TRAINING MANUAL January 22, 2019



Compressed **HYDROGEN**

Gaseous Hydrogen (GH₂)

Vehicle Maintenance and Storage Garage Modifications: Requirements and Best Practices





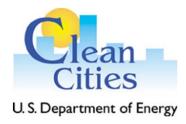


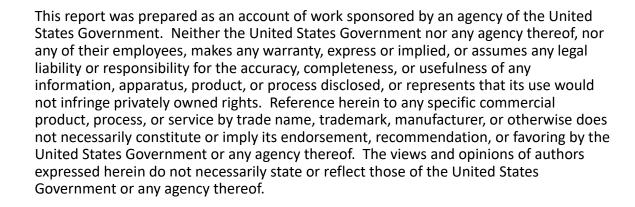




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Acronyms

| Term: | Definition: | Term: | Definition: | |
|------------|---|------------|--|--|
| ACH | Air Changes per Hour | NEC | National Electrical Code (NFPA 70) | |
| AHJ | Authority Having Jurisdiction (the regulatory body | NFPA | National Fire Protection Association | |
| | with the authority to mandate design) | NG | Natural Gas | |
| CNG | Compressed Natural Gas | NGV | Natural Gas for Vehicles or Natural Gas Vehicle | |
| CT | Current Transformer (used to monitor the current | | (depending on context) | |
| 54.05 | on an AC motor) | PM | Preventative Maintenance | |
| FACP | Fire Alarm Control Panel—this is the building fire panel | PRD | Pressure Relief Device—a device mounted on vehicle CNG fuel tanks to relieve pressure inside a | |
| H_2 | or GH ₂ -Gaseous Hydrogen | | tank when exposed to an external fire. This device | |
| HVAC | Heating Ventilation and Air Conditioning | _ | is thermally, not pressure, activated. | |
| IFC | International Fire Code | PSI | Pounds per Square Inch | |
| IMC | International Mechanical Code | PSIG | Pounds per Square Inch Gauge (atmospheric pressure is 0 psig) | |
| IR | Infrared | RNG | Renewable Natural Gas—gas produced by | |
| LEL or LFL | Lower Explosive Limit—also known as LFL or Lower | | anaerobic digestion of biomass material | |
| | Flammability Limit | SCF | Standard Cubic Feet (the volume of gas within one | |
| LNG | Liquefied Natural Gas | | cubic foot at atmospheric pressure and 60°F) | |
| LPG | Liquefied Petroleum Gas—commonly called Propane | TEFC | Totally Enclosed Fan Cooled electric motor | |
| N 4 A L L | • | UEL or UFL | Upper Explosive Limit—also known as UFL or Upper Flammability Limit | |
| MAU | Make-up Air Unit—a fan and heat source for heating a building | | | |

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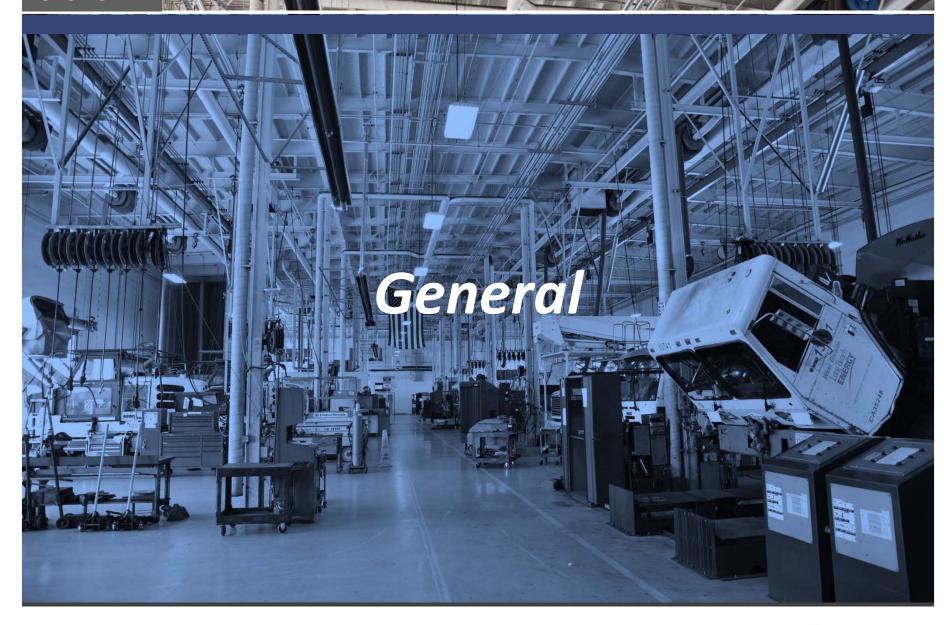
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Care in the Application of this Document

This document is focused on the upgrades that are required and recommended with the introduction of gaseous-fueled vehicles into a conventional-fuel vehicle maintenance or storage/parking garage. This document is focused on nonresidential applications. Building upgrade costs and scope are much more variable than fueling station costs and can approach the cost of fueling facilities. Upgrade costs are influenced by the type, age, condition and size of the structure, as well as the local climate and fleet operating requirements. The potential high cost and variability make it essential that Owners. Consultants, and AHJs have a thorough understanding of code requirements, best practices, and what adds safety, not unnecessary cost, to an upgrade.

This document addresses only requirements that are in addition to any conventional-fuel requirements. There may also be additional requirements not outlined herein due to the use of other fuels in the facility. The reader and fleet owner shall note that their facility may not be fully compliant with current conventional-fuel codes and thus there may

be additional upgrades not directly related to gaseous fuels that may be required to ensure a fully codecompliant facility. Additional guidance on current conventional-fuel vehicle codes can be found in the LPG Training Manual in this series.

This document is not a comprehensive design specification. Rather, it is intended to provide the reader with an overview of the requirements and industry best practice typically implemented in today's gaseous-fuel vehicle garages.

The information herein describes the most common upgrades implemented in gaseous-fuel vehicle garages. Best practices often lead codes by several years, so it is advisable to follow both current codes and best practices. The upgrade requirements herein may not be exhaustive for all facilities. Some facilities may require additional or different upgrades to ensure safety. Every garage and fleet are different, so it is incumbent on the reader and the Owner of any facility to secure

experienced professional assistance to determine what upgrades are required to ensure the safety of their project.

The applicable codes for garage upgrades are referenced herein and paraphrased to assist the reader in understanding their application. The reader, designer, and facility Owner are required to purchase original codes and read the full text to gain a full understanding of the code requirements and any nuance that may affect their garage upgrade project. It should also be noted that the recommendations contained herein are based on current codes: however, in some cases codes do not address all safety issues adequately. The reader shall ensure that any code updates are incorporated into their project.

The recommendations contained herein apply to the areas of the buildings that have vehicle occupancy only. This document does not include any recommendations on fueling station design or on indoor fueling and does not include facilities where indoor fueling occurs.





The Purpose of Upgrades

Why We Upgrade Facilities

Upgrades are required to garage facilities not because gaseous fuels are less safe than conventional fuels, but because they behave differently than conventional fuels. A vapor plume from a gaseous-fuel leak may migrate to different locations in a building than a liquid fuel spill, so it is important to understand these differences and manage the risks as we would with conventional fuels. Flammability requires three conditions: fuel, air, and an ignition source. The upgrades required and recommended herein are intended to reduce the possibility that these three elements occur simultaneously in the event of an accidental release of gas. It is not possible to remove the air, but it is possible to reduce the potential ignition sources and limit the amount of time and control the location that fuel is present. Upgrades are intended to provide a safe working environment while preserving the functionality of the facility.

Hydrogen Garage Experience

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There are very few upgraded hydrogen vehicle garages that can be used as exemplars and cited for industry experience. For this reason, hydrogen garage upgrade design borrows heavily from CNG experience. Codes and this manual will apply the experience gained through the upgrade of several hundred CNG garages as a baseline for hydrogen garage upgrades with minor adjustments to address differences in the fuels.

Workarounds

Some fleet Owners propose to use workarounds rather than upgrading their facility. Proposals include:

- 1. The easiest and safest workaround is to contract to a maintenance provider who has already upgraded their facility. All major, and perhaps minor, repairs can be done at the third-party location, and vehicles can be parked outdoors at the fleet garage.
- 2. When the maintenance need is <u>short term</u>, or the number of lighter-than-air gas vehicles is limited, some Owners manually shut off and lock out heating equipment, open all doors, and activate all fans when gaseous-fuel vehicles are in the garage. This approach may provide a safe short-term answer to this need (depending on the ventilation in the garage); however, the lockout requirement must be rigidly enforced. This approach is more practical in warm climates than cold. This is not a long-term alternative to upgrading the garage.
- 3. Closing the tank valves every time the vehicle enters the garage is another proposal, but it will be a tedious practice. This is actually an Owner recommendation when the vehicle is in the garage overnight. Note that this does not ensure that a release will not happen.
- 4. Defueling is a practice that is impractical for normal maintenance operations but is required for certain repairs (see the section on defueling in this document). Defueling should be used only when this is the only safe way to work on a vehicle.





The Purpose of Upgrades

Why are Upgrades Alone Not Sufficient?

The Author of this document has extensive experience investigating the root cause of a number of gaseous-fuel vehicle, station and facility incidents that have occurred over the past three decades. It is the Author's observation that most incidents occur with three contributing factors (in random order):

- 1. A component manufacturing or design defect.
- Insufficient or ineffective maintenance of equipment.
- 3. User error.

Training

User error is often the largest single contributor to the likelihood of an incident, and in many ways, it is the easiest to control. Fleet Owners can and should ensure that personnel that interface their fleet's operations be appropriately trained then drilled to reinforce the training. Automatic and inherent safety features that are required or recommended to garage facilities will certainly enhance the safety of the facility and its users, but it is critical to understand that no level of upgrade can prevent an incident if personnel lack proper training. Employers have confidence that their staff will use common sense when working around their facility; however, common sense comes from a thorough understanding of the risks and the likely outcome of the employee's actions—training and experience provide this understanding.

Fleets must develop detailed Standard Operating Procedures (often called SOPs) which will be used as the basis for the training and drilling mentioned above. These procedures must address all credible operational risk scenarios related to the building, vehicle, fueling, and defueling. The operating procedures provided later in this manual are abbreviated to a single sentence to provide a sample of the issues fleets must address—the procedures provided herein are not sufficiently detailed to meet this need. Operating Procedures must also be tailored to the specific vehicles and facility in which the fleet operates.









Properties of Hydrogen Gas



 $\begin{array}{c} \text{Hydrogen} \\ \text{H}_2 \\ \text{H = Hydrogen} \end{array}$

| | Property | Value |
|----|---|--|
| 1 | Constituents | 100 percent Hydrogen (H ₂). |
| 2 | State | Gaseous at all pressures in vehicle system. In stations without hydrogen generation, cryogenic liquid is stored then pumped to high pressure then vaporized before dispensing to vehicles. |
| 3 | Specific Gravity (weight vs. air) | 0.0696 (average 7 percent of weight of air at same temperature and pressure)— hydrogen rises quickly in air. |
| 4 | Flash Point (temperature where fuel vaporizes from liquid form) | Approximately -423°Fahrenheit. |
| 5 | Autoignition Temperature | Approximately 932° to 1080°Fahrenheit. |
| 6 | Flame Color | Blue to invisible. |
| 7 | Flammability range in air at atmospheric pressure | Lower Flammability Limit (LFL)~4 percent. Upper Flammability Limit (UFL)~76 percent. |
| 8 | Odor | No odor and cannot be odorized as odorant will "poison" the vehicle fuel cell. |
| 9 | Toxicity | Non-toxic, but asphyxiant in sufficient concentration. |
| 10 | Water Content | Highly dependent on source—can range from zero to saturated. |
| 11 | Source | Steam reforming of natural gas (95% from this source) or methanol. Electrolysis of water. |



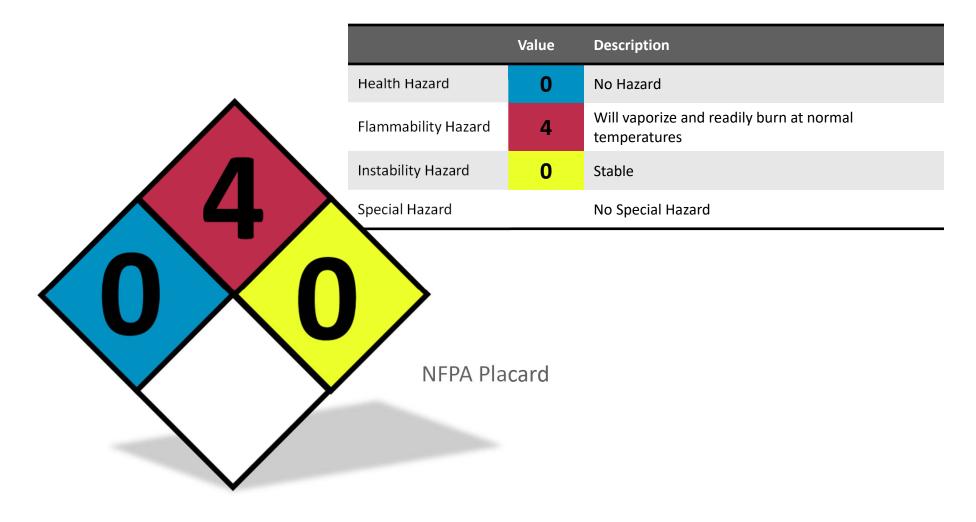
Properties of Compressed Hydrogen Gas

| | Property | Value |
|---|-------------------------------|--|
| 1 | General | Compressed hydrogen gas. |
| 2 | State | Gaseous at all pressures in vehicle system. In stations without hydrogen generation, cryogenic liquid is stored then pumped to high pressure then vaporized before dispensing to vehicles. |
| 3 | Nominal Pressure in Tank | Nominally 5000 psig and 10,000 psig. |
| 4 | Density | Approximately 179 cubic feet per pound. |
| 5 | Energy Comparison to Gasoline | 2.20 pounds of Hydrogen=1 gallon of gasoline. |
| 6 | Energy Comparison to Diesel | 2.46 pounds of Hydrogen=1 gallon of diesel. |
| 7 | Odor | No odor and cannot be odorized as odorant will "poison" the vehicle fuel cell. |
| 8 | Pump Octane Number | ~130 |
| 9 | Water Content | Less than 1 pound of water per million cubic feet of gas $(1\#H_2O/MMSCF)$ —requirement varies with local climatic temperature. |

Hydrogen Vehicle Tank or Cylinder



Properties of Compressed Hydrogen Gas





Fast Leak—Vertically Upward

Leak Behavior

Hydrogen gas has 7 percent of the weight of air and will therefore rise immediately.

Slow Leak

Under a slow leak scenario, such as a fitting leak that is not audible, a properly ventilated GH₂ vehicle garage should dilute and exhaust the leak without risk of incident. In fact, a very small leak will likely not be detected by a building combustible gas detection system. For this reason, it is good practice to check for leaks at Planned Maintenance (PM) intervals.

Fast Leak—Vertically Upward

Under a fast leak scenario, such as a serious fitting leak or component failure that results in an audible leak, the gas will have significant jet force and will release in whatever direction it is pointed. In a vertically upward leak scenario, the gas plume (jet and cloud) will quickly reach the ceiling, where it will collect and form an explosive cloud unless properly exhausted.

For this reason, combustible gas detection and exhaust fans are placed at the ceiling area of the garage.

Leak Behavior

Hydrogen gas has 7 percent of the weight of air and will therefore rise immediately.

Fast Leak—Vertically Downward (or Horizontally)—Phase 1

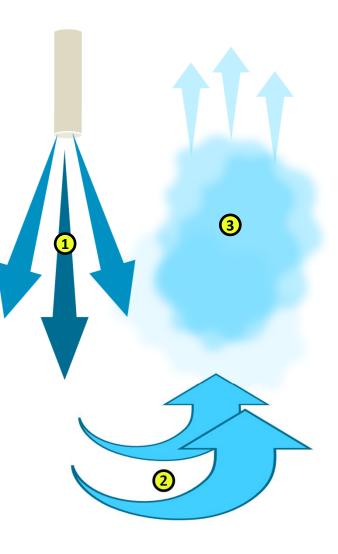
Under a fast leak scenario, such as a serious fitting leak or component failure that is audible, the gas will have significant jet force and will release in whatever direction it is pointed. In a vertically downward leak scenario, the gas plume (jet and cloud) will first vent downward (1). This scenario is also true for a horizontal release—the gas will first travel in the direction the jet is pointed.

Fast Leak—Vertically Downward (or Horizontally) —Phases 2 and 3

When the jet loses its momentum, it will slow to a stop then change direction (2) and rise.

The plume or cloud will quickly rise toward the ceiling (3).

For this reason, GH_2 garages include air introduction near the floor with exhaust at the high point. This quickly dilutes and pushes a gas plume to the detection and exhaust systems.



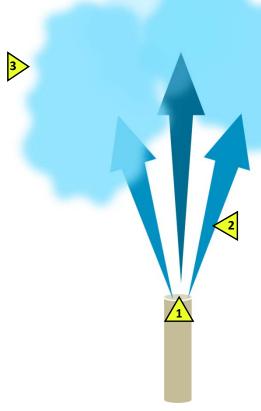
Flammable Range

The flammable range of hydrogen is between 4 percent (LFL) and 76 percent (UFL) in air by volume. Below this range the mixture is too lean to support combustion, and above this range the mixture is too rich to support combustion. This wide range of flammability is a characteristic that results in almost any amount of hydrogen in the air being flammable. There is a common misperception that if very high air changes are provided in a garage, a gas release will be diluted and kept below the LFL.

The fallacy of this belief is that the concentration is 100 percent natural gas at the source and at some point outside the leak area the concentration of gas in air is 0 percent; therefore, by definition, there is some point at which a flammable mixture exists. The location of the flammable mixture is unknown and is dynamic. Gas will mix and dilute with air and this mixture will tend to rise.

Codes focus on the 18 inches immediately below the ceiling, however best practice is to look at all ignition sources in the overall space and minimize these. Best practice includes eliminating the ignition sources between the vehicle roofline and the ceiling as this is the most likely area to have a gas release. More guidance will be given on this in the electrical section of this manual.

Since air that is distant from the release will be at 0 percent gas in air concentration, by definition, a flammable mixture will <u>always</u> exist in the presence of a leak.



Hydrogen Gas Release

- 1. At the center of the release, the gas will be 100 percent gas in air.
- 2. Concentration of gas in air reduces as gas moves away from the source.
- 3. At the perimeter of all releases, the gas will be in the flammable range.





Potential Causes of a Release

Releases can be caused by a number of personnel or equipment failures. The most common releases are generally small and may result from a manufacturing defect or wear and tear resulting in a fitting that becomes loosened, or an O-ring leak. The most common small leak is the check valve in the high-pressure fill receptacle or tubing—this can become dirty due to the lack of a fill receptacle cap. It is very important that receptacle caps be used between each fill to ensure that dirt does not enter the vehicle fueling system.

Fast leaks are very unusual and would result from a failure of a pressure connection or O-ring, or from human error during repair. One other cause of fast leaks that was once common in the industry, but has now become very rare, is an unprovoked release from a PRD. Pressure Relief Devices or PRDs are provided on each vehicle tank and often there is more than one per tank. Although these devices are intended to relieve pressure, they are thermally, not pressure, triggered. PRDs are designed to fully vent down the vehicle tank(s) in the event of a vehicle fire. Many of the unprovoked releases that happened years ago resulted from the presence of water on the vent side of the PRD. When this water froze (cold climate), the valve was damaged and released gas once the ice plug melted. For this reason, all GH₂ fleets should have an inspection of the PRDs and vent tubing in their vehicle PM plan. It should be noted that a few vehicle models also include a "burst disc" device that triggers on pressure alone. Fleet operators should confirm what type of safety devices are included in their vehicles, as this can affect the likelihood and conditions necessary for a release. Some additional PRD information:

1. PRDs are installed on the vehicle tanks in a way that prevents them from being isolated/valved-off from the tank. This is a safety feature to ensure that the PRD cannot be defeated.

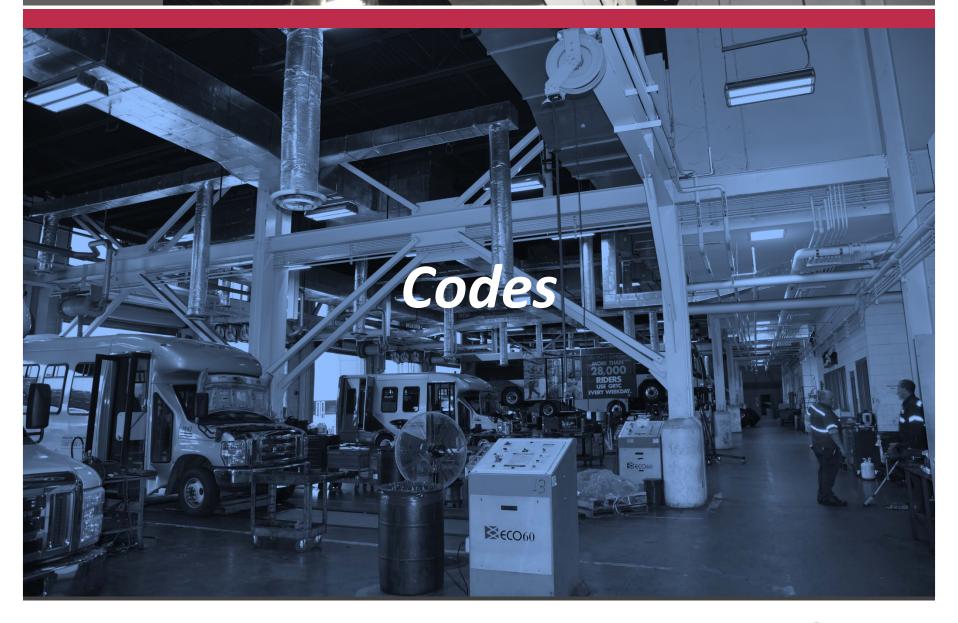
 PRD integrated with tank valve. PRD is always connected to the tank internal volume.



- 2. PRDs are not reclosing like a relief valve; therefore, once a PRD is activated, it will vent down pressure in all tanks that are not isolated. Once a PRD releases, it is a throw-away item.
- Depending on the design of a vehicle tubing system, the release of one PRD may vent down the entire vehicle. This issue can be minimized by using an automatic solenoid on each tank or group of tanks, or by manually closing tank valves during maintenance.









Codes that Dictate the Minimum Requirements

Applicability

Users of this manual need to determine which national codes and regulations apply in their jurisdiction and whether any state or local codes and regulations will be referenced. In some cases, different codes may contradict each other or require more or less stringent requirements than other applicable codes: however, users will need to comply with the most stringent requirements of all applicable codes. While users will most likely need to comply with the most current version of the codes, some jurisdictions may be enforcing an earlier version—this needs to be determined and addressed. As previously noted, in a fleet where more than one fuel is in use, the facility must meet the code requirements for all fuels.

References in this Document

This document will reference only commonly used national codes. These references and a paraphrased summary of code requirements will be provided in the section applicable to each code section. For example, code references to heating equipment will be in the heating section of this manual, and code references to electrical requirements will be in the electrical section. Users of this manual are strongly encouraged to purchase the full versions of each of the codes referenced in this document, and to review the full text of the document that pertains to their project. Code requirements that are duplicated between NFPA 2, 30A and 70 will be referenced to the code most applicable.

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International Code Council (see state versions of these national codes)

International Building Code (IBC)
(http://shop.iccsafe.org/codes/2018international-codes-and-references/2018international-building-code-andreferences.html)

International Fire Code (IFC) (http://shop.iccsafe.org/codes/2018-international-codes-and-references/2018-international-fire-code-and-references.html) (covers requirements for HVAC, gas detection, defueling, other issues)

International Mechanical Code (IMC) (http://shop.iccsafe.org/codes/2018-international-codes-and-references/2018-international-mechanical-code.html) (covers requirements for HVAC, gas detection)



Codes that Dictate the Minimum Requirements

National Fire Protection Association (NFPA)

NFPA 2: Hydrogen Technologies Code (https://catalog.nfpa.org/NFPA-2-Hydrogen-Technologies-Code-P1144.aspx?order src=D747&gclid=EAIaIQobChMIhdHNpobb2gIVRrbACh2SJQCiEAAYASAEgLE-fD BwE) (covers HVAC, electrical and other requirements)

NFPA 30A: Code for Motor Fuel Dispensing Facilities and Repair Garages (https://catalog.nfpa.org/NFPA-30A-Codefor-Motor-Fuel-Dispensing-Facilities-and-Repair-Garages-C245.aspx) (covers requirements for HVAC, gas detection, electrical classification, other issues)

NFPA 70: National Electrical Code (NEC) (https://catalog.nfpa.org/NFPA-70-National-Electrical-Code-C3315.aspx) (covers all wiring practices, including electrical requirements in hazardous locations)

NFPA 88A: Standard for Parking Structures (https://catalog.nfpa.org/NFPA-88A-Standard-for-Parking-Structures-P1213.aspx) (covers ventilation and other requirements)

Legacy Codes and Code Migration

This manual was assembled at a time when three major codes affecting the content of the manual were released as new 2018 editions with significant changes. Notably, the IFC delegating most of the gas detection system design requirements to NFPA 2 and NFPA 30A. Similarly, the 2018 IMC and NFPA 30A delegated most of the hydrogen ventilation and electrical requirements to NFPA 2. In most cases, the requirements of NFPA 2 are now the defining requirements for GH₂ vehicle garages; however, readers are encouraged to review the IFC, IMC and NFPA 30A to ensure that all requirements are identified. All three of the 2018 codes also made several minor changes and the 2018 IFC introduced some operational requirements related to service of lighter-than-air fuel vehicles.

It is likely that some jurisdictions will not yet have adopted the newest edition of these codes. To address this situation, this manual has included legacy requirements from past codes if these did not flow through to new editions. Readers are cautioned to look at the year that precedes the code references herein to ensure that the reference is applicable to their project. In some cases, such as with gas detection, there were code requirements that were dropped when code delegation occurred—these requirements are included herein as best practices. Readers are encouraged to contact code officials early in the project design phase to ascertain which codes and versions will be used in permitting the project. It is advantageous to continue this dialogue with the AHJ throughout the design phase.





Types of Garages

Defined in 2018 NFPA 30A

— Code for Motor Fuel Dispensing Facilities and Repair Garages

Major Repairs: (Section 3.3.12.1) (See also NFPA 70 Clause 511.2)

- 1. Engine overhauls
- 2. Painting, body and fender work (and other "hot work"—cutting and grinding)
- 3. Repairs that require draining of the motor vehicle fuel tank (any fuel system work)

Minor Repairs: (Section 3.3.12.2) (See also NFPA 70 Clause 511.2) (Similar to 2018 IFC Section 2311.8 and 2018 IMC Section 502.16 Exception 1)

- 1. Minor automotive maintenance work
- 2. Engine tune-ups
- 3. Fluid changes (e.g., oil, antifreeze, transmission fluid, brake fluid, air conditioning refrigerants, etc.)
- 4. Brake repairs
- 5. Tire rotation, repair, and replacement



The upgrade requirements of a "minor repair" garage are less extensive; however, given that most garages do some work that would be considered "major repair" it is best practice to consider the facility to be "major repair," as this gives the fleet operator more flexibility in the work performed.

The new 2018 IFC code does not specifically reference major and minor repair; however, it allows an exception from most garage upgrades if the work performed is not on the fuel tank, not hot work, and is just an exchange of parts. However, the exception is contingent on the GH₂ vehicle not entering the garage with more than 200 cubic feet of gas in the storage tank (2018 IFC 2311.8 Exception 3). This clause partially contradicts Exception 2 in the same section; however, should an AHJ enforce the requirements of Exception 3, it effectively requires that all vehicles be defueled prior to entering a "minor repair" garage, making the "minor repair" designation unusable from a practical standpoint.

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Types of Garages

2016 NFPA 2 (2016 NFPA 2 Section 18.3.1.2) and 2018 IMC (2018 IMC Section 502.16 Exception 2) have similar wording but are clearer in their intent. These codes allow repairs that would normally require a "major repair" garage to take place in a "minor repair" garage if the vehicle has less than 200 scf of fuel on board.

NFPA 2 (2016)

Hydrogen Technologies Code

Chapter 17—Parking Garages

1. Applies to open and enclosed parking structures.

Appendix (A.17.2)

- Since the fire hazard of GH₂ vehicles is similar to conventionalfuel vehicles, no additional code requirements are provided in NFPA 2.
- 2. General requirements of NFPA 88A will still apply as they would to any vehicle regardless of fuel type.

Chapter 18—Repair Garages

- 1. Applies to hydrogen fuel vehicle repair garages.
- 2. Reference is made to major and minor repair garages without definition in NFPA 2. The definitions from NFPA 30A should be used.

NFPA 88A (2015)

Standard for Parking Structures

Scope: (Section 1.1)

1. Applies to open and enclosed parking structures.

It is best practice to apply the ventilation requirements of NFPA 88A as a minimum standard to all parking garages and major and minor repair maintenance garages as vehicles will be left unattended in most maintenance garages. Major repair garages have additional, higher ventilation requirements defined in NFPA 30A (in lieu of electrical upgrade) and the IMC that apply under certain conditions.

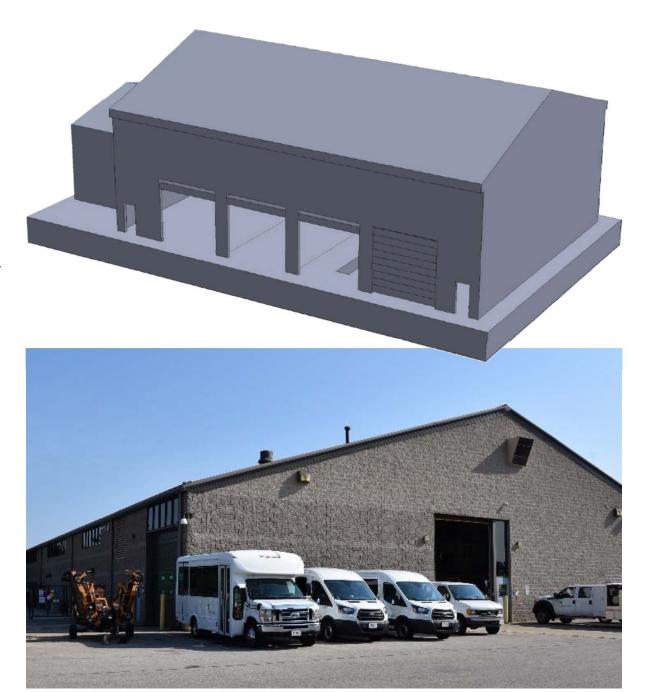




Building Geometry

Gable Roof with Single or Double Pitch

Pitched roof structures are <u>very</u> well suited to lighter-than-air fuels (CNG, LNG and GH₂), as leaks will tend to rise and naturally collect at the peak where they can be readily exhausted from the space. This structural geometry has the added benefit of additional building volume in the peak portion of the building interior, allowing a gas release to collect further away from potential ignition sources. From a gas release standpoint, steeper pitches are preferred over shallow pitches.

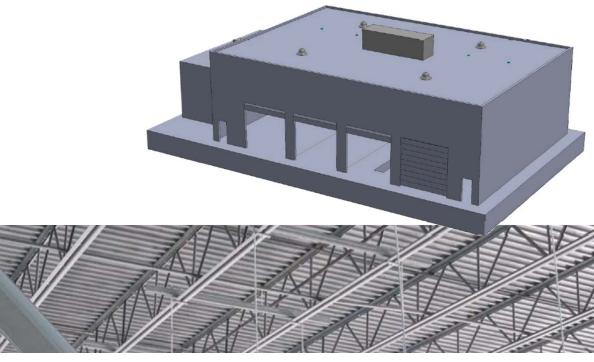




Building Geometry

Flat Roof with Open-Web or Bar-Joist Structure

Flat-roof structures (or very shallow pitched roofs) with open-web or bar-joist type roof structural systems are well suited to lighter-than-air fuels (CNG, LNG and GH₂), as leaks will tend to rise and can be pulled with exhaust air to an exhaust point without structural obstructions. This is the most common design for large-span buildings built in the last 20 years.







Building Geometry

Flat Roof with Precast T-Beams

Flat-roof structures with precast concrete T-beams require more elaborate ventilation and gas detection systems designed for lighter-than-air fuels (CNG, LNG and GH₂), since the TEEs form pockets that must be ventilated. This tends to increase upgrade cost. This structural system was commonly used 30 to 40 years ago. There is a "waffle" variant of this design that is even more challenging than the T-beam to ventilate.









Purpose and Importance of Ventilation

Ventilation is the single most important factor in the design of upgrades for a gaseousfuel vehicle garage, and in many cases it is also the costliest. Properly designed and operated ventilation systems will manage the path of an accidental gas release by pushing and pulling the gas plume (cloud) quickly toward an exhaust point. Prior to exhausting the gas, the concentration of gas will be diluted by the continuous introduction of fresh air.

Many conventional-fuel garages utilize a system of exhausting at the floor and introducing fresh (make-up) air at the ceiling. If this is the case, provision must be made to comply with requirements for all fuels. This commonly used conventional-fuel garage ventilation approach is unsuitable for lighter-than-air fuels and it is also inferior from a personnel comfort standpoint. A well-designed ventilation system will also improve indoor air quality and employee comfort.

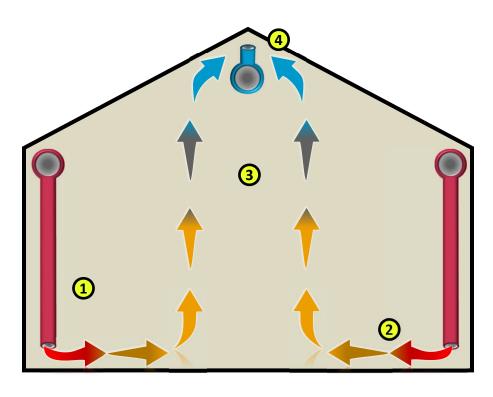
All ventilation in a vehicle garage must be non-recirculating. This requires 100 percent fresh air to ensure that any exhausted gas/air mixture is not reintroduced into the building interior. The use of systems that intentionally recirculate a portion of the exhaust air to save on heating costs is not acceptable. In cold climates, designers should consider the use of heat-recovery units using plate heat exchangers to recover heat from the exhaust air.

It is also good practice to exhaust at a rate that is 0.5 to 1.0 ACH more than the make-up air rate. This will create a slightly negative pressure in the garage space, ensuring that a gas release will not be "pushed" into adjacent untreated spaces.

Baseline and Emergency Ventilation

Baseline ventilation is the continuous changing of air to provide a safe and hygienic work environment. This minimum level of air change is typically as required by applicable codes and will be explained further in this document. Baseline ventilation systems can be open loop with separate heat and exhaust systems, or closed loop if a heat-recovery unit is used. No recirculation of air is permitted.

Emergency ventilation systems are typically activated with a combustible gas detection system. Emergency systems may be used to provide part of the code-required air changes, or they may go beyond minimum code levels to provide even greater levels of safety. These systems are generally open loop with direct exhausting fans and automatically opening garage doors to provide make-up air.



Design Philosophy for Baseline Ventilation Systems

Baseline ventilation systems operate continuously (when vehicles are in the facility) to ensure that a small or large release of gas is quickly diluted and exhausted. The IMC provides a good general description of the best (and required) configuration of baseline ventilation systems as explained below.

- 1. Heating systems must have controls to verify outside air flow before firing burners. Warm air is introduced near the floor, typically on perimeter walls or between overhead doors.
- 2. Warm air "sweeps" the floor to provide warmth to personnel and to ensure that any cold plume of gas is quickly warmed and diluted.
- 3. Air is "pushed" toward the exhaust point by the continuous warm make-up air. Note that the gas detection system should also be configured to be in the path of a potential leak plume.
- 4. Air is exhausted at the high point of the garage. A gable building is shown, but the high point of a flat-roof building near the centerline is also appropriate.
- 5. Gaseous-fuel vehicle garage portions of the facility must not share any HVAC systems with areas not upgraded for gaseous fuels.
- 6. Gaseous-fuel vehicle garage portions of the facility must be at negative pressure relative to untreated areas to ensure that any gas leak will not migrate to untreated areas.





Code Requirements for Major Repair Garages

2015 IMC and 2015 IFC (2018 IFC 2311.8.8 and 2018 IMC 502.16.1 excludes hydrogen from its ventilation requirements) (2015 requirements are shown in case the AHJ has not adopted the 2018 IMC and IFC)

Make-up air is to be introduced near floor level uniformly on exterior walls at a continuous rate of 5 ACH, or not continuous but automatically started with an interlock to the gas detection system (2015 IFC 2311.2) (2015 IMC 502.16.1) or an interlock to the room lighting (2015 IFC 2311.2) (2015 IMC 502.16.2). Exhaust ventilation is to be at the high point of the room on exterior walls or roof. It is the Author's opinion that the reliance on the lighting interlock is problematic since an issue could occur after-hours with unattended vehicles in the facility.

2018 IMC and 2018 IFC

The 2018 IFC 2311.8.8 and 2018 IMC 502.16.1 and .2 exclude hydrogen from its ventilation requirements and instead directs users to Chapter 6 of NFPA 2.

2016 NFPA 2

Exhaust is to be within 12" of the ceiling (2016 NFPA 2 Section 6.17.2.1.4.3) and shall provide effective ventilation of the room (2016 NFPA 2 Section 6.17.2.1.4.5). Exhaust ventilation shall discharge a minimum 50 feet from any air intakes. Ventilation is to be provided at a rate of one cubic foot per square foot of floor area (2016 NFPA 2 Section 6.17.1).

2018 NFPA 30A

This code does not explicitly have minimum mechanical ventilation requirements for hydrogen.

Code Requirements for Minor Repair Garages and Parking Garages

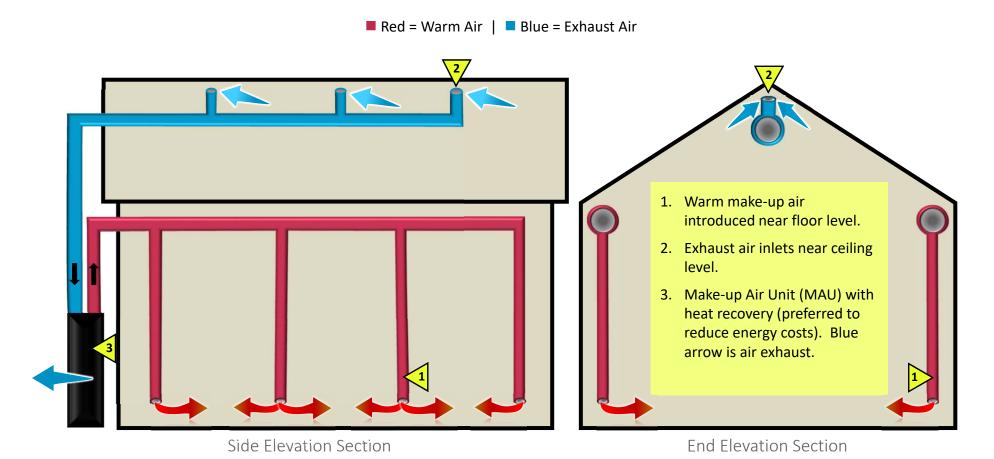
The Author has combined these two garage types since all repair garages involve the storage of vehicles so logically parking garage requirements also apply to repair garages. The codes do not provide other useful guidance on minor repair garages so many of the recommendations are best practice and not code driven.

2015 NFPA 88A

All enclosed garages (all fuels) are required to have 1 cfm of mechanical ventilation per square foot of floor space (Section 6.3.1 and A.6.3.1). Open parking structures do not have a mechanical ventilation requirement (Section 6.3.2).



Best Practice Baseline (Continuous) Ventilation for Gable Roof with Single or Double Pitch Roof



Best Practice Baseline (Continuous) Ventilation for Gable Roof with Single or Double Pitch Roof—Typical Installation (CNG garage is shown but the same system is applicable to GH₂)

- 1. Fan at each end of peak exhaust duct provides continuous exhaust. Two fans provide redundancy.
- 2. Duct in center of building near the peak, with registers extending up to the peak.
- 3. Heating duct at each side blows heat to the floor area.
- 4. Direct-fired make-up air unit mounted outside. No energy recovery is provided in the pictured unit. Unit must "prove" air flow before firing.





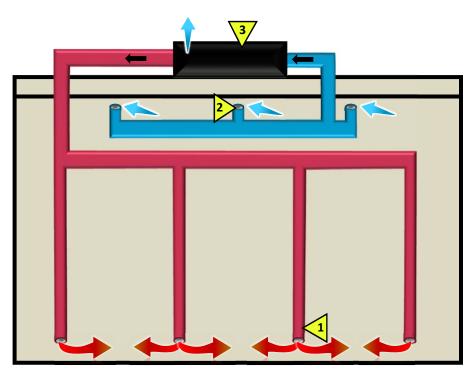




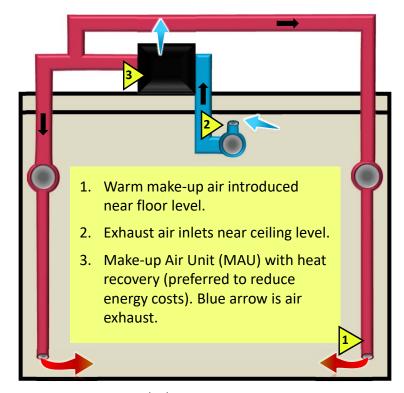
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Best Practice Baseline (Continuous) Ventilation for Flat Roof with Open-Web or Bar-Joist Structure

■ Red = Warm Air | ■ Blue = Exhaust Air



Side Elevation Section



End Elevation Section



Best Practice Baseline (Continuous) Ventilation for Flat Roof with Open-Web or Bar-Joist Structure—Typical Installation (CNG garage is shown but the same system is applicable to GH₂)

- 1. Exhaust air inlets near ceiling level.
- 2. Heated make-up air blown to the floor using nozzles on the drop ducts.
- Rooftop heating unit with energy recovery. This unit does not recirculate any air—heat is recovered through a heat exchanger.
- 4. Two typical make-up air ducts introducing fresh heated air close to the floor.

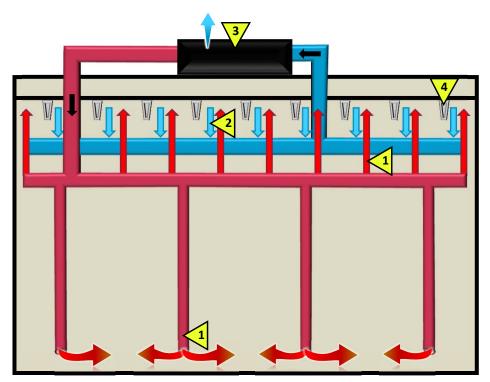




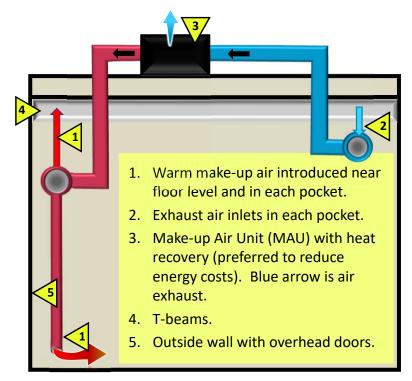


Best Practice Baseline (Continuous) Ventilation for Flat Roof with Precast T-Beams

■ Red = Warm Air | ■ Blue = Exhaust Air







End Elevation Section



Best Practice Baseline (Continuous) Ventilation for Flat Roof with Precast T-Beams – Typical Installations (CNG garages shown but the same system is applicable to GH₂)





1. Warm make-up air introduced in each pocket on the outside wall.

Exhaust air inlet in each pocket on the inside wall.
All pockets are flushed.

2. Warm make-up air introduced in each pocket, coupled with exhaust, flushes the pocket.

Best Practice Supplemental/Emergency Ventilation

Logically, one would assume that doubling the air change rate in a garage would halve the time that a flammable mixture of gas is present; but in fact, doubling the air change rate causes more turbulent mixing of gas and air, resulting in even faster dilution. For this reason, it is best practice to provide supplemental direct-venting (non-ducted) exhaust fans in addition to baseline ventilation. These fans are simple, relatively inexpensive, and provide additional safety. In warm months, these are used by some garage operators to enhance employee comfort. In case of emergency, the fans are started automatically by the combustible gas detection system and overhead garage doors are automatically opened to provide make-up air. Given that these fans will operate in a gas leak situation, the motors should be Class I, Division 1 or 2 rated, and the impellor must be non-sparking (best practice, not code requirement).

View from below and above of direct-vented emergency-exhaust fan.





Wall-mount type fan mounted in a clerestory which forms a high point and natural collection point for lighter-than-air gases.





Best Practice Ventilation Design

Designers must consider the path of the exhaust plume after it exits the building. Although 2018 IMC Section 601.5.1 requires a minimum 10-foot separation between exhaust fan discharges and MAU or other building air intakes for most fuels, the 2018 IMC directs the user to the 2016 NFPA 2 for ventilation. Under NFPA 2, the separation requirement is 50 feet (2016 NFPA 2 Section 6.17.2.1.4.5). It is recommended that designers also consider prevailing winds and air currents around buildings (best practice). Designers should design the exhaust system so that it vents vertically upward, if possible.



- 1. The air intake on this rooftop MAU is remote from the exhaust fan, but maximizing this distance is preferred.
- 2. This exhaust fan is an up-blast unit, which is recommended. Equipping the unit to discharge at a higher height and further from the MAU is preferred.





What are the Issues with Heating Systems?

With a hydrogen autoignition temperature of approximately 1000°Fahrenheit (F), heating systems must be designed to maintain temperatures that are safely below the autoignition temperature. NFPA 2 has set a safe limit of 750°F. Heating systems should have the following characteristics:

- 1. No surfaces greater than 750°F under any operating condition.
- 2. No open flames.
- 3. No opening to a sparking element or other ignition source.
- 4. Heating systems do not need to be rated for hazardous locations unless they are located in a hazardous area. This is very unlikely in the vehicle areas of a garage, but would be the case in a flammable or combustible material storage room.

Workarounds

Some upgrade designers have proposed using inappropriate heating equipment with the provision that it will be switched off automatically by the gas detection system in the event of a gas release. Unfortunately, this approach will not provide a safe environment since:

- 1. The gas plume will likely encounter the heating equipment before it contacts the gas detector.
- 2. The gas detector is not instantaneous. There will be a brief delay before the detector has determined that a gas leak exists.
- 3. Some heating equipment, such as radiant tube heaters, will remain above the autoignition temperature for some time.

Therefore, designers must specify the <u>removal of all non-compliant heating equipment</u>. It is recommended that this equipment be removed so it cannot be re-commissioned later.

See additional workarounds discussed on Page 2 of this manual.



Code Requirements for Major Repair Garages

2016 NFPA 2

- 1. Heating appliances must be installed with the combustion chamber below 18 inches below the ceiling (Section 18.5.4).
- 2. Open-flame heaters and heaters with surface temperatures greater than 750°F are not permitted (Section 18.5.5).

Code Requirements for Minor Repair Garages and Parking Garages

The Author has combined these two garage types since all repair garages involve the storage of vehicles so logically parking garage requirements also apply to repair garages. The codes do not provide other useful guidance on minor repair garages so many of the recommendations are best practice and not code driven.

2018 NFPA 30A

Appliances must be of an approved type in repair garages. Solid-fuel stoves, space heaters and improvised furnaces are not permitted (Section 7.6.2) (see also NFPA 2 Section 18.5.2).

Best Practice Tip

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For safety, the code requirements for major repair garages can be applied to all vehicle spaces in the facility. This practice is frequently used in lighter-than-air gaseous-fuel vehicle garages.

Non-compliant/Unsafe Heating Equipment



The open-flame unit heater to the right would ignite a gas/air mixture if a gas plume encountered the heater.



The Rooftop packaged Unit (RTU) to the right recirculates a portion of the return air to save energy (similar to a residential furnace). This recirculated air is directly exposed to a burner flame and would ignite a gas/air mixture if one occurred.



Non-compliant/Unsafe Heating Equipment

The standard radiant gas (1) and electric (2) heaters operate above 1000°F and would ignite a gas/air mixture if a gas plume encountered the heater.

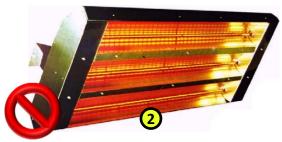
The radiant gas heater may also cause flareouts from its burner since these are not sealed on standard units.

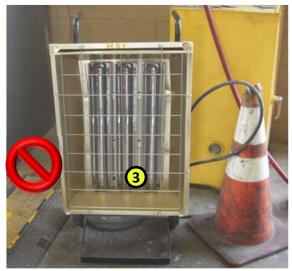
Steam cleaning units need to be located in a non-vehicle room with separate ventilation.

Propane, kerosene, and electric heaters (3) should never be used in any vehicle area of any garage, regardless of vehicle fuel.

Waste-oil furnaces (or any other nonsealed-combustion heater) are not allowed in the vehicle portion of the garage (4). These heaters can be safely located remotely and ducted into the vehicle space.









Best Practice Safe Heating Equipment

There is a wide variety of safe, compliant heating equipment options. Some, such as hydronic in-floor heating, may not be a practical option for the retrofit of an existing facility. Some options offer low initial cost but higher operating costs—these will be identified in the following pages.

Given that many garages will be required to increase and relocate the airflow in the garage, long-term heating costs should be considered. With the increased air flow, it is often required that at least part of the heat should be from a warm-air system. Reliance on radiant heat alone will not be sufficient in cooler climates. Without tempering the make-up air, the garage will feel "drafty." Owners also need to consider that warm-air systems are susceptible to losing heat when large doors are frequently opened.

Paint Booths

Paint booths can be upgraded at modest cost since they are already designed as a Class I, Division 2 location; however, there are some issues to be addressed:

- 1. If a gas detector is to be used, it should be located in the ventilation ducting after filtration. This unit may be susceptible to "dirty lens" faults. Many Owners do not use a gas detector and instead have a practice of having minimal fuel in the vehicle tanks and running the exhaust air system whenever a GH_2 vehicle is in the booth.
- 2. It is recommended that <u>no heat</u> be used in the curing process for paint. The use of heat could result in a PRD release due to the thermal material in the PRD (eutectic) flowing under the heat. Fully defueling the vehicle will not necessarily prevent this damage and the PRDs may fail at the next normal fueling.



Best Practice Safe Heating Equipment—High Initial Cost/Low Operating Cost

Hydronic heating systems use boilers (two shown to far right) along with unit heaters (two shown to near right), in-floor tubing, or hydronic coils in rooftop MAUs to provide space heating without any flame. In-floor heating is a high cost, but very effective, means of providing space heat in a maintenance shop, and it keeps the floor dry and holds heat when doors are frequently opened.





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Best Practice Safe Heating Equipment—High Initial Cost/Low Operating Cost

Rooftop units with energy-recovery heat exchangers are initially costlier but may recover up to 70 percent of the heat from exhaust air to preheat incoming air.



Best Practice Safe Heating Equipment—Moderate Initial Cost/Low Operating Cost



Direct-fired MAUs installed outside of the vehicle space provide a safe, lowcost, high-efficiency heat source. Note that the fan must start and "prove" airflow prior to firing the burner.

The equipment shown does not include heat recovery so there is an additional operating cost due to the lost heat.

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Sealed-combustion or separated-combustion unit heaters can be used in the vehicle space. Users must confirm that the unit is fully sealed and that no surfaces exceed 750°F.

Best Practice Safe Heating Equipment—Recommended Only for Supplemental Heat or Warm Climates



Several manufacturers now produce gas-fired radiant tube heaters with surface temperatures below 750°F. These units should be designed and recommended by the heater manufacturer for CNG garages, must be installed with a sealed and ducted combustion air source and must be monitored and controlled to keep temperatures below 750°F.

Designers may wish to contact the manufacturer to determine whether these units can be used in GH_2 vehicle garages where the maximum 750°F also applies.

Users should be aware that the output from these heaters will be much lower than standard radiant tube heaters. These units are most appropriate for use in warmer climates or as supplemental heat. Units will need to be a maximum of 10 to 12 feet above the floor to be effective.

Best Practice Safe Heating Equipment—Recommended Only for Supplemental Heat or Warm Climates



Class I, Division 2, Group D rated catalytic gas-fired heaters can be used in any location in a garage for supplemental heat.

Users should be aware that the output from these heaters will be insufficient for primary heating. These units are most appropriate for use in warmer climates or as supplemental heat. Units will need to be a maximum of 10 to 12 feet above the floor to be effective.



Class I, Division 2, Group D rated forced-air and convection electric heaters can be used in any location in a garage for supplemental heat.

Users should be aware that the output from these heaters will be effective in small spaces only. High equipment and energy costs make this appliance unsuitable for primary heating in large spaces.

Defined in 2017 NFPA 70 Article 500.5

Class I, Division 1, Group B

- 1. Ignitable mixtures of flammable gases or liquid-produced vapors are present under normal conditions.
- 2. Ignitable mixtures of flammable gases or liquid-produced vapors may be present because of repair, maintenance, or leakage.
- 3. Ignitable mixtures of flammable gases or liquid-produced vapors may be present because of equipment breakdown or faulty operation.

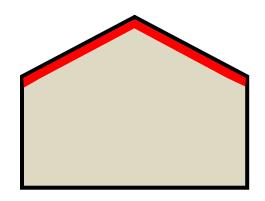
This is an area where one might frequently expect to have a flammable mixture present. There are no Class I, Division 1, Group B locations required by any of the codes listed herein that are related to the use of GH_2 in the garage.

Class I, Division 2, Group B

- Ignitable mixtures of flammable gases or liquid-produced vapors are used but are contained within closed systems and escape only through accidental rupture or equipment malfunction.
- 2. Ignitable mixtures of flammable gases or liquid-produced vapors are prevented through positive ventilation but could become hazardous through a failure of the ventilation system.
- 3. An area adjacent to a Class I, Division 2, Group B location that could receive a flammable mixture from the Division 1 location, unless positive ventilation from a clean source of air is provided.

This is an area where one might infrequently expect to have a flammable mixture present due to an equipment (or personnel) failure. NFPA 70 Table 511.3(D) specifies a Class I, Division 2 location within 18 inches of the ceiling unless 1 cfm/ft² of continuous exhaust is drawn within 18 inches of the ceiling.

Note that where Group B (Hydrogen) rated equipment in unavailable, Group D equipment is often allowed by the NEC.



Code Requirements for Major Repair Garages

2017 NFPA 70 (NEC)

The 18 inches at the ceiling are designated as Class I, Division 2 unless a minimum of 1 cfm/ft² of exhaust ventilation is provided within 18 inches of the ceiling, then no classification is codified (Table 511.3(D)). In most cases of retrofit, capital cost considerations and interruption make the exhaust air the desirable approach. And this quantity of ventilation is required under NFPA 88A, which is best practice as a minimum baseline ventilation in the maintenance garage as well. Other options include upgrading conduit and equipment to Division 2 rated or relocating electrical equipment out of the 18-inch location. On new construction, locating the equipment outside of the 18-inch location is preferable.

2018 IFC

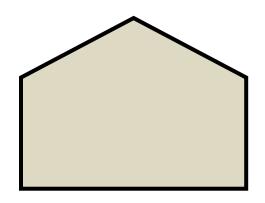
The 18 inches at the ceiling are designated as Class I, Division 2 unless a minimum of one cubic foot per minute per square foot of floor space of exhaust ventilation is provided then no classification is codified (Section 2311.8.10).

A conservative interpretation of this location is

A volume that extends 18 inches perpendicular to the inside of a gable roof. The hazardous location runs parallel to the roof—see illustration to the left.

For flat roof buildings, the hazardous area is interpreted as extending 18 inches from the underside of the roof deck.



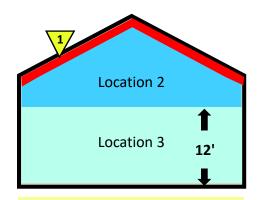


Code Requirements for Minor Repair Garages and Parking Garages

The Author has combined these two garage types since all repair garages involve the storage of vehicles so logically parking garage requirements also apply to repair garages. The codes do not provide other useful guidance on minor repair garages so many of the recommendations are best practice and not code driven.

2017 NFPA 70

Parking garages are not required to be classified as a hazardous area (Section 511.3.A).



1. Red location is 18" Class I, Division 2 area specified in NEC (NFPA 70)

Purpose of Electrical Upgrades

The code-required electrical upgrades are intended to remove ignition hazards from those locations where gas might tend to accumulate, especially at the ceiling and building high points in the case of lighter-than-air fuels.

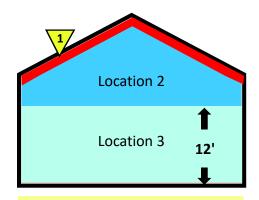
Best Practice for Electrical Upgrades

Code upgrades to the top 18 inches are required; however, the best practice approach also addresses two additional locations as shown to the right with a delineation of 12 feet from the floor (this delineation point is best practice in the industry but is <u>not a code requirement</u>). The focus with this upgrade is <u>not</u> to create an enlarged Class I, Division 2 location, but to remove obvious ignition sources in the location. The reason for upgrading these locations is that a release from a vehicle will pass through one or both of these locations before the gas plume stratifies at the ceiling.

Best Practice Upgrades in Location 2

- 1. Electrical classification—General Purpose
- 2. No upgrades to conduits or non-arcing and non-sparking devices (lighting, boxes, etc.).
- 3. Arcing and sparking devices—relocate or upgrade if practical. Items such as a bridge crane with open buss bars (cannot be relocated or upgraded)—remove power from the crane if gas is detected.





1. Red location is 18" Class I, Division 2 area specified in NEC (NFPA 70)

Best Practice Upgrades in Location 3

- 1. Electrical classification—General Purpose.
- 2. No upgrades to conduits or to non-arcing and non-sparking devices (lighting, boxes, etc.).
- 3. Arcing and sparking devices—relocate or upgrade if practical. If items such as welders and grinders cannot be relocated or upgraded—remove power using a gas-detection-activated electrical contactor from the loud and sparking devices if gas is detected. NFPA 2 Section 18.6 requires that hot work be performed in approved locations and with equipment meeting NFPA 51, 51B, 70, and certain grounding requirements.
- 4. It should also be noted that the location from the floor to an elevation of 12 feet above the floor (Author suggested best practice) is the work area of the garage, and some amount of ignition sources from grinders, welders, and tools is considered normal and necessary to have a functioning garage. Where such ignition sources cannot be mitigated, Owners should implement safety procedures to reduce this risk.
- 5. Some designers use shunt-trip breakers to remove power from all equipment that is deemed to be a likely ignition source. This is a safe practice, but it requires manual reset and prevents the gas detection system from restoring normal building operation automatically after a Level 1 alarm occurs. The equipment that is shunt tripped cannot include exhaust fans, overhead doors or any other equipment required for the proper operation of the fire alarm, gas detection or other safety systems.

Best Practice for Electrical Upgrades—Sample Details



Using a contactor to remove power from the bridge crane eliminates a potential ignition hazard (open buss bars). The contactor is controlled by the gas detection system.



The many conduits above would be very expensive to relocate or upgrade and pose very little sparking risk. Most retrofit garage upgrades use the 1 cfm/ft² exemption from the Class I, Division 2 requirement.

Best Practice for Electrical Upgrades—Sample Details



There is misunderstanding of Class I, Division 2, Group B requirements. Many general-purpose components meet Division 2—for example the Division 1 rated light above is not required. The sealed fixture below meets Division 2 requirements even though there is no Division 2 label affixed to it. Designers should be familiar with the differences and opportunities to safely reduce upgrade costs.



Required for gas detection systems (2018 IFC Section 916.5). It is best practice to provide a standby generator to power the gas detection system, fans, overhead doors, lights and other safety-related equipment.

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The use of explosion proof or pneumatic power tools is not required but some garage Owners take this extra safety step.



Code Requirements for Major Repair Garages

2018 IFC, 2016 NFPA 2, 2018 NFPA 30A

Since GH₂ is a non-odorized fuel, there is a code requirement to install a combustible gas detection system (see 2018 IFC Section 2311.8.9, as well as 2016 NFPA 2 Section 18.3.3 and 2018 NFPA 30A Section 7.4.7). Additional code references are inserted into the applicable paragraphs of this section. 2018 NFPA 30A Section 7.4.7 defers the design of gas detection systems to the requirements set out in NFPA 2—references in this section to 2018 NFPA 30A requirements are included to provide additional detail of requirements for other fuels and may be considered as best practice recommendations for GH₂.

Gas detection systems allow the garage operator to reduce the normal (baseline) ACH to conserve energy while improving safety by responding to a gas release. Systems also provide fast notification to response personnel to address a situation before it escalates. The use of a gas detection system is a code requirement for hydrogen vehicle major repair garages and is best practice for other hydrogen vehicle garages.

Minimum of annual gas detection calibration (2018 IFC Section 916.11).







Code Requirements for Minor Repair Garages and Parking Garages

The Author has combined these two garage types since all repair garages involve the storage of vehicles so logically parking garage requirements also apply to repair garages. The codes do not provide other useful guidance on minor repair garages so many of the recommendations are best practice and not code driven.

2015 NFPA 88A

Although there is no code requirement to provide a combustible gas detection system, it is a very common practice to provide this system in minor repair and vehicle storage garages to enhance the safety of the facility.

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Best Practice for the Design of Combustible Gas Detection Systems

Although it is strongly recommended that the gas detection equipment supplier validate the design, there has been a tendency for equipment suppliers to refrain from making specific design recommendations related to the spacing and location of gas detectors. The recommendations herein represent several typical industry approaches although these would need to be adapted for a specific facility.

Terminology and Technology



IR Point Detector

Measures gas at a single point in the garage. These must be configured in a grid, but the system will report actual LFL at each detector location. For hydrogen applications, only catalytic technology will detect a hydrogen leak (IR technology used with hydrocarbons will not work for GH₂).



Open-Path Detector

These detectors operate using IR technology and therefore are not effective for detecting ${\rm GH_2}.~{\rm H_2}$ does not absorb IR light.

Catalytic (pictured)

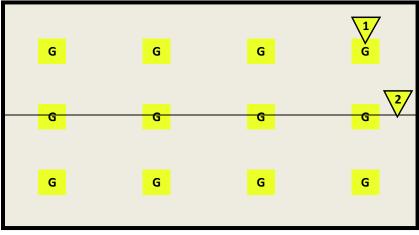
This is the only sensor technology used for GH₂ sensing and can be configured to monitor for hydrocarbons and GH₂ using the same sensor. Generally regarded as older technology, catalytic sensors require calibration at least four times per year. The sensor will need to be changed about every three to five years. Sensors can be "poisoned" by exposure to silicones, sulphur compounds, and solvents and can be susceptible to false readings from wind. This technology is only used in point detectors.

One vendor provides an automatic calibration unit that addresses the frequent calibration concerns.

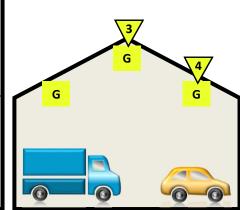


Typical Layout Using Catalytic Point Detectors

- 1. Point detectors located approximately 15' from wall and 30' from the next detector.
- 2. Recommended location: exhaust air inlet.
- 3. Required location: at high point of garage.
- 4. Recommended location: directly above vehicle bays.







End Elevation Section



Additional Design Considerations

- 1. In addition to locating detectors at the peak or high point, detectors are also required at the inlet to exhaust air systems and mechanical ventilation inlets where GH₂ vehicles are serviced or defueled (NFPA 2 Section 18.3.3.4).
- 2. Gable-style garages can utilize fewer detectors (for example just at the peak) if there is a steep pitch (for example >3/12).
- 3. Flat-roof bar-joist garages typically use the 30' x 30' detector grid as previously noted. In maintenance areas this may be adjusted to keep detectors above vehicles.
- 4. For T-beam maintenance garages, place one (or more) point detectors directly above the vehicle.
- 5. Assign a unique number to each detector and label it, so it is visible from the floor.
- 6. Systems must be fail-safe (2018 NFPA 30A 7.4.7.3 and 2018 IFC Section 2311.8.9.2), such that a failure of a system component will place the system into a response mode.
- 7. Install tubing for floor-level calibration or consider sourcing an automatic calibration system.
- 8. Gas detection circuits must be monitored for integrity as required in NFPA 72 (2018 NFPA 30A Section 7.4.7.4) (2016 NFPA 2 Section 18.3.3.7).
- Gas detection controllers must be listed and labelled to UL 2017 or UL 864 and detectors to UL 2075 for Hydrogen (2015 IFC Section 2311.7.2.1.1).
- 10. Gas detection systems must be provided with standby power (2018 IFC Section 916.5).



Typical Layout Using Catalytic Point Detectors



1. Catalytic type combustible gas point detectors located in 3 rows above bays and at peak of maintenance shop areas.

Best Practice Design Details







Equip the system for "Floor Level Calibration" to avoid the need and cost of using a lift to calibrate detectors (see tubing on detector that is routed to floor level).



Provide highly visible status lights inside the garage and outside above overhead doors.

Best Practice Design Details





Provide manual gas detection activation buttons at man doors to allow staff to manually put the system in Level 2 response.

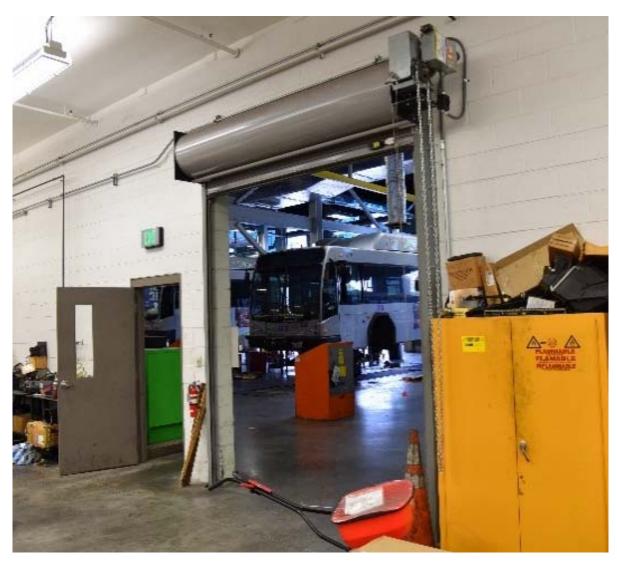
| Best Practice Design Details— System Response | Initiating Event | | | | |
|---|---|----------------------|---------------------------|---------|---|
| Gas Detection System Response | 25% LEL (Level 1) (2016 NFPA 2 Section 18.3.3.3) (2018 IFC Section 916.8.1) | 50% LEL (Level 2) | Manual Push Buttons | Trouble | System Failure (2016 NFPA 2 Section 18.3.3.6) (2018 IFC Section 2311.8.9.2) (This would be failure of the overall controls) |
| Gas Detection Strobes (2018 IFC Section 2311.8.9.1) (2016 NFPA 2 Section 18.3.3.5) | x | Х | Х | X | X |
| Gas Detection Horns (2018 IFC Section 2311.8.9.1) (2016 NFPA 2 Section 18.3.3.5) | x | Х | Х | | x |
| Fuel Valves to Building Heaters (close) (2018 IFC Section 2311.8.9.1) (2016 NFPA 2 Section 18.3.3.5) | X | Х | Х | Х | X |
| Open Overhead Outside Doors (2018 IFC Section 2311.8.9.1) and Close Doors Between Shop and Adjacent Vehicle and Non-vehicle Areas | x | X | X | X | X |
| Start Emergency Fans (2018 IFC Section 2311.8.9.1) | x | Х | Х | х | х |
| Remove Power for Crane and Welding/Sparking/Noisy Equipment | х | Х | Х | Х | x |
| Report and Display Fault on FACP | | Х | Х | | X |
| Automatic System Reset When Condition Clears (Non-latching) | Х | | | Х | |
| Manual System Reset When Condition Clears (Latching) | | Х | Х | | x |

Architectural and Other Upgrades

General

There is no gaseous-fuel specific code guidance for architectural upgrades. There are a number of best practices. Many of these upgrades are focused on reducing the possibility of migration of a gas plume into untreated areas of the garage. These upgrades may include:

- 1. Walls, doors, and barriers around repair rooms are to be a minimum of one-hour fire rated and constructed in accordance with the requirements of Sections 707 and 711 of the IBC (2018 IFC 2311.8.3). Note that other code requirements related to isolating occupancy types may require a two-hour separation between garage rooms and between garages and other portions of the facility.
- Install automatic doors to close off untreated areas, such as parts rooms and machine shops (see picture to right). These should close upon gas detection and fire.
- 3. Install self-closing man doors to close off untreated areas from the garage.



Architectural and Other Upgrades





- 4. Install bulkheads in stairways and hallways that could lead to a gas plume migrating into untreated areas. This approach can be evaluated against, or combined with, HVAC system pressure balancing to keep a plume out of these areas.
- 5. Seal and fire-stop the tops of walls that divide areas of the garage or garage areas and untreated areas.
- 6. Remove, pressurize, or ventilate false ceilings so gas cannot become trapped in them.
- 7. Seal and fire-stop wall penetrations in walls that divide areas of the garage or garage areas and untreated areas (pictured top). (2018 NFPA 30A Section 7.6.3 and A.7.6.6—these are CNG requirements but should be applied in a GH₂ vehicle garage.)
- 8. Ignition sources, such as a hot work area (pictured bottom), should be separated from vehicle areas by full walls or partial walls. Local pressurization of the area is also commonly used by flooding the hot work area with make-up air near floor level to repel a vapor plume

Architectural and Other Upgrades



Recommended Equipment Upgrades

1. Personnel will be required to work on the roof of some gaseous-fueled vehicles, such as transit buses and refuse trucks, to perform tank inspections. To safely meet this need, many garage Owners install fall arrest systems like the three shown here.





Summary of Upgrades

GH₂ Building Upgrade Requirements—Major Repair Garage

| | Minimum Code Requirements | Typical Recommended Practice | High-End Upgrade Approach | | |
|----------------------------|--|--|---|--|--|
| Electrical | Class I, Division 2 within 18" of ceiling or upgrade continuous ventilation to 1 cfm/ft² (IFC and NFPA 70) | Remove all arcing/sparking sources above 12' from floor (not a full upgrade to Class I, Division 2) | | | |
| Heating | No open flames or surfaces >750°F (NFPA 2) | No open flames or surfaces >750°F | No open flames or surfaces >750°F Heat-recovery heating units | | |
| Ventilation— Continuous | 1 cfm/ft ² -Same as diesel (=2.5 ACH for a 24' ceiling or 3 ACH for a 20' ceiling) and no recirculation (IFC, IMC, NFPA2, NFPA 88A) | 1 cfm/ft ² Fresh air in at building exterior near floor/exhaust at highest point(s)—no recirculation. Not shared with other spaces. | | | |
| Ventilation— Emergency | No specific requirement | 1 cfm/ft² continuous + additional 1 (or more) ACH direct exhaust at roof—activated by gas detection. Open overhead doors for make-up air. | 1 cfm/ft² continuous + additional 5 ACH direct exhaust at roof—activated by gas detection. Open overhead doors for make-up air | | |
| Gas Detection | Required for non-odorized GH ₂ (IMC, IFC and NFPA 2, 30A) | Catalytic based system on ~30' grid—Fail-safe design | | | |
| Generator | Required for gas detection (IFC) | Back-up gas detection, ventilation, overhead doors. | | | |
| Architectural | One- to two-hour fire-rated | 2-hour fire-rated interior walls sealed to the extent practical. Fire-rated doors between occupancy/usage areas. | | | |



Summary of Upgrades

GH₂ Building Upgrade Requirements—Minor Repair or Storage Garage

| | Minimum Code Requirements | Typical Recommended Practice | High-End Upgrade Approach | |
|--|---|--|--|--|
| Electrical | No requirements | Remove all arcing/sparking sources above 12' from floor (not a full upgrade to Class I, Division 2) | | |
| Heating | No requirements | No open flames or surfaces >750°F | No open flames or surfaces >750°F Heat-recovery heating units | |
| Ventilation— Continuous (required for diesel as well) | 1 cfm/ft ² -Same as diesel (=2.5 ACH for a 24' ceiling or 3 ACH for a 20' ceiling) and no recirculation (NFPA 88A) | 1 cfm/ft ² Fresh air in at building exterior near floor/exhaust at highest point(s)—no recirculation. Not shared with other spaces. | | |
| Ventilation— Emergency | No requirements | 1 cfm/ft² + additional 5 ACH direct exhaust at roof—activated by gas detection. Open overhead doors for make-up air. | | |
| Gas Detection | Not required | Catalytic based system on ~30' grid—Fail-safe design | | |
| Generator | Not required | Back-up gas detection, ventilation, overhead doors. | | |
| Architectural | One- to two-hour fire-rated | 2-hour fire-rated interior walls sealed to the extent practical. Fire-rated doors between occupancy/usage areas. | | |



Summary of Upgrades

GH₂ Building Upgrade— Alternative Approach

Garage Owners with a limited number of vehicles or a short-term need for upgrades are often looking for a novel approach to reducing time, cost and operational interruption. One method that is sometimes considered is to upgrade a small part of their facility. A commercially available option to this approach is shown to the right. This curtained-off divider isolates a fugitive gas release and includes its own heating and ventilating system to prevent escape of a leak plume to other areas of the garage. This system is novel, but designers are encouraged to review the option with the AHJ to confirm that a curtain system will be accepted.



Representation of Clean Energy's "Easy Bay"



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Summary of Upgrades

Installations to Date:

- 1. Harrisburg, PA
- 2. Lebanon, PA
- 3. Mississauga, ON
- 4. Edmonton, AB
- 5. Bristol, PA
- 6. Baltimore, MD
- 7. Fort Smith, AK
- 8. Clackamas, OR
- 9. Liberty Lake, WA
- 10. Jeffersonville, IN



NGV Easy Bay installed 2015 Lebanon, PA



Summary of Upgrades

Full System Price: \$175,000 to \$250,000

Variables that affect price:

- Amount of heat required
- Height of the ceiling
- How much electrical to relocate
- CNG only, or CNG + LNG
- Size of the area (total square footage) being upgraded



NGV Easy Bay installed 2016 Harrisburg, PA







GH₂ Vehicle Defueling

2018 IFC now defers to NFPA 2 for defueling (Section 2311.8.11). For reference, the requirements from the 2015 IFC are also included below if the local AHJ is operating from the 2015 version of the IFC. NFPA 2 Section 18.7 designates the requirements for depressurizing (defueling) a vehicle tank. They can be summarized as follows:

NFPA 2 Requirements

- 1. Discharged to a safe location.
- 2. Grounded and bonded.
- 3. All equipment and the defueling system must be designed and approved for the purpose of defueling.
- 4. NFPA 2 Section 18.3.3 indicates that indoor defueling would be code-compliant. It is best practice, and strongly recommended, that defueling only take place outdoors, remote from building openings and vented high above any air intakes. Defueling is a relatively infrequent activity, and the additional inconvenience of defueling outdoors is more than balanced by the reduction in risk.

2015 IFC Requirements (applicable only if local AHJ is using this version)

- 1. Use a closed transfer system with atmospheric venting.
- 2. Equipment must be listed and labelled for this purpose.
- 3. Maximum 1-inch vent pipe and flow cannot exceed 1000 scfm—automatic flow control is required. Best practice would require a <u>much</u> lower flow rate to reduce flammability risk in the surrounding area and to ensure that the vehicle tank is not damaged due to excessively fast depressurization.
- 4. Vehicle manufacturer to supply equipment for connection to the vehicle.
- 5. Vehicle tank must be securely anchored (this would not apply if still installed in the vehicle).
- 6. Vehicle and venting equipment must be grounded.
- 7. A documented procedure and AHJ approval of system.
- 8. Location and height of vent is not provided (it is for CNG in section 2308); however, venting must be to a safe location. It is recommended that the designer also comply with the CNG requirements in 2015 IFC Section 2308, as these are more instructive on some issues.





GH₂ Vehicle Defueling





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Garage Owners should <u>not consider</u> <u>defueling to be an alternative to any</u> <u>building upgrade</u>. Defueling is slow and can damage the vehicle tank if improperly performed. It also introduces additional risk. Defueling is an activity that will be practiced and required when a tankmounted component requires maintenance and cannot be isolated from the tank.

The (CNG) defueling systems in the pictures to the left (GH₂ systems would be very similar in appearance) are both codecompliant, but range considerably in price (lowest on the left and highest on the right) due to the additional safety features of the right-hand unit.





Cost

Cost of Upgrades

There is a wide range of costs for upgrades to GH_2 vehicle garages (based on CNG industry experience with very similar upgrades). Many of the variable factors have already been discussed, but in summary the main variables are:

- 1. Size of facility.
- 2. Age and type of construction.
- 3. Climate in the area of the facility (see table on next page).
- 4. Nature of the work performed at the facility and vehicles domiciled there.
- 5. Risk tolerance of decision makers.

A new facility can be designed to be $\underline{GH_2}$ ready at very limited marginal cost, while existing facilities may require extensive renovation. Many existing garages are not fully code compliant for the fuels they currently use, so GH_2 compliance may trigger upgrades to current codes for all fuels.

Estimates for the cost of a gas detection system alone range from approximately \$7 to \$10 per square foot. Overall data collected when researching this course showed many of the facilities in the \$5 to \$30 per square foot range, but upgrade-intensive areas of the garage (major repair bays) were as high as \$80 to \$100 per square foot for that area (this averaged down considerably when parking areas were added to the calculation).



Cost

Cost of Upgrades

Costs to upgrade garages for GH_2 vehicles will be lower in warm climate areas. The table below summarizes those differences.





| Issue: | Cold Climate Garage | Warm Climate Garage |
|---|---|--|
| In cold climates, vehicles are often stored indoors. | This adds a large footprint (several times the size of the maintenance garage) where upgrades are required. | Outdoor parking or parking under a naturally-ventilated canopy requires virtually no upgrade. |
| In cold climates, higher output heating systems are required. | Larger heating systems are more expensive, often requiring heating of make-up air and supplemental heating. | Heating of make-up air may not be required, and heating systems are smaller. |
| Heat recovery | A system for heat recovery should be considered to reduce heating cost and environmental impact. | Heat recovery is typically not required as the heating load is low. In garages with air conditioning, cooling recovery may be considered. |
| In warm (not hot) climates it is common for maintenance garages to operate with overhead doors open much of the year. | This is generally only in summer months so there is no consistent safety benefit. | Operating with doors open provides additional air changes, which adds to the safety of the facility. |

TRAINING MANUAL





Best Practice/Advice from Fleet Owners

In the process of compiling this manual, the fleet Owners interviewed were very forthcoming with advice for others. In some cases, it was requested that this be kept confidential, and therefore a composite list was assembled and is presented. Items are not listed in order of importance. In the case of differing opinions, both have been provided. Many of these recommendations were taken from CNG fleet operators. The items applicable to GH₂ are provided. Some items are not safety related.



Code Required Operating Procedures (2018 IFC Section 2311.8.1)

- 1. Close vehicle fuel isolation valves before any fuel system work.
- 2. Any gaseous-fuel vehicle with fuel system damage must be inspected for fuel system integrity prior to bringing it in the garage.
- 3. Minimum of annual gas detection calibration (2018 IFC Section 916.11).

GH₂ Best Practices/Lessons Learned

- 1. If you are designing a new facility (even if you don't have GH₂ vehicles), design it to be GH₂ "friendly" (easily ventilated roof, HVAC system that will not need to be replaced or heavily renovated).
- 2. If you are designing or upgrading your facility, tour other GH₂/CNG facilities and learn from their experience. Don't reinvent the wheel.
- 3. Our agency limits defueling—only when required, due to our concerns about possible cylinder damage.
- 4. Depending on gas detection system technology, plan for quarterly, semi-annual, or annual gas detection system calibrations and functional tests using gas to trigger the building response systems.
- 5. Provide gas detection test/calibration points accessible at floor level.
- 6. Have hand-held gas detectors (see picture to the left) available to maintenance staff and use them if a leak is suspected and at regular PM intervals.
- 7. Train some maintenance staff as GH₂ cylinder/vehicle inspectors. Recommend having CSA-certified inspectors on staff.



Best Practice/Advice from Fleet Owners

GH₂ Best Practices/Lessons Learned (continued)

- 8. Provide training for station technicians and vehicle technicians before the vehicles arrive.
- 9. Consider allocating some area(s) of the shop as minor repair to reduce upgrade requirements/cost.
- 10. Don't try to "get by" classifying your garage as "minor repair"—it is too limiting. Instead, upgrade for "major repair."
- 11. Locate water heaters, steam cleaners and other hot equipment outside of the vehicle space.
- 12. Provide a "fall arrest" system above one or more bays (the more the better) to allow safe personnel access on top of the buses.
- 13. Design your fueling system and garage to accommodate future fleet growth. Ensure that designers are working with the maintenance director/manger and front-line staff to determine day-to-day and growth needs.
- 14. Train and "sell" employees before vehicles arrive. Everyone should have input, not just top-down.
- 15. Install a generator to back up the ventilation, overhead doors, lighting and gas detection in the event of a power outage



Best Practice/Advice from Fleet Owners



GH₂ SOPs

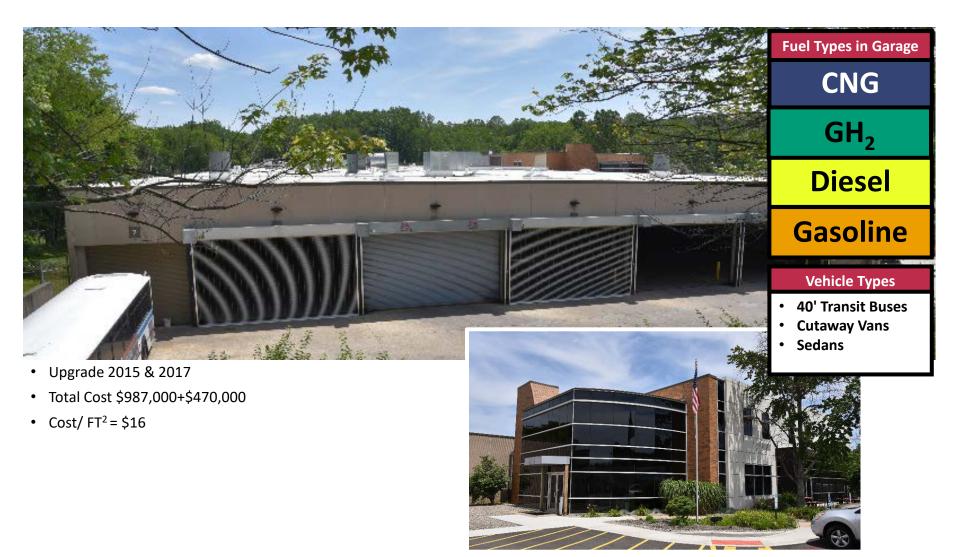
- 1. Train drivers in safe fueling and emergency procedures.
- 2. If the garage has not been upgraded, perform work outdoors. Alternatively, operate indoors with heaters turned off and exhaust fans operating continuously with overhead doors open. Do not leave vehicles indoors unattended.
- 3. Do not fuel vehicles before bringing them in for work, when possible.
- 4. Cut battery knife switch (if so equipped) if vehicles are left in shop overnight (all fuel types).
- 5. Have drivers drain fuel filter at start of shift.
- 6. During normal maintenance work, close ¼ turn valve and run vehicle until it stalls (to empty fuel lines).
- 7. Turn fuel off at tank for overnight in garage.
- 8. Turn fuel off at tank if any fuel system work is required (2015 IFC Section 2311.5).
- 9. Any fuel leak is an immediate "out of service"—vehicle not allowed in shop.
- 10. Scheduled maintenance includes fuel system check.
- 11. Do "hot work" (torches, grinders, welding, and similar work) outdoors, if possible. Use a heat induction unit where possible to avoid an open flame for hot work.





SARTA

Stark Area Regional Transit Authority, Canton, OH





Building Statistics



Maintenance Shop

- Area: 11,000 FT²
- Bays: 6, plus brake repair, plus chassis wash, plus paint booth
- Flat roof with bar-joist structure



Bus Parking Garage

- Area: 83,000 FT²
- Flat roof with bar-joist structure



Heating Systems

Climate



Hydronic ducted rooftop heating unit w/o heat recovery (top right).

Gas-fired boilers produce hot water for heaters (bottom left).

Hydronic unit heaters in maintenance shop (bottom right).









Baseline (Continuous) Ventilation

- No recirculation—fresh air only on makeup air
- No heat recovery
- Exhaust at ceiling height
- 4 ACH

- 1. Rooftop centrifugal exhaust-air fan.
- 2. Warm make-up air introduced at ceiling level.
- 3. Warm make-up air introduced at floor level.









Emergency (Supplemental) Ventilation

- Direct vent (not ducted) roof-mounted
- Exhaust at ceiling height
- 6 ACH additional exhaust flow





SARTA

Case 1: Stark Area Regional Transit Authority

Gas Detection

- 56 point detectors on a >30' grid in maintenance and parking garages
- Catalytic detectors monitor both H₂ and CNG and provide toxic gas (CO) monitoring
- · Automatic calibration
- Detection system powers overhead doors open and starts emergency exhaust fans, starts horns and strobes
- Approximate cost \$5/FT²

Gas detection control panel (near right).

Automatic calibration system (below).









Electrical Upgrades

Lighting was lowered to 18 to 24 inches below ceiling level. No other upgrades inside the garage as 4 ACH of continuous exhaust and/or electrical is >18 inches below ceiling (NFPA 30A).

Generator was added to power all ventilation, gas detection, overhead doors and other critical or required loads.

Miscellaneous Upgrades— Fall Arrest System

1. Rail above several bays to provide safe access for cylinder inspections on heavy buses.







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