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TRAINING FOR COST-EFFECTIVE, CODE-COMPLIANT MAINTENANCE FACILITIES

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CODE REQUIREMENTS AND BEST PRACTICES: OUTDATED REQUIREMENTS FOR MAJOR HYDROGEN FACILITIES

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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

This report serves as a review and expansion of the Hydrogen Codes and Best Practices report in order to provide information on outdated codes that may still be in use for major garages. Specifically, the 2015 version of NFPA 30A, as well as all versions previous to 2015, does not exclude maintenance facilities that service hydrogen vehicles from its requirements for vehicle maintenance facilities. The result is that NFPA 2, the Hydrogen Technology Code, and NFPA 30A, the Code for Motor Fuel Dispensing Facilities and Repair Garages both apply. Fortunately, the 2018 version of NFPA 30A simply references NFPA 2 for matters pertaining to major hydrogen maintenance facilities.

Adhering to both old and new codes may add cost and complexity to a maintenance facility upgrade, so garage owners should work with code officials as early as possible to encourage the use of the most current codes. The latest codes will be based on the most current research, and will ensure the highest standard of operability and safety.

Recent versions of the International Fire Code (IFC) have been harmonized with NFPA 2, so if your local authority having jurisdiction (AHJ) uses IFC, please refer back to the Code Requirements and Best Practices report for Hydrogen at www.altfuelgarage.org.

Vehicle Safety

The engineering and design of fuel cell electric vehicle (FCEV) compressed hydrogen storage systems (CHSS) ensure containment of the hydrogen fuel and prevent its accidental release. These designs follow component and system industry standards and include elements such as hydrogen compatible materials. Design criteria also includes 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 J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles is the industry standard for FCEVs, and has been harmonized with international vehicle standards. One test in that document defines the maximum allowable leakage rate from the CHSS during holds at maximum full-fill static pressure.

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 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 the solenoid(s), providing enough battery power to get to safety, and then shut off, 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

Hydrogen Emergency Response Training Resources   July 20, 2017 / 15

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

A key difference between hydrogen and liquid fuels is the flammability range of hydrogen - the flammability range for hydrogen is 4%–74% hydrogen in air, and the most easily ignited mixture is 29%. This is much greater than the 2% gas-to-air ratio for gasoline vapor, thus 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) is 99.99%. Because there is no odor, it is only detectable in air with hydrogen gas sensors.

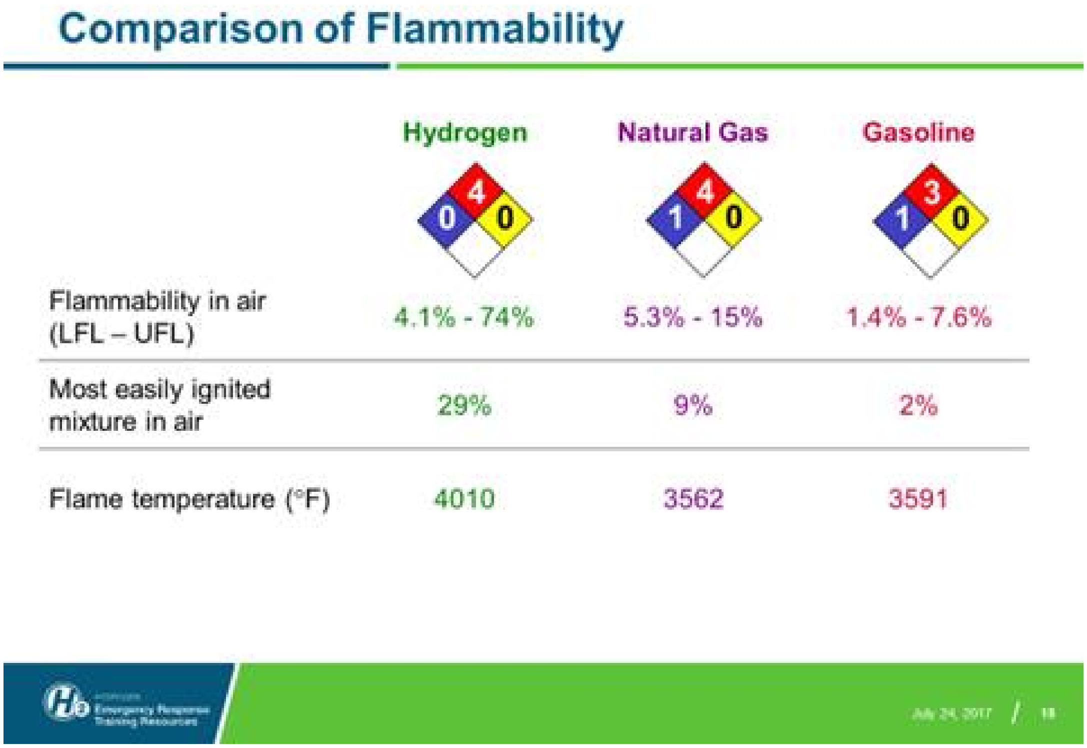

Figure 2: A comparison of hydrogen flammability characteristics to those of other fuels.

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, the gas detection systems do 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, it is the uncontrolled release that 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). Minor releases of hydrogen may also occur when disconnecting fuel system components in order to perform a repairs to the fueling system/CHSS.

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.

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 30A 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 is similar, and requires similar modifications in alternative fuel garages. The following are excerpts containing the definitions and exceptions concerning major and minor repair garages as presented in NFPA 30A:

> A major repair garage is defined as:
>
> > *A building or portions of a building where major repairs, such as engine overhauls, painting, body and fender work, and repairs that require draining of the motor vehicle fuel tank, are performed on motor vehicles, including associated floor space used for offices, parking, or showrooms.*
>
> A minor repair garage is defined as:
>
> > *A building or portions of a building used for lubrication, inspection, and minor automotive maintenance work, such as engine tune-ups, replacement of parts, fluid changes (e.g., oil, antifreeze, transmission fluid, brake fluid, air conditioning refrigerants, etc.), brake system repairs, tire rotation, and similar routine maintenance work, including associated floor space used for offices, parking, or showrooms.*

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. 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 Major Repair Facilities under 2015 version of NFPA 30A

To date, the majority of maintenance facilities that have been upgraded to service hydrogen vehicles already serviced vehicles that use conventional liquid fuels such as gasoline and diesel, and may 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 https://altfuelgarage.org .

Code Adoption Issues for Hydrogen-Only Garages

As previously mentioned, some jurisdictions have not adopted the latest version of NFPA 30A, 2018 edition. 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. The following sections describe how to comply with NFPA 30A and the IFC. Additional details on how to work with an AHJ to ensure the adoption of the most current compliance practices can be found in the best practices section later in this report.

Gas Detection

Hydrogen gas detection systems generally have at least 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. In a garage that services natural gas vehicles, this level will be different, and may require separate detection systems. A local AHJ may request that the two gasses trigger two different alarms so that first responders will know what actions to take to address any safety concerns in the event of an alarm.

Figure 3: Gas Detector, Photo Courtesy of Sierra Monitor

Ventilation

Ventilation and exhaust system design is another area where careful design considerations must be made. Hydrogen and natural gas are lighter than air fuels, and will rise in the event of a leak. Gasoline and diesel vapors, as well as propane, are heavier than air and tend to sink. In garages with fuels that are both lighter and heavier than air, ventilation intakes must be located both at the floor and at the ceiling in order to dilute and extract fuel vapors in the event of a leak. A local AHJ may allow the existing ventilation fans to be used as long as they are compliant with gaseous fuel use and equipped with automatic dampers to close off the flow from floor level and open the pickup points at the ceiling level.

An alternative to this configuration is to automatically reverse the flow of the ventilation system for conventional fuels so that outside air is drawn into the facility and discharged at floor level in order to provide dilution makeup air for the ceiling-mounted hydrogen ventilation system. Automatically reversing the ventilation system for the conventional fuels is a function of the gas detection and control system.

Unfortunately, ventilation volumes and strategies is one area where IFC and NFPA 30A differ slightly. Both agree that natural ventilation may be allowed at the discretion of the AHJ. However, if the AHJ elects to require mechanical ventilation, the IFC and NFPA differ in their calculations and control strategies. Knowing which code requirements the local AHJ follows is critical to determining which control strategy should be employed for your project.

NFPA 30A Ventilation Requirements

Figure 4: Louvered Wall

Ventilation effectiveness under NFPA 30A is also based on the total volume of the structure. NFPA 30A focuses on electrical sources of ignition in the area 18” below the ceiling classified as Class I, Division 2. The document states that electrical devices located in this area do not need to meet Class I, Division 2 specification if the structure has an effective continuous ventilation rate of at least 4 ACH. If the structure does not have a continuous ventilation rate of at least 4 ACH, existing electrical devices that do not meet the Class I, Division 2 specification must be relocated to below the classified zone. As an alternative to relocating the existing electrical devices, the devices may be replaced with electrical devices rated Class I, Division 2.

If the structure does not have a continuous ventilation rate of at least 4 ACH, existing electrical devices that do not meet the Class I, Division 2 specification must be relocated to below the classified zone. As an alternative to relocating the existing electrical devices, the devices may be replaced with electrical devices rated Class I, Division 2. This is discussed in more detail in the next section.

NFPA does not specifically address operational parameters of ventilation systems in facilities where major hydrogen vehicle maintenance and repair work is to be performed. Generally, fire marshals and other AHJs tend to refer to the IFC operational guidelines mentioned below: 1) continuous operation, 2) continuous operations while occupied via interlock with lighting, or 3) detection system-triggered. If the third operational parameter is selected, then all electrical devices in the "ceiling zone", including the detection system, must be removed, relocated, or replaced with devices rated Class I, Division 2.

IFC Ventilation Requirements

The IFC deals with ventilation requirements in section 2311.7.1, which states that garages used for the repair of lighter-than-air fuel vehicles should have an approved mechanical ventilation system. One exception to this requirement is a garage with natural ventilation, and a code official may approve other equivalent strategies.

The IFC further states that facilities in which major lighter-than-air vehicle repairs are to be performed shall be ventilated at a rate of one cubic foot per minute (CFM) for each 12 cubic feet of structural space or, stated another way, five air changes per hour (ACH). Note that this calculation is based on the total volume of the structure, not square footage of the floor or ceiling.

Furthermore, the code provides three options for controlling ventilation: 1) continuously, 2) continuously while the space is occupied, via interconnection with the lighting circuit, or 3) upon demand for dilution ventilation triggered by the hydrogen detection system. A description of each method for operation and control of the ventilation system follows:

1. For ventilation systems that operate continuously, the fans are constantly running. Continuously operating ventilation systems are most commonly employed in warmer climates where ambient air does not require conditioning for worker comfort. In colder climates where the air inside the facility is heated for worker comfort, the cost of heating "once-through" air will likely be prohibitive. Continuously operating ventilation systems require electrical power for the fans and may entail increased fan maintenance costs.
2. For ventilation systems activated by interconnecting with the facility lighting controls, the ventilation system is interlocked with the lighting circuit so that the fans operate whenever the facility lighting is switched on. The applicable codes and regulations assume that interior lighting will always be activated whenever a maintenance facility is occupied. Similar to the continuous ventilation system, the associated high heating costs may make this type of system cost prohibitive in colder climates.
3. For ventilation systems controlled using a combustible-gas-detection system, the fans are only activated when the sensors detect the presence of hydrogen (manual operation is also possible). It is important to note that while a gas detection system is required for proper operation of this type of ventilation system, gas detection systems are not required for all hydrogen vehicle maintenance facilities.

The potential energy impacts of continuous operation and tempering of the entire volume of air in a facility leads many fleets, particularly those in cold climates, to elect to use hydrogen detection as the triggering mechanism. With a hydrogen detection system strategy, the installation cost of larger ventilation systems is often comparable with the continuous ventilation strategy, but the operating cost is greatly reduced. Various approaches to ventilation system design are discussed later in this section. Proper specification, design, and installation of hydrogen detection systems are discussed later in this document.

Electrical Wiring and Equipment

Electrical wiring, lighting, and electrical appliances all present potential ignition sources to a release of lighter-than-air fuels within a maintenance facility. Sparks are a cause for concern, and can generated by an abnormal condition such as a short circuit within a wire conduit or junction box or during normal operation of an unprotected electric motor. Additionally, unsealed conduits may also provide a means of gas migration from one portion of the facility to another. Before modifying a maintenance facility to service hydrogen fuel vehicles, the existing design must be taken into consideration so that each of the safety risks are mitigated.

NFPA 30A classifies all areas within 18 inches of the ceiling as Class I, Division 2 when lighter-than-air fuels are used. This means that wiring, lighting, fans, and other electrical appliances may need to be relocated if natural gas vehicles are serviced.

In these cases, the number of conduits or junction boxes that are located in the hazardous zone may be large enough that relocating each of them is unreasonable because of the cost or complexity. There is precedent in the natural gas industry for obtaining Class I, Division 2 status if conduits or junction boxes are provided with seal-offs, which create a physical barrier that minimizes the passage of gases from traveling freely through the conduit and will prevent the migration of flammable gas into the conduits (see *ecmweb.com/content/sealed-fittings-why-are-they-necessary*). The use of seal-offs in lieu of relocation must be approved by the AHJ.

Figure 5: Relocating multiple conduits shown here would be costly and complex. Photo courtesy of Gladstein, Neandross & Associates, NREL

According to NFPA 30A, low-voltage wiring and containing conduits may be exempt from the Class I, Division 2 requirements if they are determined to be non-sparking. Examples of potentially exempt low- voltage wiring and containing conduits include loudspeaker and security camera wiring; wiring used for data transmission; alarms; and wiring used for similar applications (Figure 6). However, the AHJ must approve the low-voltage wiring; otherwise, it may be considered hazardous and subject to Class I, Division 2 requirements.

Figure 6: Low-voltage wiring and devices. Photo courtesy of Gladstein, Neandross & Associates, NREL

Figure 7: A typical overhead crane. Photo courtesy of Gladstein, Neandross & Associates, NREL

Space Heating

NFPA 30A Sections 18.5.1-18.5.6 discuss various requirements of heat-producing appliances.

Maintenance facilities in most locations require some form of space heating during the winter months in order to ensure worker comfort. Heat may be provided using a forced air central heating system that warms and recirculates the air throughout the maintenance facility or utilizes an air-to-air heat exchanger. Localized space heating is another method for heating a maintenance facility. Localized space heating is typically accomplished using gas-fired infrared direct radiation or tube-type heaters, gas- (or propane-) fired devices equipped with fans, or electric infrared heating units. Most of these types of heating apparatus are mounted to either the walls of the facility or suspended from the ceiling. Portable heaters used to provide supplemental heat in specific areas are typically located on the floor of the facility.

All heating systems except forced-air types present specific challenges for hydrogen vehicle maintenance facility compliance. Codes and regulations require that specific conditions be met for both heaters and heating systems. Classification of the maintenance facility as either a major repair or minor repair category is also an important factor.

For major repair garages, NFPA 30A states that *"open flame heaters or heating equipment with exposed surfaces having a temperature in excess of 750 °F shall not be permitted in areas subject to ignitable concentrations of gas."* Because it is generally not possible to delineate *"areas subject to ignitable concentrations of gas,"* for practical reasons all heating devices in a major repair garage are subject to this limitation.

With the exception of forced air central heating, each of the heaters listed above provides a potential ignition source in the event of a hydrogen release. For flame-fired heaters it is, of course, the flame itself. For gas-fired infrared direct radiation heaters, even for those where the flame is contained within the heating elements, the surface temperature of the radiant heating elements may exceed 750°F, thereby presenting a potential ignition source. Electric heaters that employ heating coils and a fan may or may not be compliant depending upon the operating temperatures reached by the heating coils. The figures below present various types of space heating equipment commonly found in maintenance facilities that would need to be replaced, modified, or eliminated.

Figure 8: Gas-fired infrared tube-type heater. Photo courtesy of Gladstein, Neandross & Associates, NREL

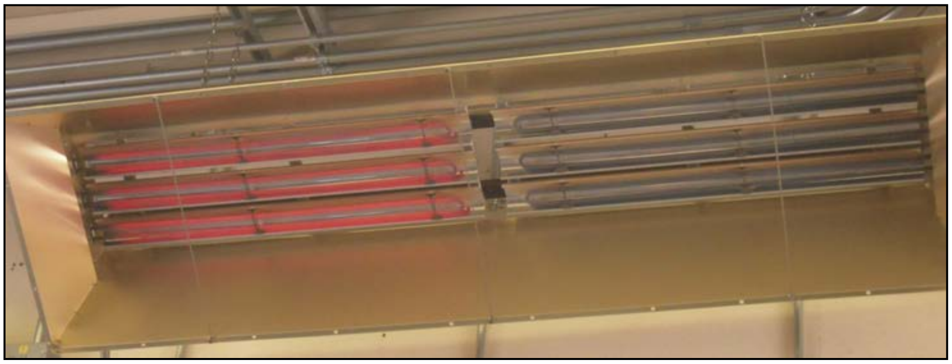

Figure 9: Electric infrared radiant heater. Photo courtesy of Gladstein, Neandross & Associates, NREL

Figure 10: Floor-mounted portable propane heater. Photo courtesy of Gladstein, Neandross & Associates, NREL

Figure 11: Gas-fired fan heater. Photo courtesy of Gladstein, Neandross & Associates, NREL

Compliance with the codes and regulations can be achieved by simply removing the non-compliant heating units and/or replacing them with units that are compliant. Gas-fired and electric infrared tube-type radiant heaters (Figure 8, Figure 9) are commonly employed in maintenance facilities that service conventionally fueled vehicles. Manufacturers of these types of heating systems now manufacture units that have contained flames and surface elements that do not exceed 750°F. In this instance, modifying the maintenance facility's heating system to be compliant with the codes and regulation for servicing hydrogen vehicles would only require replacement of the heater(s). However, it is essential that the supply air and exhaust flow from gas-fired infrared tube-type radiant heater(s) be completely contained and directed to and from the outside of the maintenance facility. This can be accomplished by routing the inlet air and exhaust air through the facility wall or roof.

Portable propane heaters (Figure 10) should be prohibited from use. Gas-fired fan-type heaters (Figure 11) are not compliant because of their inherent open flames and must be replaced with units that meet the codes. This includes gas-fired fan-type heaters in which the pilot light is the only open flame.

Although forced air heating systems do not present direct hazards as potential ignition sources for combustible gas, modifications may be required to their air flow systems. However, such continuous ventilation will extract warmed air from the building, and such single-pass heating may be cost prohibitive, particularly in colder months.

Hydrogen Detection, Control Systems, and Alarms

The primary functions of a combustible gas detection and alarm system are to:

- Provide early warning to occupants that a hydrogen gas release has occurred
- Initiate actions to eliminate potential ignition sources
- Initiate actions that provide conditions to promote quick dilution of the concentrated gas to levels below the LFL.

Combustible gas detectors used in Hydrogen vehicle maintenance facilities are designed and calibrated to measure hydrogen concentrations as a percentage of the LFL. The LFL concentration for hydrogen in air is 4.1%. Gas detectors read from 0%–100% of the LFL, which means that a detector that displays a reading of 100% would indicate that the actual concentration of hydrogen in the air is only 4%. Using this scale, hydrogen detectors can be programmed to provide alarms at any concentration.

NFPA 30A, Section 7.4.7.1 states that a detection level of 25% of the LFL (1% actual hydrogen in air) should be used to initiate alarms and other actions. The use of two gas detection levels rather than a single value has gained wide acceptance within the fire protection community and, with AHJ approval, may be incorporated into the operational design. By using two levels (i.e., 20% and 40% of the LFL), preliminary detection (20%) occurs earlier so that protective actions can be initiated, followed by more extreme actions if concentrations reach the second level. A two-level approach is recommended because it greatly reduces the incidence of “nuisance” alarms while still ensuring personnel and facility safety. It is important to note that a two-level detection concept must be approved by the AHJ before it can be used at a vehicle maintenance facility.

Combustible gas detectors inside a vehicle maintenance facility should be located near the highest point of the structure’s ceiling. However, it is also common for gas detectors to be installed at intermediate locations to “intercept” the likely path that a vapor release would take as it rises to the high point. The number, location, and spacing of detectors must be determined by a licensed design engineer and approved by the AHJ. Figure 12 displays a ceiling-mounted, combustible gas detection head.

Figure 12: A ceiling-mounted combustible gas detection head. Photo courtesy of Sierra Monitor.

Because the gas detectors are located on or near the structure's ceiling, it may be useful to consider detectors that are equipped with a calibration means that does not require direct access to the unit. Gas detectors are calibrated by directing a calibration trace gas toward the unit. This is usually accomplished by connecting tubing through which calibration gases can be directed to the unit.

Figure 13: Calibration gas for detector calibration.

If a two-level hydrogen detection approach is used, the alarms connected to the detection system controls will activate first at the lower level, then again when the LEL reaches the higher level. The two levels of 20% and 40% of LEL have been widely accepted by AHJs. However, the actual values, which can be set by the user, must be approved by the AHJ. For this type of system, it is typical for a beacon to be illuminated with a specific color indicating each level, and the alarm horn to be activated. Alarm notification devices should be placed throughout the interior of the vehicle maintenance facility so that personnel in the structure can see them regardless of parked vehicles or other equipment inside. In addition, a similar alarm beacon and sound panel should be located outside the building and in the maintenance office. Some AHJs and facility managers also require alarm beacon and sound panels to be located within adjacent offices and administrative areas. Common alarm status lights and horn panels are shown below in Figure 12.

Figure 14: Examples of alarm status lights and horn panels (external and internal). Photo courtesy of Gladstein, Neandross & Associates, NREL

It is recommended that the combustible gas detection system be kept independent from the facility's fire detection and alarm systems. In addition, it is recommended that the two systems have distinctly different colored lights and alarm sounds.

Combustible gas detectors merely read the hydrogen concentration in the air. Because of this, a control system is required for translating and interpreting the readings. As described previously, the three primary functions of the control system are to alert personnel of the existing conditions, increase ventilation within the structure, and eliminate possible ignition sources.

Alerting personnel is accomplished by means of the alarm beacons and sound horns. The control system can be programmed to activate the ventilation fans, open the facility doors, and/or activate any other types of secondary ventilation equipment in order to increase air flow. The control system eliminates potential ignition sources by turning off (i.e. shunt tripping) the potentially hazardous electrical circuits and heating appliances within the maintenance facility.

As part of the retrofit process, selected electrical circuits should be modified so that shunt trips are provided on all non-critical electrical circuitry. It is recommended that the shunt trips be activated only if the system detects a gas concentration of 40% LFL rather than the early-warning 20% LFL. All electric circuits within the maintenance facility should be fitted with shunt trips except the following:

- 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.).

Table 1: Possible Series of Actions Based on the Two Suggested Levels of Detection

	Gas Concentration Level		
Condition	**Normal**	**20% LFL**	**40% LFL**
Operation Lights – Green	On	Off	Off
Operation Lights – Amber	Off	On	Off
Operation Lights – Red	Off	Off	On
Warning Horns	Off	On – Level 1	On – Level 2
Strobe Alarms	Off	On – Level 1	On – Level 2
Supervisory Advisory	No	Yes	Yes
Fire Department Callout	No	No	Yes
Ventilation Fans	Manual	On	On
Roll-Up Doors/Louvers	Manual	Open	Open
Automatic Gas Valve	Open	Open	Closed
Shunt Trip Building Loads	No	No	Yes
Automatic Reset of System if Fault Clears	N/A	Yes	No – Manual Reset Required

A master gas detection system control panel that displays system and detector status, historical information, and other variables should be located in the maintenance supervisor's office or other selected location. This programmable device is essentially the "brains" of the gas detection system. In addition, it is recommended that a status panel be located outside of the building. This will allow emergency response teams to ascertain the internal conditions without having to enter the structure. A typical gas detection system control panel is displayed in Figure 15.

Figure 15: A combustible gas detection system control panel. Photo courtesy of Gladstein, Neandross & Associates, NREL

In the unlikely event that the gas detection system fails, the codes and regulations require that similar actions be initiated that would occur in the event of a release. These actions include activating the ventilation system (fans and makeup air), deactivating the heating systems, closing any hydrogen source valves, and sounding and lighting the alarms. Initiating these functions can be performed by accessing the gas detection system controller.

Some AHJs and/or insurance underwriters may require that back-up power be available in the event of a power failure. Back-up batteries are usually selected to provide power to the gas detection and alarm system. However, batteries lack the power and duration needed to run other critical pieces of equipment, such as exhaust fans, makeup air, etc. To ensure there is sufficient power to operate all critical equipment, a stand-by generator equipped with an automatic transfer switch is typically employed. In the event of a main power failure, the standby generator will automatically start and begin providing power to the maintenance facility. It is important to note that obtaining the necessary permits for an emergency generator may prove difficult in some regions due to air pollution concerns associated with engine exhaust. A typical emergency generator installation is shown in Figure 16.

Figure 16: A typical emergency generator installation. Photo courtesy of Gladstein, Neandross & Associates, NREL

In the event of a main power failure, it is unlikely that work will continue to be conducted within the vehicle maintenance facility. With all electricity (except the battery-powered detection and alarm system components) disconnected, it may be sufficient to merely evacuate the building and wait until the main power is restored. The gas detection system controls can be programmed to shunt-trip unnecessary equipment as a precaution. Therefore, if a leak occurs while the building is evacuated, potential ignition sources will be eliminated. The gas detection system is designed to alert personnel and prevent anyone from entering the maintenance facility until main power is restored.

It is essential that the gas detection, control, and alarm system be designed by an engineer registered within the state in which the facility is located. A registered engineer will be able to select equipment to ensure compatibility of components, evaluate operating conditions, and determine required functions. Approval must be obtained by the AHJ prior to preparing final designs and ordering equipment.

As noted above, the gas detection and control system is fully integrated with several functions within the vehicle maintenance facility, including shunt trips, activation of fans, opening of facility doors and other makeup air ventilation, and sounding of alarms. As an early step in the design process, a plot plan (layout) of the facility depicting the location of these functions and the hardware used to support them should be prepared for internal use and for preliminary approval by the AHJ.

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 (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 (minor repair facility) given that the fuel supply container is defueled to 200 scf [1] and the 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).

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.

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. 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 tends to 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.

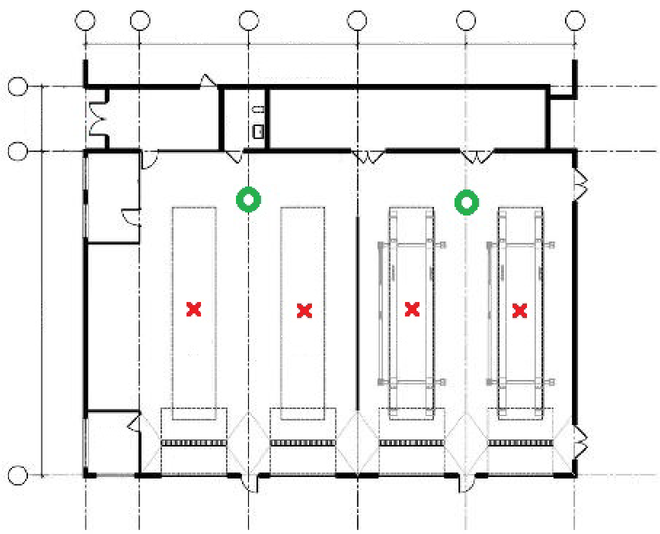

Figure 17: Diagram of recommended gas detector placement between vehicle bays.

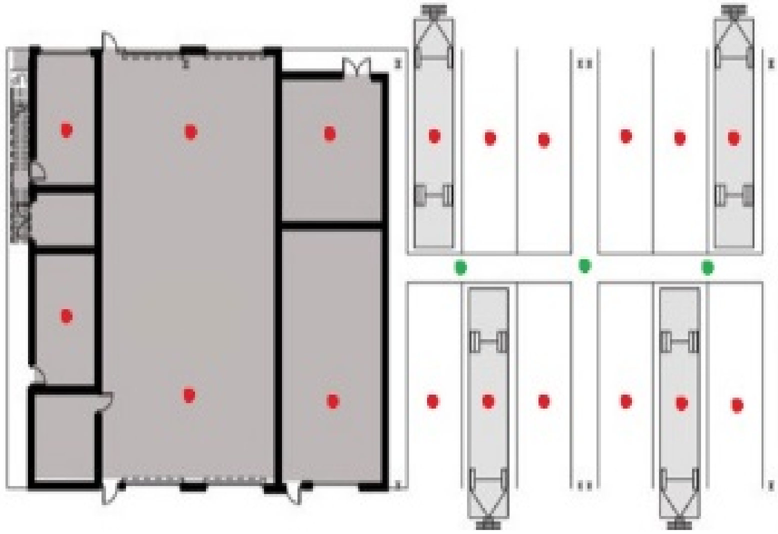

Figure 18: Diagram of recommended gas detector placement between rows of vehicle bays.

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 methane 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)

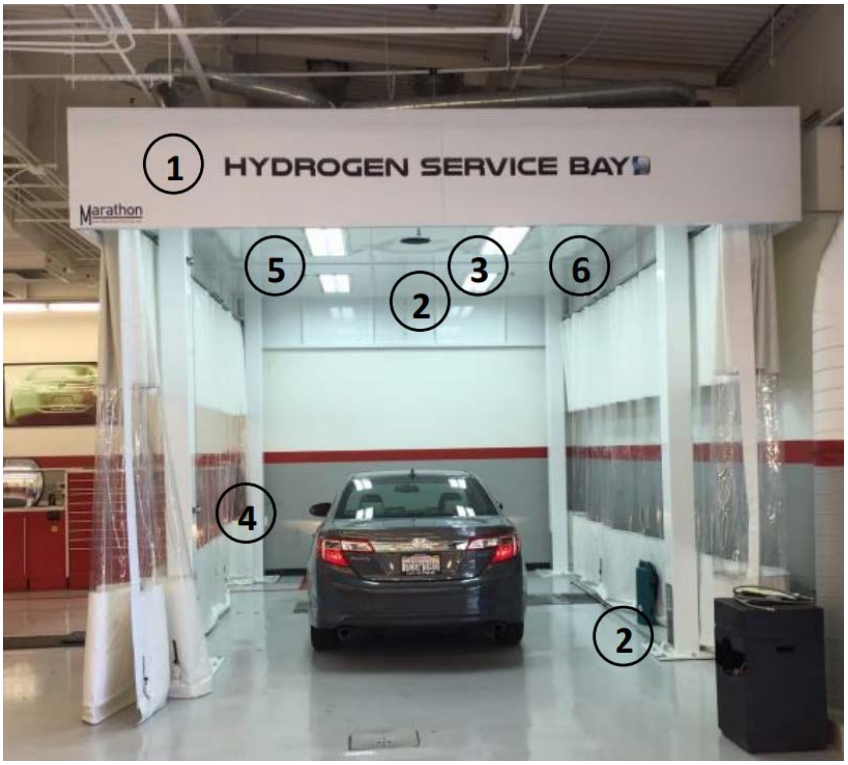

Figure 19: Hydrogen Service Bay, Annotation descriptions below. MarathonSprayBooths.com

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 4 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

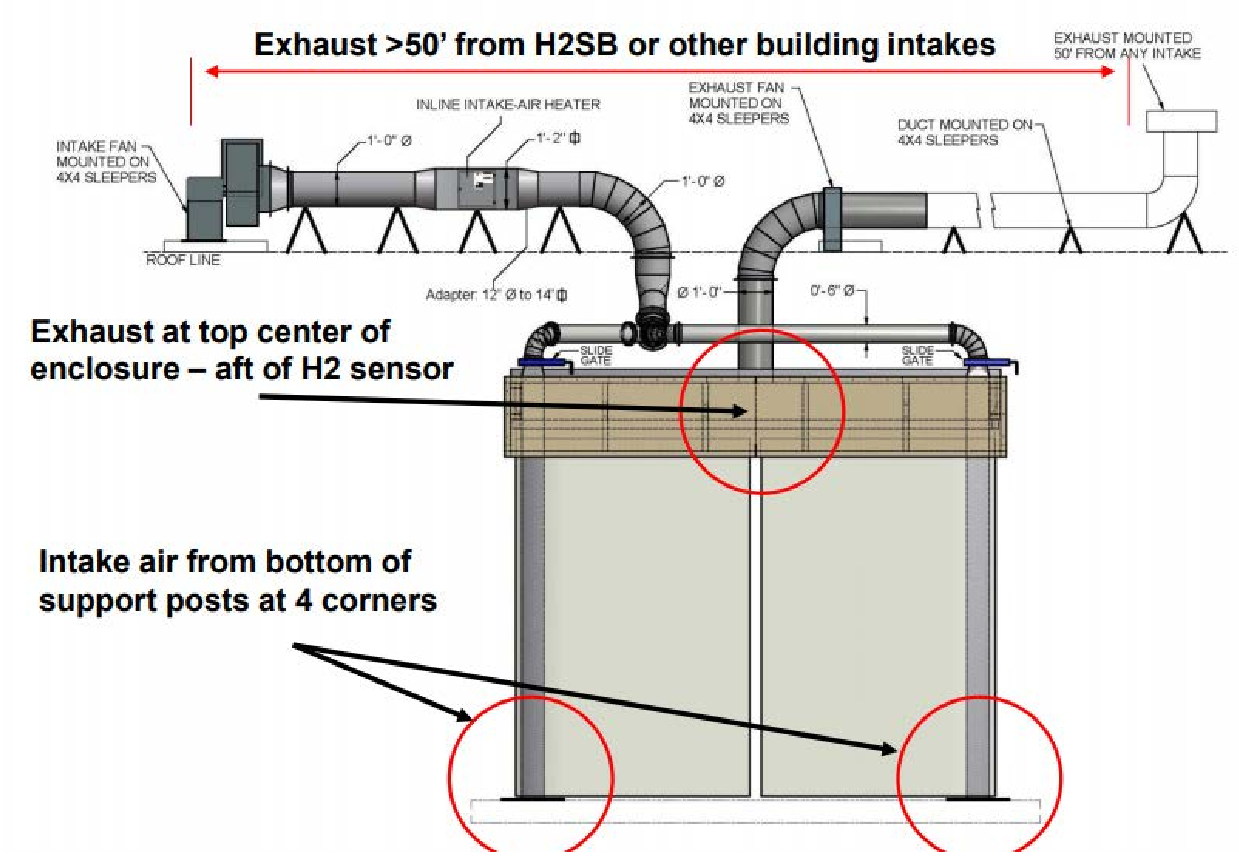

Figure 20: Exhaust considerations with the Hydrogen Service Bay. MarathonSprayBooths.com

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

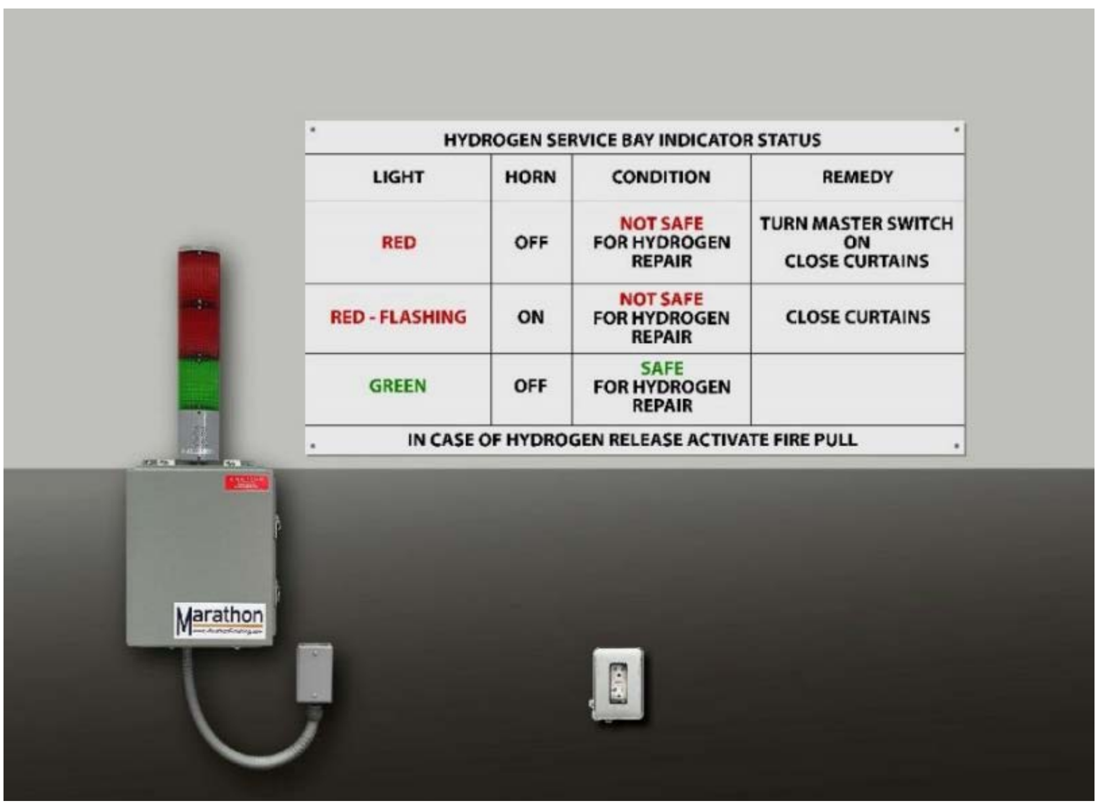

Figure 22: Visualization of an alarm display with adequate signage. MarathonSprayBooths.com

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 generally 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 2: Properties of Alternative Fuels

Compound	Formula	Density (lb/ft³) 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	-	-	-