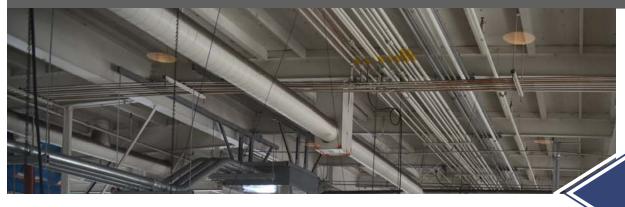
TRAINING MANUAL January 22, 2019



Liquefied Natural Gas (LNG)

Vehicle Maintenance and Storage Garage Modifications: Requirements and Best Practices









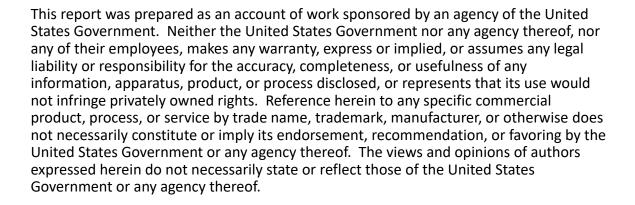




Authored and Produced by: Marathon Technical Services USA Inc. and Clean Fuels Ohio. © 2018 United States Department of Energy and Marathon Technical Services USA Inc.

Disclaimers







Neither Marathon Technical Services USA Inc. nor Clean Fuels Ohio, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by Marathon Technical Services USA Inc. nor Clean Fuels Ohio or any affiliates. Users of this manual accept that by using this manual they are also accepting all liability associated with the use or misuse of the information herein. Users shall read and accept the further conditions outlined in the "Care and Application of this Document" page herein.

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)	
	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	TEFC	Totally Enclosed Fan Cooled electric motor	
	Propane	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			

Table of Contents

SECTION 1: Gene	eral
-----------------	------

SECTION 2: Gas Fundame	
SECTION 7: (326 FIING 3 M P	ntaic

SECTION 3: Codes

SECTION 4: Buildings and Systems

SECTION 5: Defueling SECTION 6: Costs

SECTION 7: SOPs

SECTION 8: Case Studies

Care in the Application of this Document	1
The Purpose of Upgrades	2
Properties of Utility Natural Gas	6
Properties of Liquefied Natural Gas	7
LNG Leaks and Releases	9
Codes that Dictate the Minimum Requirements	14
Types of Garages	16
Building Geometry	20
Ventilation Amount and Location	23
Heating Systems	36
Electrical Upgrades – Required/Recommended	46
Design of a Combustible Gas Detection System	55
Architectural and Other Upgrades	65
Summary of Upgrade Requirements	67
Defueling	74
Costs	76
Best Practice and Advice from Fleet Operators	80
Case 1- City of Long Beach, CA	LNG-C1-1
Case 2- City of Sacramento, CA	LNG-C2-1

About the Author



Rob Adams
P.Eng., CPA, CMA, PMP, CMC, MBA
Principal and Founder of Marathon
Technical Services

radams@marathontech.ca

Rob Adams

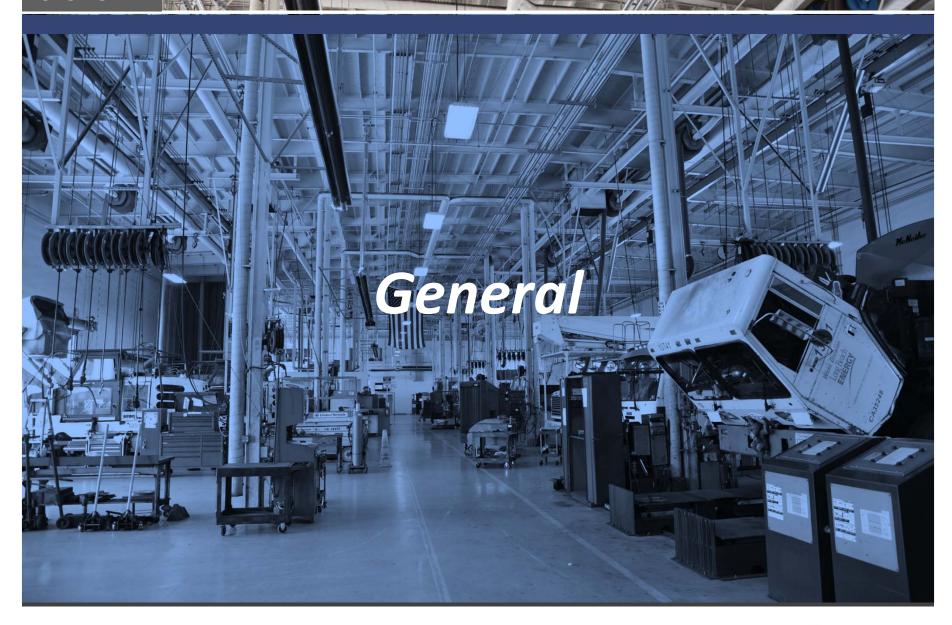
- A gaseous-fuel industry pioneer and expert
- Professional Engineer with full-time experience in the gaseous-fuels industry since 1984
- Over 200 gaseous-fuels projects and over 50 vehicle garage upgrade projects
- Job experience working for a large gas utility, co-founder of a major gaseous-fuels equipment supplier and founder of Marathon Technical Services
- Experience in all gaseous fuels with a focus on CNG
- Over 25 years of industry training experience
- radams@marathontech.ca

Marathon Technical Services

- Specialist consultant in the alternate fuels market
- Technical and business consulting for fueling station and garage upgrade projects
- Forensic incident investigation and cause analysis
- www.marathontech.ca
- 519.699.9250

Clean Fuels Ohio

- Clean Cities Coalition for the State of Ohio
- www.cleanfuelsohio.org
- 614-884-7336





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.

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 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.





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 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

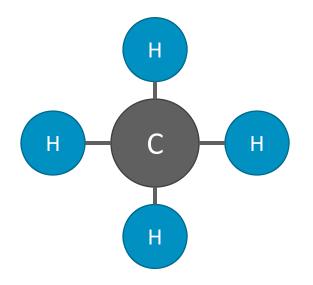
User error is often the largest single contributor to the likelihood of an incident, and in many ways it is the easiest to control. Fleet Owners can and should ensure that personnel that interface their fleet's operations be appropriately trained then drilled to reinforce the training. Automatic and 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 previously. 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 Utility Natural Gas



Methane

 CH_4

C = Carbon

H = Hydrogen

	Property	Value
1	Constituents	90 to 95 percent Methane ($\mathrm{CH_4}$). Other hydrocarbons including Ethane ($\mathrm{C_2H_6}$), Propane ($\mathrm{C_3H_8}$), Butane ($\mathrm{C_4H_{10}}$). Inert gases including Nitrogen.
2	State	Gaseous in utility gas system and at atmospheric temperature and pressure.
3	Specific Gravity (weight vs. air)	0.55 to 0.65 (average 60% of weight of air at same temp. and press.)— rises in air of same temperature.
4	Flash Point (temperature where fuel vaporizes from liquid form)	Approximately -300°Fahrenheit.
5	Autoignition Temperature	Approximately 1000°Fahrenheit.
6	Flame Color	Yellow-orange to blue.
7	Flammability range in air at atmospheric pressure	Lower Flammability Limit (LFL)~5 percent. Upper Flammability Limit (UFL)~15 percent.
8	Odor	Methane is odorless so mercaptan odorant is added in quantities so that the average person can smell it (rotten eggs) at concentration of 1 percent gas in air or 20 percent LFL.
9	Toxicity	Non-toxic, but asphyxiant in sufficient concentration.
10	Water Content	Less than 7 pounds of water per million cubic feet of gas (7# $\rm H_2O/MMSCF$).
11	Source	Domestic fossil fuel that is cleaned and purified for use in pipeline system. Gas produced from anaerobic digestion of biomass material—also called Renewable Natural Gas (RNG). Gas is cleaned and purified for use in pipeline system.



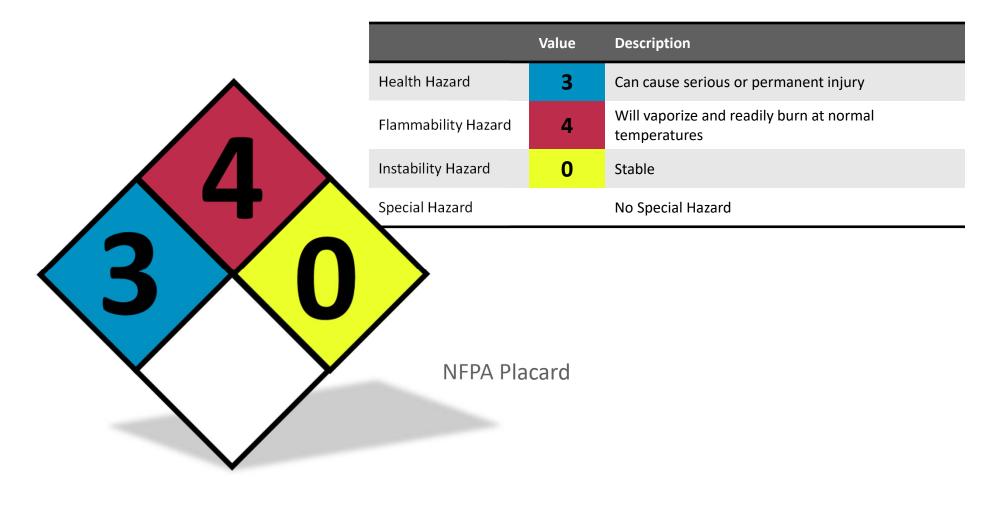
Properties of Liquefied Natural Gas

	Property	Value
1	General	Liquefied natural gas—tends to have higher methane content than pipeline natural gas as some heavier hydrocarbons may be removed during liquefaction.
2	State	Cryogenic liquid in the fueling station and vehicle tank—stored at <-259°Fahrenheit. Gaseous on the vehicle downstream of the tank.
		Typically 50 to 150 psig.
3 Nominal Pressure in Tank	Nominal Pressure in Tank	Approximately 600 times the density of natural gas at atmospheric pressure.
4	Density	Approximately 26.6 pounds per cubic foot.
5	Energy Comparison to Gasoline	5.38 pounds of LNG=1 gallon of gasoline.
6	Energy Comparison to Diesel	6.06 pounds of LNG=1 gallon of diesel.
7	Odor	No odor and not odorized.
8	Pump Octane Number	~120
9	Water Content	No water.

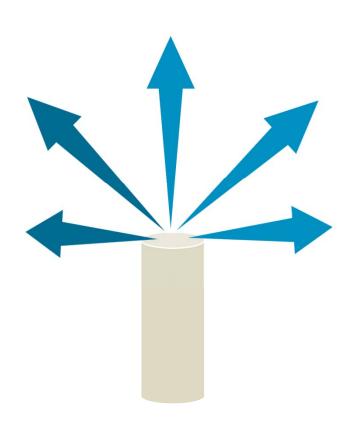
LNG Vehicle Tank



Properties of Liquefied Natural Gas



8



Fast Leak—Any Direction

Leak Behavior

Although natural gas is lighter than air, there are conditions under which it will not always rise immediately.

Slow Leak

Under a slow leak scenario, such as a fitting leak that is not audible, a liquid leak should vaporize before a liquid pool can form. A properly ventilated LNG 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 vehicle leaks at Planned Maintenance (PM) intervals. A vehicle tank relief valve release should also fall into this category, as there will be a small "burb" of cold gas that will reduce the pressure and the relief valve will reseal.

Fast Leak—Any Direction

Under a fast leak scenario, such as a serious fitting leak or component failure that results in an audible leak, the LNG will have a jet force and will release in whatever direction it is pointed. If it is a liquid leak, the liquid will fall to the floor and pool until it is fully vaporized (which happens quickly). The vaporized liquid will be colder than the surrounding air and will tend to hang by the floor until it warms sufficiently to be buoyant, at which point it will rise to the ceiling.

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

Leak Behavior

Although natural gas is lighter than air, there are conditions under which it will not always immediately rise.

Fast Leak—Any Direction— Phase 1

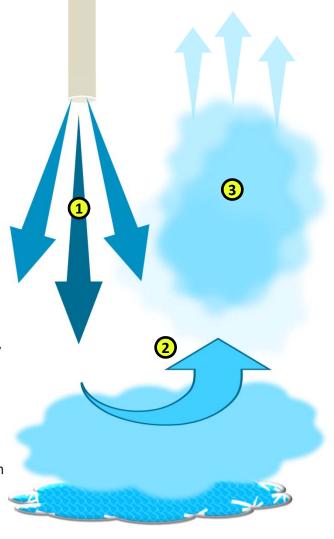
Under a fast leak scenario, such as a serious fitting leak or component failure, the gas or liquid will have a jet force and will release in whatever direction it is pointed. In a liquid leak scenario, liquid will release downward (1).

Fast Leak—Any Direction—Phases 2 and 3

Liquid will pool below the leak if sufficient volume is leaked in a short time. Gas leaking from an LNG system is vaporizing from a cryogenic liquid state and the vapor will be very cold as it evaporates from the pool. The cold gas will be heavier than air until the gas warms. This cold gas plume will tend to remain at the floor (2) until it warms to near-atmospheric air temperature.

As it warms, it will rise as a plume or cloud toward the ceiling (3).

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



It is very unlikely that liquid-state natural gas will spill to the floor, as vaporization will be very fast.

Flammable Range

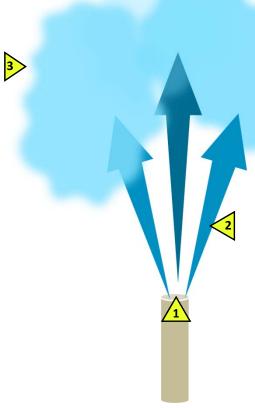
The comments below apply to vaporized gas.

It is well understood that the flammable range of natural gas is between 5 percent (LFL) and 15 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 narrow range of flammability is a characteristic that greatly increases the safety related to the use of natural gas. There is a common misperception that if very high air changes are provided in a garage, then 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 and the 18 inches at the floor for LNG, 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.



Natural 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.



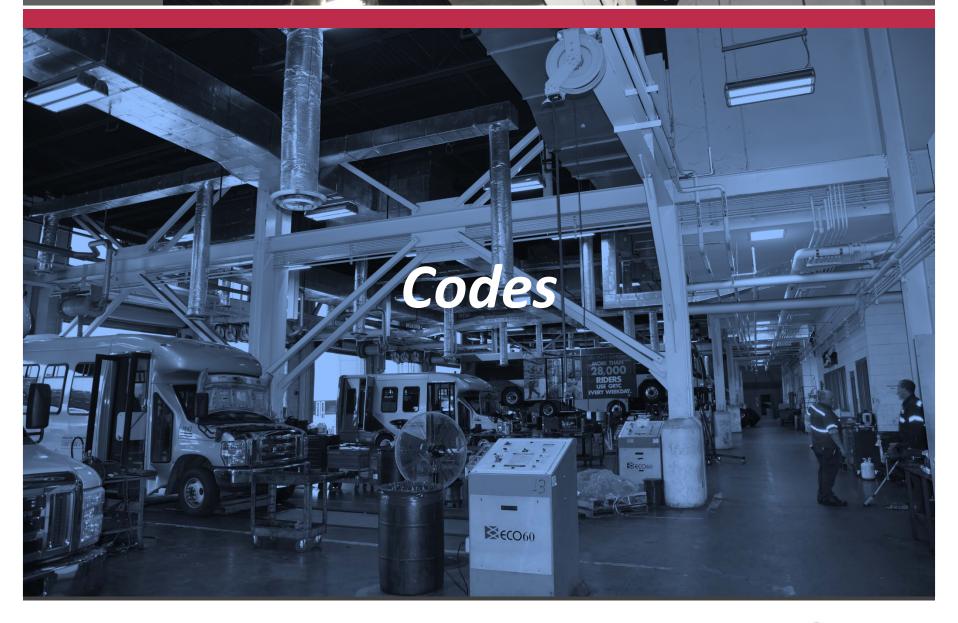


Potential Causes of a Release

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. The most common small leak is the vehicle tank relief valve, which is designed to relieve pressure due to "boil off" in the tank. Excess pressure will accumulate if the vehicle has not been driven for several days, or if the vacuum jacket around the tank is compromised. This pressure is intentionally relieved by the relief valve, which will reseal after the excess pressure is relieved.

Fast leaks are very unusual and would result from a failure of a pressure connection, component, or from human error during repair.

12





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 manual, and to review the full text of the document that pertains to their project. Code requirements that are duplicated between NFPA 30A, 88A and 70 will be referenced to the code most applicable.

14

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/2018international-codes-and-references/2018international-fire-code-andreferences.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 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, other requirements)

NFPA 52: Vehicular Natural Gas Fuel Systems Code (https://catalog.nfpa.org/NFPA-52-Vehicular-Natural-Gas-Fuel-Systems-Code-P1182.aspx?order src=D747&gclid=EAIaIQ obChMIx jKjsaV3QIVxrfACh029gvTEAAYAS AAEgKLKvD BwE) (applies only to natural gas station design and indoor fueling which are outside of the scope of this manual)

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 30A. 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.



Defined in 2018 NFPA 30A

— Code for Motor Fuel Dispensing Facilities and Repair Garages



- 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) (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.





Types of Garages

Defined in 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 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.



17

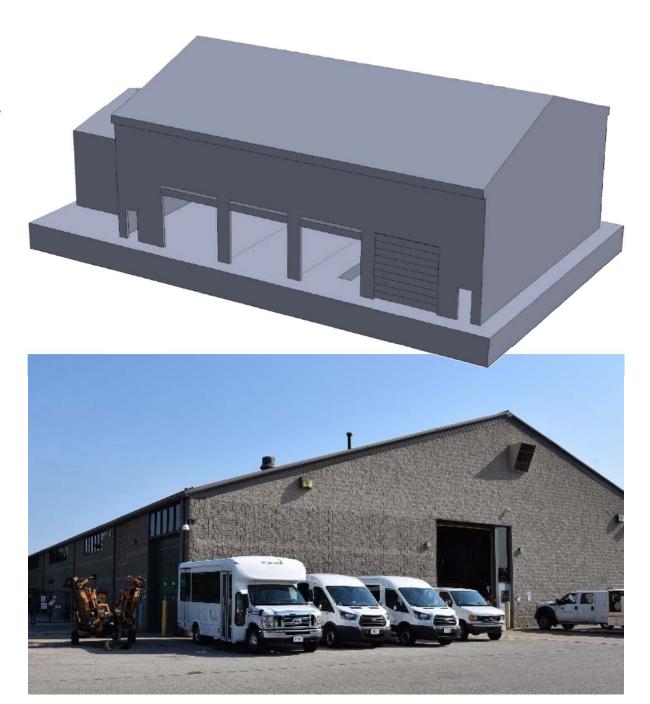




Building Geometry

Gable Roof with Single or Double Pitch

Pitched roof structures are <u>very</u> well suited to lighter-than-air fuels (CNG, LNG and H₂), 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.

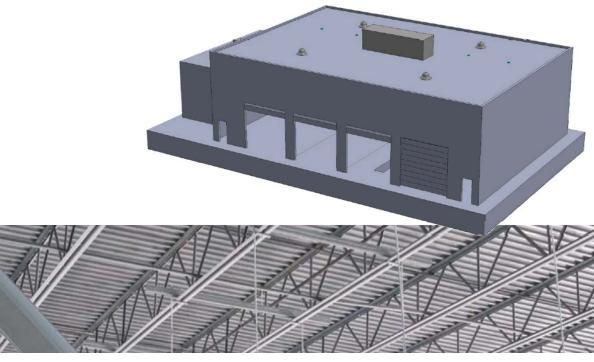




Building Geometry

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 $\rm H_2$), 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.





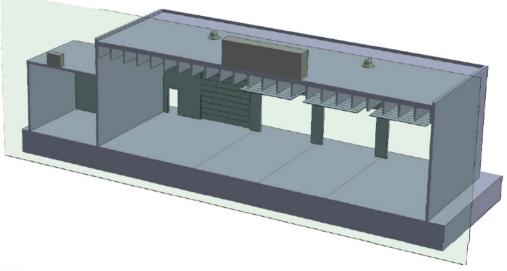


Building Geometry

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 $\rm H_2$), 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.

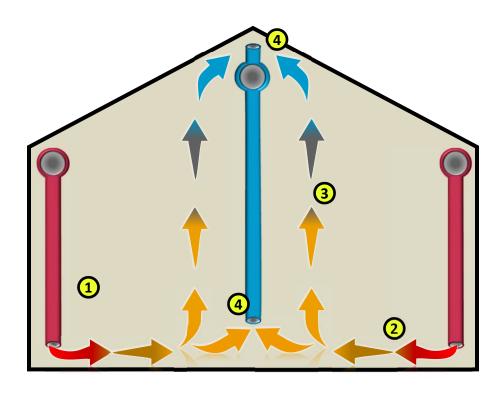
All ventilation in a vehicle garage must be non-recirculating. This requires 100 percent fresh air to ensure that any exhausted gas/air mixture is not reintroduced into the building interior. The use of systems that intentionally recirculate a portion of the exhaust air to save on heating costs is not 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 (spaces that have not been upgraded for LNG vehicles).

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, but also at floor level. 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

2018 IMC and 2018 IFC (2018 IFC 2311.8.8 refers to the requirements of the 2018 IMC)

Make-up air is to be introduced near floor level uniformly on exterior walls at a continuous rate of 5 ACH (2018 IMC 502.16.2.1 and .2), or not continuous but automatically started with an interlock to the gas detection system (2018 IMC 502.16.2.2.2). Exhaust ventilation is to be at the high point of the room on exterior walls or roof.

2018 NFPA 30A

This code does not explicitly have minimum mechanical ventilation requirements except the 4 ACH required as an alternative to upgrading the top 18 inches of the space to Class I, Division 2 (2018 NFPA 30A Section 8.2.1—this is somewhat contradicted by 2018 NFPA 30A Table 8.3.2 that specifies a Division 2 location unless 1 cubic foot per minute per square foot of floor space is provided).

Best Practice Tip

If the designer prefers not to provide 5 ACH of continuous exhaust as required by the IMC, best practice is to use either the 4 ACH or the 1 cfm/square foot required by 2015 NFPA 88A (this standard applies to parking structures but can be applied as a minimum ventilation level in the major repair garage).

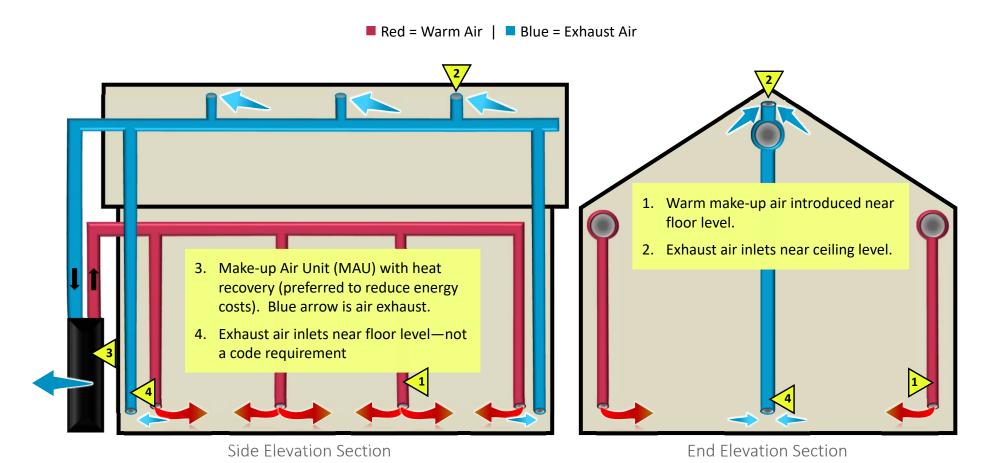
Code Requirements for Minor Repair Garages and Parking Garages

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

- 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.







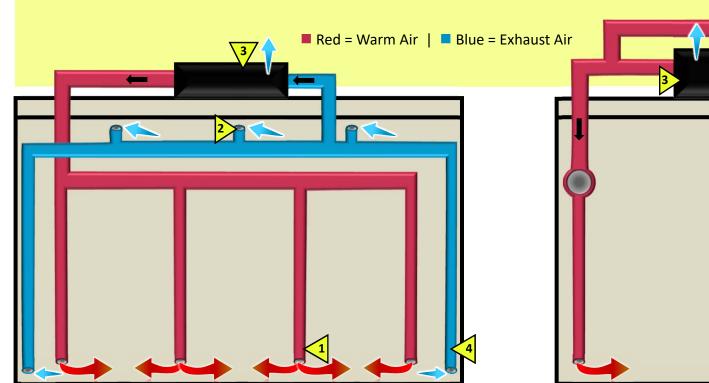


27

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

- 1. Warm make-up air introduced near floor level.
- 2. Exhaust air inlets near ceiling level.

- 3. Make-up Air Unit (MAU) with heat recovery (preferred to reduce energy costs). Blue arrow is air exhaust.
- 4. Exhaust air inlets near floor level—not a code requirement.



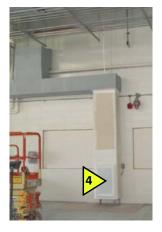






Best Practice Baseline (Continuous) Ventilation for Flat Roof with Open-Web or Bar-Joist Structure—Typical Installation

- 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.



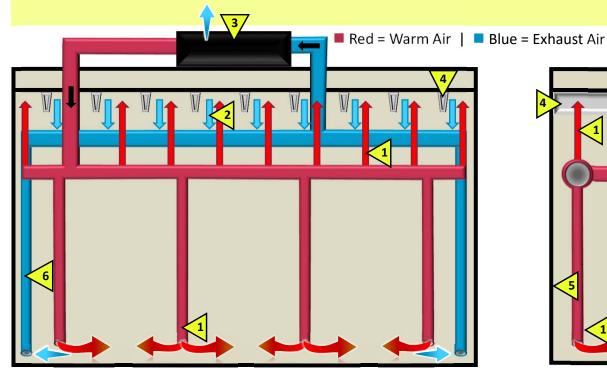




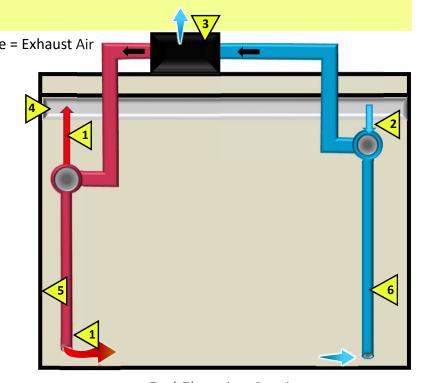
Best Practice Baseline (Continuous) Ventilation for Flat Roof with Precast T-Beams

- 1. Warm make-up air introduced near floor 3. Make-up Air Unit (MAU) with heat level and in each pocket.
- 2. Exhaust air inlets in each pocket.
- recovery (preferred to reduce energy costs). Blue arrow is air exhaust.
- 4. T-beams.

- 5. Outside wall with overhead doors.
- 6. Exhaust air inlets near floor level—not a code requirement.







End Elevation Section



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





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.

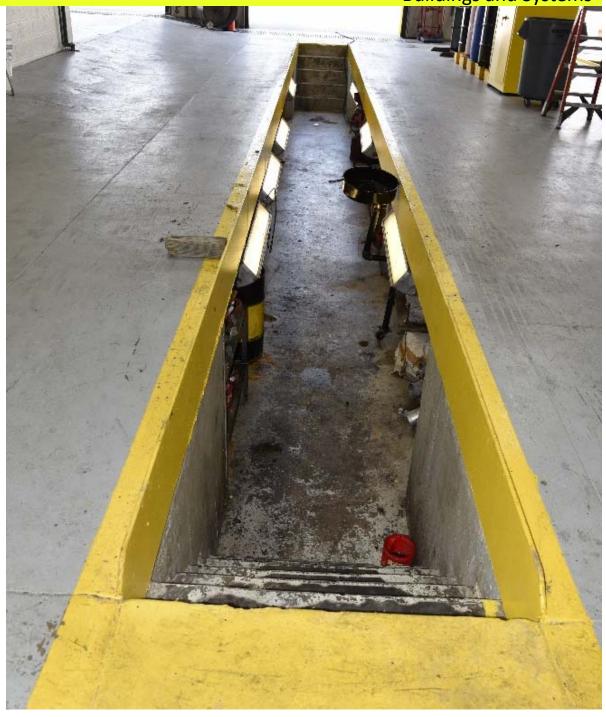
Buildings and Systems

Ventilation Amount and Location

Best Practice Baseline (Continuous) Ventilation for Service Pits

Pits must be ventilated for conventional liquid fuels and LPG (2018 IMC 502.15); therefore, any pits should be brought to the required standard.

It is critical that any pits in an LNG vehicle garage be brought up to current standards, as it is possible for a liquid or vaporous LNG plume to dwell in a pit.



Buildings and Systems

Ventilation Amount and Location

Best Practice Baseline (Continuous) Ventilation for Floor Areas

Exhaust ventilation in conventional-fuel garages often utilize floor-level inlets; however, with lighter-than-air fuels, ceiling-level inlets are required. With LNG it is best practice (although not a code requirement) to provide both floor-level and ceiling-level exhaust. This provides dilution and exhaust of cold heavy vapor as well as exhaust of the warmed plume that rises to the ceiling.





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.





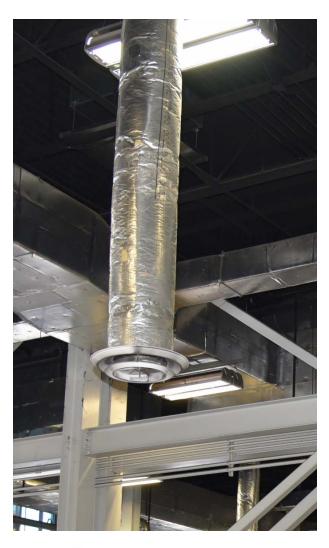
Best Practice Ventilation Design

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, designers should attempt to maximize the separation between these; best practice would be much more (this clause references return air but would apply to exhaust air). It is recommended that designers provide a minimum 25 feet of separation between these openings, but more may be required due to prevailing winds and air currents around buildings (best practice). Designers should also 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 natural gas autoignition temperature of approximately 1000°Fahrenheit (F), heating systems must be designed to maintain temperatures that are safely below the autoignition temperature. NFPA 30A 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.
- 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.

36





Code Requirements for Major Repair Garages

2018 NFPA 30A

- 1. 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).
- 2. Open-flame heaters and heaters with surface temperatures greater than 750°F are not permitted (Section 7.6.6).

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).

Best Practice Tip

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.

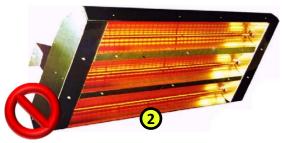
The radiant gas heater may also cause flareouts from its burner since these are not sealed on standard units.

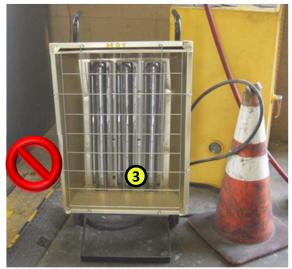
Steam cleaning units need to be located in a non-vehicle room with separate ventilation.

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 an IR type and will need to 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 an LNG 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 will increase the likelihood of a boil off relief valve activation from the vehicle tank. Owners may consider an outside vent line that is connected to the vehicle relief valve vent line to direct any relieved gas directly out of the booth and the building.



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.









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.

43



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. Radiant heating systems that are safe for CNG are also safe for LNG.

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 D

- 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.

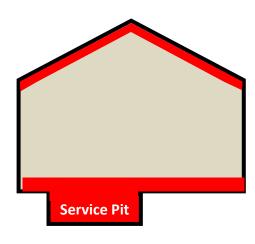
This is an area where one might frequently expect to have a flammable mixture present. There are no Class I, Division 1, Group D locations required by any of the codes listed herein that are related to the use of LNG in the garage.

Class I, Division 2, Group D

- 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.
- An area adjacent to a Class I, Division 2, Group D 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 30A designates a Class I, Division 2, Group D location within 18 inches of the ceiling in a CNG or LNG major repair garage. This requirement is waived if the garage is equipped with 4 Air Changes per Hour (ACH) of continuous ventilation.

Code Requirements for Major Repair Garages



2018 NFPA 30A

The 18 inches at the ceiling are designated as Class I, Division 2 (specified in 2018 NFPA 30A for CNG but would apply to LNG as well) unless a minimum of 4 ACH of the entire room is provided, then no classification is codified (2018 NFPA Section 8.2.1 and A.8.2.1—this is somewhat contradicted by 2018 NFPA 30A Table 8.3.2 that specifies a Division 2 location unless 1 cubic foot per minute of exhaust ventilation per square foot of floor space is provided). (2017 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.) In most cases of retrofit, capital cost considerations and interruption make the 4 ACH the desirable approach. 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.

47

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.

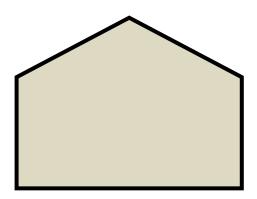
2017 NFPA 70

In addition to the ceiling area, the NEC also designates a Class I, Division 2 zone within 18 inches of the floor (NFPA 70 Table 511.3(C)).





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).

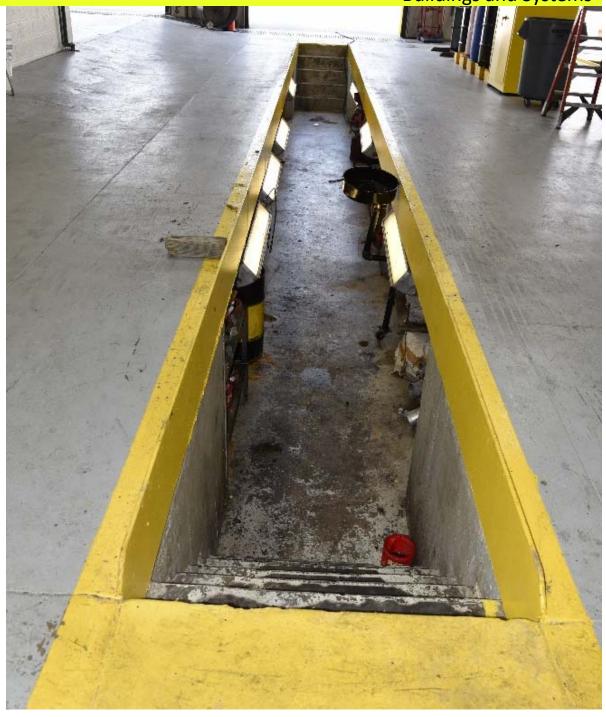
Buildings and Systems

Electric Upgrades— Required/Recommended

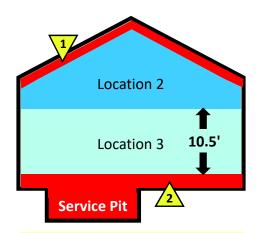
Best Practice Baseline (Continuous) Ventilation for Service Pits

For all fuels, pits must be electrically classified as Class I, Division 1 unless at least 1 cfm/ft² of exhaust ventilation is provided within 12" of the floor of the pit, in which case the electrical classification within the pit is Class I, Division 2 (for major repair garages) (2017 NFPA 70 Table 511.3(C)).

It is critical that any pits in an LNG vehicle garage be brought up to current standards, as it is possible for a liquid or vaporous LNG plume to linger in a pit.



49



- Red location is 18" Class I, Division 2 area specified in NFPA 30A
- 2. Red location is 18" Class I, Division 2 area specified in 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, and at the floor since LNG could dwell there until it is fully vaporized and warmed to near ambient temperature.

Best Practice for Electrical Upgrades

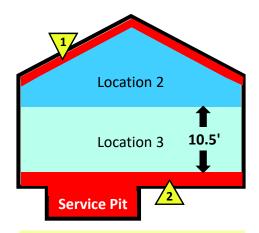
Code upgrades to the top 18 inches are required; however, the best practice approach also addresses two additional locations as shown to the right with a delineation of approximately 12 feet from the floor or 10 feet from the top of the floor-level hazardous area (this delineation point is best practice in the industry but is not a code requirement). The focus with this upgrade is not 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 to 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.



50



- 1. Red location is 18" Class I, Division 2 area specified in NFPA 30A
- 2. Red location is 18" Class I, Division 2 area specified in NFPA 70

Best Practices for Electrical Upgrades (continued)

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 gasdetection-activated electrical contactor from the loud and sparking devices if gas is detected.
- 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 4 ACH exemption from the Class I, Division 2 requirement.

Best Practice for Electrical Upgrades—Sample Details



There is misunderstanding of Class I, Division 2, Group D 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.



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



53

Code Requirements for Major Repair Garages

2018 IMC, 2018 IFC, 2018 NFPA 30A

Since LNG is a non-odorized fuel, there is a code requirement to install a combustible gas detection system (see 2018 NFPA 30A Section 7.4.7 and 2018 IFC Section 2311.8.9). Additional code references are inserted into the applicable paragraphs of this section. 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. It is therefore a best industry practice that is almost universally used, and it is recommended herein.

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.



Best Practice for the Design of Combustible Gas Detection Systems

There are a number of design variations possible, and the final design will depend greatly on the configuration of the garage. The following section describes several approaches, each with its own benefits and limitations. 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



Point Detector

Measures gas concentration 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. Point detectors use either catalytic technology or infrared (IR) technology. Point detectors tend to be more cost effective in smaller spaces than open-path detectors (on the right), but can also be cost effective in large spaces. This is the most common detector style in use today.



Open-Path Detector

Measures gas along a path of up to (typically) 400 feet in the garage. A transmitter and receiver are required. Over shorter distances, a mirror can be used to reflect the signal back to a receiver beside the transmitter (above). This system will not report actual LFL at a specific location but provide an indication of a gas release over a broader area than a point detector. Open-path units use IR technology. Open-path detectors tend to be more cost effective in larger spaces.





Terminology and Technology

Catalytic (pictured top left)

Generally regarded as older technology, catalytic units are less expensive to purchase, but the sensor requires 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.

This is the only sensor technology used for H_2 sensing, and can be configured to monitor for hydrocarbons and H_2 using the same sensor. In a garage with LNG and GH_2 vehicles, this may be the best sensor type to use.

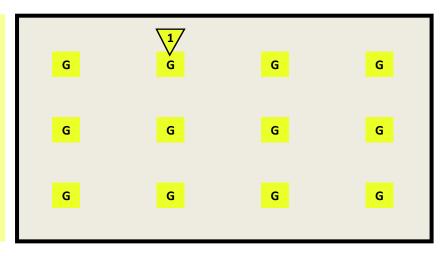
Infrared (pictured bottom left)

Measures gas concentration by measuring absorption of infrared light which is specific to each hydrocarbon. IR units are more expensive than catalytic, but should last 7 to 10 years, with annual calibration recommended.

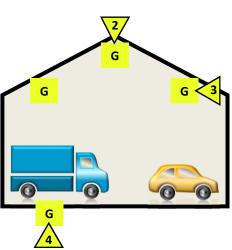
Typical Layout Using Point Detectors

- 1. Point detectors located approximately 15' from wall and 30' from the next detector (NTS).
- 2. Required location: at high point of garage.
- 3. Recommended location: directly above vehicle bays.
- 4. Required location: in vehicle service pits.

Plan View Inverted Roof Section



End Elevation Section



Typical Layout Using Point Detectors

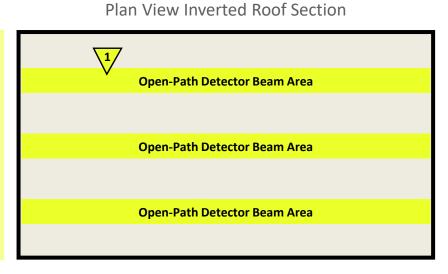


1. IR type combustible gas point detectors located in 3 rows above bays and at peak of maintenance shop areas.

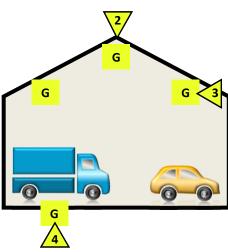


Typical Layout Using Open-Path Detectors

- 1. Open-path detectors located approximately 15' from wall and 30' from the next detector.
- 2. Required location: at high point of garage.
- 3. Recommended location: directly above vehicle bays.
- 4. Required location: in vehicle service pits.



End Elevation Section



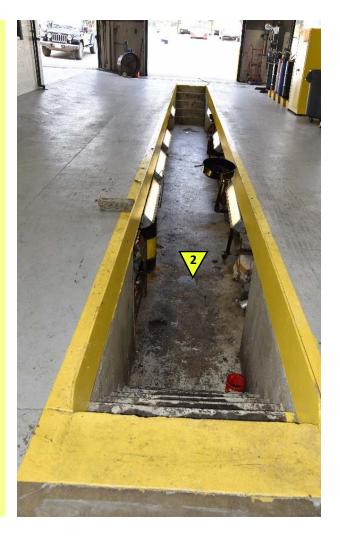


Additional Design Considerations

- 1. Gable-style garages can utilize fewer detectors (for example just at the peak) if there is a steep pitch (for example >3/12).
- 2. 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.
- 3. T-beam maintenance garages can place one (or more) point detectors directly above the vehicle.
- 4. For T-beam <u>parking</u> garages, an open-path type detection system may be preferable. In this scenario, a point detector(s) should be installed in the exhaust air duct as well.
- 5. 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.
- 6. Assign a unique number to each detector and label it, so it is visible from the floor.
- 7. Gas detection circuits must be monitored for integrity as required in NFPA 72 (2018 NFPA 30A Section 7.4.7.4).
- 8. Gas detection controllers must be listed and labelled to UL 2017 or UL 864 and detectors to UL 2075 for Methane (2015 IFC Section 2311.7.2.1.1).
- 9. Gas detection systems must be provided with standby power (2018 IFC Section 916.5).



- 1. IR type combustible gas and CO/NO₂ (toxic gas) point detectors located in floor-level exhaust duct of maintenance shop areas. This is a best practice, not a code requirement, but it provides an early warning of an LNG release and an indication of noxious fumes in the garage. In both cases, additional ventilation is started.
- 2. Service pits in LNG vehicle garages require combustible gas detection (2018 IFC 2311.8.9 and 2016 NFPA 30A 7.4.7.1).



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) (2018 NFPA 30A Section 7.4.7.1) (2018 IFC Section 916.8.1)	50% LEL (Level 2)	Manual Push Buttons	Trouble	System Failure (2018 NFPA 30A Section 7.4.7.3) (2018 IFC Section 2311.8.9.2) (This would be failure of the overall controls)
Gas Detection Strobes (2018 NFPA 30A Section 7.4.7.2) (2018 IFC Section 2311.8.9.1)	X	Х	Х	X	X
Gas Detection Horns (2018 NFPA 30A Section 7.4.7.2) (2018 IFC Section 2311.8.9.1)	x	Х	X		Х
Fuel Valves to Building Heaters (close) (2018 NFPA 30A Section 7.4.7.2) (2018 IFC Section 2311.8.9.1)	X	х	Х	Х	X
Open Overhead Outside Doors (2018 NFPA 30A Section 7.4.7.2) (2018 IFC Section 2311.8.9.1) and Close Doors Between Shop and Adjacent Vehicle and Non-vehicle Areas	х	Х	Х	х	X
Start Emergency Fans (2018 NFPA 30A Section 7.4.7.2) (2018 IFC Section 2311.8.9.1)	Х	Х	Х	X	X
Remove Power for Crane and Welding/Sparking/Noisy Equipment	x	Х	X	Х	Х
Report and Display Fault on FACP		х	Х		X
Automatic System Reset When Condition Clears (Non-latching)	x			Х	
Manual System Reset When Condition Clears (Latching)		Х	Х		X

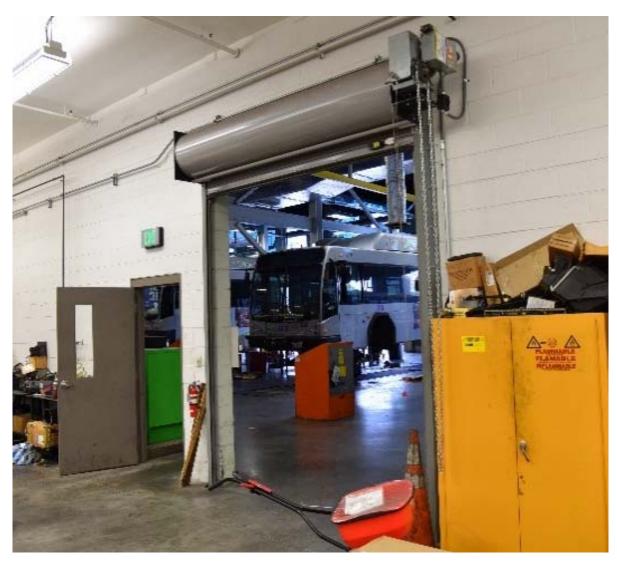


Architectural and Other Upgrades

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 (pictured). 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





General (continued)

- 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 left) (2018 NFPA 30A Section 7.6.3 and A.7.6.6).
- 8. Ignition sources, such as a hot work area (pictured bottom left), should be separated from the 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

Recommended Equipment Upgrades

- 1. The exhaust temperature of natural gas engines is higher than conventional diesel engines (but similar to clean diesel engines). High temperature exhaust hoses will be required if engines are to be run in place in a maintenance garage.
- 2. Natural gas engines may require different oil than diesel engines—this will require an additional tank, piping and dispensing system.

LNG 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 4 ACH (NFPA 30A)	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 30A)	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 (NFPA 88A)	1 cfm/ft ² or 4 ACH if declassification of top 18" is required. Fresh air in at building exterior near floor/exhaust at highest point(s)—no recirculation. Not shared with other spaces.		
Ventilation— Emergency	5 ACH Fresh air in at building exterior near floor/exhaust at highest point(s)—no recirculation (IMC, IFC)	4 ACH continuous + additional 1 (or more) ACH direct exhaust at roof—activated by gas detection. Open overhead doors for make-up air.	4 ACH continuous + additional 5 ACH direct exhaust at roof—activated by gas detection. Open overhead doors for make-up air.	
Gas Detection	Required for LNG (IMC, IFC and NFPA 30A)	IR 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.		



LNG 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	IR 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.		



LNG 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"



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



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







Defueling

LNG Vehicle Defueling

There is no code requirement directly requiring a defueling system or defueling capability in an LNG vehicle garage; however, there are several safety and environmental benefits:

- 1. Tank evacuation is required to allow repair of tank or in-tank pump.
- 2. The tank evacuation system safely transfers LNG from the vehicle tank using vaporized LNG to push liquid LNG and safely stores it using a closed system (as with other gaseous fuels, some residual fuel at low pressure (about 25 psig) will be vented to atmosphere). Fuel removed from a tank can then be returned to a vehicle.
- 3. The evacuation system is safer for personnel and the public than venting to atmosphere, which has been common industry practice. The evacuation system is also faster, so it reduces labor cost.
- 4. The closed evacuation system is environmentally responsible.







Cost

Cost of Upgrades

There is a wide range of costs for upgrades to LNG vehicle garages. 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 <u>LNG ready at very limited marginal cost</u>, while existing facilities may require extensive renovation. Many existing garages are not fully code compliant for the fuels they currently use, so LNG compliance may trigger upgrades to current codes for all fuels.

Estimates for the cost of a gas detection system alone range from approximately \$5 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 LNG vehicles are generally 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.	





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 but have applicability to LNG. 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. LNG vehicles shall not be brought into a repair garage with more than 170 psig in the vehicle tank—the actual pressure must be measured and recorded.
- 4. Minimum of annual gas detection calibration (2018 IFC Section 916.11)

LNG Best Practices/Lessons Learned

- 1. Be committed to your fuel of choice—don't "dabble" in alternate fuels.
- 2. If you are designing a new facility (even if you don't have LNG vehicles), design it to be LNG "friendly" (easily ventilated roof, HVAC system that will not need to be replaced or heavily renovated).
- 3. If you are designing or upgrading your facility, tour other CNG and LNG facilities and learn from their experience. Don't reinvent the wheel.
- 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.



Best Practice/Advice from Fleet Owners

LNG Best Practices/Lessons Learned (continued)

- 7. Provide training for station technicians and vehicle technicians before the vehicles arrive.
- 8. Consider allocating some area(s) of the shop as minor repair to reduce upgrade requirements/cost.
- 9. Don't try to "get by" classifying your garage as "minor repair"—it is too limiting. Instead, upgrade for "major repair."
- 10. "Do not use a single bay upgrade to save cost." In some cases, it is lower cost to upgrade the entire shop and it provides much more operational flexibility.
- 11. Locate water heaters, steam cleaners and other hot equipment outside of the vehicle space.
- 12. Use the same fuel lanes for all fuels.
- 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

LNG 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.





OF LONG REPORTED TO THE PORTED TO THE PORTED

City of Long Beach, Long Beach, CA



Built LNG and CNG compliant 2008

Fuel Types in Garage

CNG

LNG

Diesel

Gasoline

Vehicle Types

- Refuse Trucks
- Medium and Light Duty Vehicles
- 100 Heavy CNG Trucks—growing to 200
- 2,700 pieces of equipment
- 1,600 pieces of rolling stock



Building Statistics

Maintenance Shop

- Built "CNG and LNG Ready" in year 2000
- Light vehicle shop area: 21,920 ft2, 19 bays, ceiling height 30ft (top right)
- Medium/Heavy vehicle shop area: 21,150 ft2, 20 bays, ceiling height 30ft (bottom right)
- Flat roof with bar-joist structure
- Both shops are "major repair"
- Vehicles stay in shop overnight as required with continuous shop ventilation
- No maintenance pits







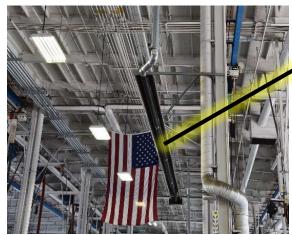




Heating Systems

Climate





Gas-fired, sealed, CNG rated, 750°F temperature. Ducted combustion air. Heaters operate primarily in early morning during cooler months.

Explosionproof electric unit heaters used in the light vehicle maintenance garage.





Exhaust Ventilation

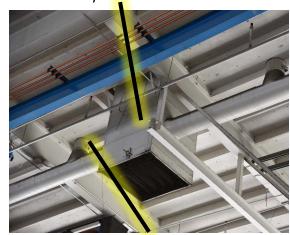
Baseline (Continuous) Ventilation

- No recirculation—no forced make-up air
- Garage operates most of the year with doors open
- Doors have screens to provide make-up air
- Exhaust at floor and ceiling height
- 5 ACH





Ceiling height exhaust –fans run continuously.



Note the small branch duct to ventilate small pockets.



Floor height continuous exhaust—ventilation for LNG vapor as well as conventional liquid fuels.







Gas Detection—new in 2016 (\$118K system cost)

- Point detectors on a ~30' grid
- Detection system powers overhead doors open and starts emergency exhaust fans, starts horn and strobes
- 90-day calibration and test gas response interval

Shunt trips remove power at 50% LEL.

Point detectors located in all maintenance shops(top left).

Annunciation lights in various locations inside and outside the maintenance shops (top center).

Control panel (top right) and remote annunciation panel in lobby (bottom right).

















Miscellaneous Upgrades— Fall Arrest System

Defueling System

- Defueling system without gas recycle to compressors at CNG station
- Equipped to defuel LNG
- Defueling is done only for repairs that cannot be isolated from the vehicle tank(s)—defueling has not yet been used



Rail above several bays to provide safe access for cylinder inspections on rooftop-mounted cylinders (refuse trucks).



City of Sacramento, Sacramento, CA



Built LNG and CNG compliant in 2008

Fuel Types in Garage

CNG

LNG

Diesel

Gasoline

Vehicle Types

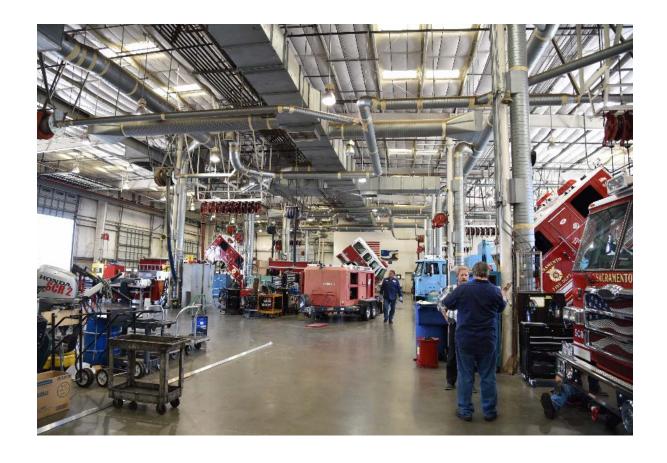
- Refuse Trucks
- Medium and Light Duty vehicles
- Will be phased out of LNG in ~ 2022



Building Statistics

Maintenance Shop

- Built 2001
- "Major repair" garage
- Bays: 10 heavy vehicle
- Flat (very shallow pitch) roof with bar-joist structure





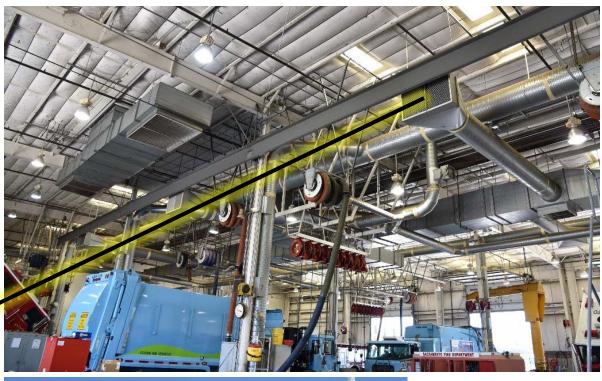
Heating Systems

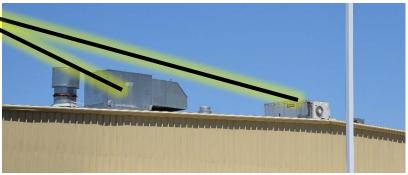
Climate



Direct-fired rooftop make-up air unit providing heated make-up air through ducted registers.

Direct-fired rooftop make-up air unit providing heated make-up air through ducted registers.









Floor-height continuous exhaust—ventilation for LNG vapor as well as conventional liquid fuels.

Ceiling-height continuous exhaust.

Heating Systems

Baseline (Continuous) Ventilation

- No air recirculation
- Garage operates most of the year with doors open—closed during cooling season as garage is air conditioned
- Exhaust at floor and ceiling height
- 5 ACH
- Start fans on gas detection and at 4:00 am to operate all day
- Vehicles are stored in the garage overnight and this garage is used for all types of maintenance and repair work



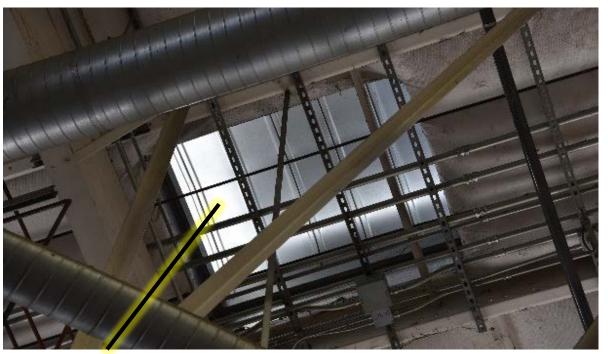




Exhaust Ventilation

Emergency Exhaust





Ceiling-height exhaust tied to gas detection to exhaust CNG or vaporized LNG.





Gas Detection

- Point detectors on a ~30' grid
- Exhaust-mounted detectors to monitor for LNG leaks
- Detection system powers overhead doors open and starts emergency exhaust fans, starts horn and strobes
- Calibration and testing conducted quarterly

Duct-mounted detectors on floor-level exhaust ducts.



Miscellaneous Upgrades—Separate Hot Work Area

Room within main garage set up to allow hot work (welding and grinding) in a protected area that contains sparks and repels an LNG leak. There are no restrictions on the type of work performed in this garage.



