario.
- First responder interaction training.
- Procedures for after an emergency situation.
- Training for maintenance of gas detection system equipment.
- General OEM guidelines for the onboard fuel storage system and engine fueling components for alternative fuel vehicles

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Appendix A: Supporting, Non-Facility Code Information

SAE J2990-1, Gaseous Hydrogen and Fuel Cell Vehicle First and Second Responder Recommended Practice

SAE J2990-1, Section 7.3 discusses damaged hydrogen vehicle storage isolation recommendations. As discussed previously, vehicles must be defueled before working on the CHSS. Nonetheless minor releases of hydrogen may also occur when disconnecting fuel system components in order to perform a repairs to the fueling system/CHSS. Though rare, a tank or fitting failure may cause a release of hydrogen that results in the entire volume of the tank emptying rapidly. This would be a component failure.

Compressed hydrogen storage cylinders are equipped with thermally-activated pressure relief devices (TPRDs) that, in the case of excessive temperature (i.e. from fire), will melt open and release the contents of the cylinder(s) in under 5 minutes. Hydrogen TPRDs are built and tested to ANSI HPRD 1.A TPRD that releases without exposure to heat is a failure, which the standard is meant to prevent.

Appendix B: Properties of Conventional and Alternative Fuels

Table 1: Properties of Alternative Fuels

Compound	Formula	Density (lb/ft^3) Gases @ STP	Auto-Ignition Temperature (°F)	Lower Flammability Limit (LFL) %	Upper Flammability Limit (UFL) %
CNG (Methane)	CH_4 (majority)	0.0447	1,004	5.3	15.0
Propane	C_3H_8	0.1175	850-950	2.2	9.5
Gasoline	C_8H_{18}	0.287	495	1.4	7.6
Diesel	-	>0.3825	600	1.0	6.0
Hydrogen	H_2	0.0056	1,050-1,080	4.1	74.00
Air	-	0.0806	-	-	-