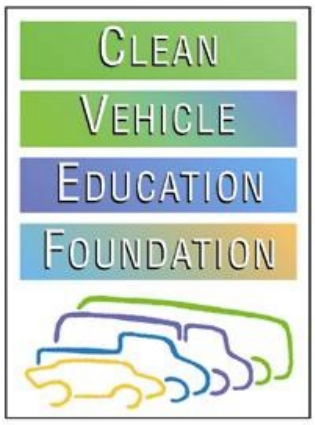

Guideline for Determining the Modifications Required for Adding Compressed Natural Gas and Liquefied Natural Gas Vehicles To Existing Maintenance Facilities

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Acronyms

ACH	Air Changes per Hour
AHJ	Authority Having Jurisdiction
ASE	Automotive Service Excellence
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
CNG	Compressed Natural Gas
cuft	cubic feet
CVEF	Clean Vehicle Education Foundation
^{o}F	Degrees Fahrenheit
IBC	International Building Code
ICC	International Code Council
IFC	International Fire Code
IMC	International Mechanical Code
LCNG	Compressed Natural Gas made from vaporized Liquefied natural gas
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NFPA	National Fire Protection Association
NGV	Natural Gas Vehicle
OEM	Original Equipment Manufacturer
PRD	Pressure Relief Device
QRA	Qualitative Risk Assessment
RLM	Refrigerated Liquid Methane
sqft	square foot

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Background

The growth of natural gas vehicle (NGV) fleets in recent years, especially for those vehicles in interstate commerce, has increased the need for additional gaseous fuel friendly maintenance facilities across the country. The NGV industry has largely focused its efforts on development of vehicles and fueling infrastructure, while leaving issues dealing with the design and operation of maintenance facilities to fleet owners. The fleet owners have used their internal staff and/or consultants to interpret the intent of the applicable codes to develop a facility design for liquefied natural gas (LNG) and/or compressed natural gas (CNG) applications that will be approved by the authority having jurisdiction (AHJ). This is sometimes a difficult process since the codes are "performance" documents (provide little design guidance) and use language such as, "areas subject to ignitable concentrations of gas", which requires expert evaluation of expected hazardous conditions. Guidance that provides a better understanding of the intent of the code committee when the language was drafted is needed in order to apply those requirements to the diverse (ceiling height, layout, roof construction, heating, ventilation electrical etc.) design of maintenance facilities.

This document looks at the modifications necessary for existing liquid fuel maintenance facilities to service both CNG and LNG vehicles.[1] The basic national codes are outlined and the rational and/or assumptions used to develop the codes are discussed. It is important to note that an individual existing maintenance facility must be evaluated to determine any necessary modifications since the building design and activities performed in the facility can have a significant impact on the modifications required.

This document does *not cover* the indoor fueling facility requirements addressed in NFPA 52.

[1] In 2008, the Clean Vehicle Education Foundation completed a study on new NGV-friendly transit bus garages. While the study was developed for new bus maintenance facilities, the guidance provided is applicable to any new NGV maintenance facility. That study is available at: http://www.cleanvehicle.org/committee/pdfs/CVEF_FUEL_FLEXIBLE.pdf . Another resource is a set of guidelines for CNG maintenance facilities produced by the Federal Transit Authority in 1996. Those guidelines go beyond the codes requirements, but may have set precedence in some jurisdictions. Those guidelines may be viewed at http://ntl.bts.gov/lib/34000/34600/34684/DOT-VNTSC-FTA-96-03.pdf .

Overview of Existing Codes

Existing National Code Requirements

The national codes that cover vehicle maintenance facilities are the:

- International Code Council's International Fire Code (IFC 2012)
- International Mechanical Code (IMC 2012)
- International Building Code (IBC 2012)
- National Fire Protection Association's NFPA 30A (2012) Code for Motor Fuel Dispensing Facilities and Repair Garages
- NFPA 52 (2010) Vehicular Gaseous Fuel Systems Code
- NFPA 88A (2007) Standards for Parking Structures.
-

It is important to note that the ICC code series and NFPA 30A, 52 and 88A are codes that, if adopted, are adopted voluntarily by states (they usually do not adopt the latest edition) and enforced by the local Authority Having Jurisdiction (AHJ). The local AHJ may enforce additional requirements beyond the national codes and, therefore, they should at least be consulted directly before final design of any modifications, preferably they should be part of the initial evaluation discussions. The codes summarized in this report can be found at: http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp?cookie%5Ftest=1 and http://www.iccsafe.org/Store/Pages/Category.aspx?cat=ICCSafe&category=330&parentcategory=Store%20Products.

Code Development Process and Hazard Analysis

The codes discussed in this report were developed over a number of years beginning in the late 1990s. The codes are written as performance documents, not design documents, and the performance requirements are based on assumed hazards. These hazards are determined by the expert knowledge and any actual field experience of the members of the code committees that developed the codes.

- For CNG systems, the basic hazard is the unintended release and ignition of the natural gas while the vehicle is in the repair garage. In the 1990s, some first generation pressure relief devices (PRD) installed on natural gas cylinders had either a design flaw or were improperly selected for the design working pressure. The result was a number of incidents where there was premature release of the cylinder contents. This full release of the cylinders contents led to the assumption by the code committees that the reasonable level of hazard for CNG vehicles was a release of 150% of the largest cylinder (see Note 4 in section on electrical classifications) on the vehicle, where the extra 50% was a safety factor. Since PRDs on CNG cylinders are designed to only release the fuel in the event of a fire, and not due to pressure increases in the cylinder, a redesign of the PRDs was made and the safety design standards were revised. Since that time (over 10 years ago), PRDs

have not experienced a premature failure and have performed as expected to protect the cylinder during a fire. The quantification of the level of hazard for CNG vehicles is part of an ongoing study and will be submitted to the relevant code committees for reconsideration of existing requirements.

- For LNG vehicles, the existing codes do not define a specific release scenario but assume two types of releases. The basic hazard for LNG systems is the possible ignition of gas released from the LNG tank relief valve due to pressure building as the contents warm over a period of time. The vacuum insulated LNG tanks are designed to have a 'hold time' up to several days before the pressure builds to the relief valve setting. Typically an LNG tank's pressure would build at a rate of about 15 psig per day giving a 'hold time' of about seven days for a typical design (contact tank manufacturer for specific information). This is a normal operating parameter of LNG tanks. There are operating procedures that can greatly reduce the probability of a LNG tank relief valve release during planned maintenance/repair operations, such as operating the vehicle to reduce the pressure in the tank, and monitoring the pressure and rate of pressure rise in the tank before entering the repair garage. The codes also have requirements that address possible liquid LNG releases in the facilities. Based on historical incident records, there has not been a reported case of a liquid LNG release in a maintenance facility.

Once the all of the probable hazards have been identified, including those discussed above, and the risks have been quantified, a best practices document will be developed that will provide specific mitigation strategies to reduce or eliminate those hazards. Physical or engineering solutions to mitigate a specific hazard may be cost effective in actually eliminating it where procedural mitigation techniques may only reduce the risk associated with the hazard since they are subject to the additional risk of human error.

Existing Code Requirements by Facility Activity

The codes discussed below *only apply* to major repair facilities. Both NFPA 30A and the IFC exempt minor repair facilities from all of the code requirements specific to CNG and LNG.

- IFC 2211.7 exempts garages that do not work on the vehicle fuel system or do not use open flames or welding from all additional requirements.
- By definition NFPA 30A exempts garages that do not perform engine overhauls, painting, body and fender work and any repairs requiring draining vehicle fuel tanks from all additional requirements. The maintenance work that can be done without any modifications to the facility include lubrication, inspection, engine tune-ups, replacement of parts, fluid changes, brake system repairs, tire rotation and similar routine maintenance work

When a maintenance facility is considering adding CNG and /or LNG vehicles to their operations, an analysis of maintenance tasks by type as a percentage of the overall activities should be done. The analysis can help determine if the facility could be divided into 'major repair' and 'minor repair' areas. With proper physical separation, the codes require only that those areas of the facility designated as 'major repair' areas to be subject to the additional requirements for CNG and LNG.

Existing Code Requirements by Category

The sections below discuss the existing national code requirements for liquid and gaseous fuels (CNG and LNG) repair garages or maintenance facilities. There are seven main areas to consider when reviewing the existing codes: ventilation, pits or basement ventilation, gas detection, heating equipment (sources of ignition), electrical classification, vehicle preparation for entering repair garage and maintenance, and decommissioning of fuel containers. In each area, the requirement for each fuel will be shown side by side for comparison.

Table 1 – Code References by Category

Modification Category	Code References
Ventilation	IMC (2012) Table 403.3; NFPA 88A (2007) 5.3.2; IFC (2009) 2211.7.1, 2211.1.1, 2211.7.1.2; NFPA 30A (2012) 7.5.1, 7.5.2,7.5.3, 7.5.4, 7.4.7.2,7.4.7.3
Ventilation in Pits	IFC (2009) 2211.3; NFPA 30A 7.4.5.4
Gas Detection	IFC (2009) 2211.7.2,2211.7.2.1, 2211.7.2.2, 2211.7.2.3; NFPA 30A (2012) 7.4.7,7.4.7.1, 7.4.7.2, 7.4.7.3, 7.4.7.4
Sources of Ignition	NFPA 30A (2012) 7.6.6
Electrical Classification	NFPA 30A (2012) 8.2.1
Preparation of vehicles for Maintenance	IFC (2009) 2211.5
Maintenance and decommissioning of containers	NFPA 52 (2010) 6.13, 6.14

NOTE: While the various codes have similar requirements, there are a few discrepancies that should be considered. They are noted in the tables for each area.

Ventilation - Code Requirements

The International Mechanical Code (IMC 2012) Table 403.3 requires all vehicle repair garages, regardless of fuel type or maintenance performed, to have a ventilation rate of 0.75 cfm/sqft of floor area. Any ventilation rates required for CNG or LNG maintenance facilities would simply increase this base rate. As noted above, there are no requirements for ventilation rates over-and-above the base rate for CNG or LNG minor repair garages (see "Existing Code Requirements by Facility Activity" above)

NFPA 88A 5.3.2 requires a ventilation rate of 1 cfm/sqft of floor area for enclosed parking garages housing liquid and gaseous-fueled vehicles. ***Based on this requirement, it should be considered that the base rate for all repair garages would be at least 1 cfm/sqft since even in minor repair garages vehicles could be parked waiting repair for a period of time***.

Where mechanical ventilation is required by IFC 2211.7.1, it must operate continuously except when it is either interlocked with a gas detection system for LNG or electrically interlocked with the lighting circuit for CNG applications.

The codes state the ventilation rate using three different formats. Conversions for each format are shown in Table 2.

Table 2 – Ventilation Rate Conversions

Rates	CFM/sqft	CFM/12 cuft	Air changes/hour
CFM/sqft	1	1/12ft	60/room height ft
CFM/12 cuft	12ft	1	5
Air changes/hour	Room height ft/60	1/5	1

There is a discrepancy between NFPA 30A and IFC 2211.7.1in the requirements for mechanical ventilation (see footnote 2). NFPA requires mechanical ventilation for fuel dispensing areas but the IFC requires it for the CNG maintenance areas as well. Since the codes are so similar in other areas, CVEF will look into the rational for the IFC requirements to determine if the actual requirement should be limited to the dispensing area as stated in NFPA 30A.

Table 3 below provides the codes requirements for garage ventilation by fuel type.

Table 3 – Ventilation – General

Subject	**Liquid Fuels**	**CNG**	**LNG**
Ventilation – General	**NFPA 30A 7.5.1, 7.5.2, 7.5.3 and 7.5.4** Provides for ventilation systems serving a fuel dispensing area inside a building or a repair garage. Fuel dispensing is not part of this guideline. **IFC –** No specific requirements for liquid fuels but does reference the IBC for general ventilation requirements. **IMC 2012 Table 403.0** Has general ventilation requirements for all	**NFPA 30A – No specific requirements for CNG** **IFC- 2211.7.1, 2211.7.1.1 and 2211.7.1.2** – Require approved mechanical ventilation systems for CNG repair garages at 1 cfm per 12 cuft of room volume (5 air changes per hour). There are two exceptions to these requirements: (1) Work is not performed on the fuel system and is limited	**NFPA 30A – 7.4.7.2 & 7.4.7.3** only require that the operation and failure of gas detection systems be interlocked with an existing mechanical ventilation system for garages repairing LNG engine fuel systems. **IFC- 2211.7.1, 2211.7.1.1 and 2211.7.1.2** – Require approved mechanical ventilation systems for LNG repair garages at 1 cfm per 12 cuft of room

	repair garages of 0.75 cfm per sqft of floor area. **NFPA 88A 5.3.2** Has a ventilation requirement for enclosed parking garages during hours of operation set at 1cfm per sqft of floor area. [2]	to exchange of parts and maintenance requiring no open flame or welding. (2) Repair garages with AHJ approved natural ventilation.[2]	volume (5 air changes per hour). There are two exceptions to these requirements: (1) Work is not performed on the fuel system and is limited to exchange of parts and maintenance requiring no open flame or welding. (2) Repair garages with AHJ approved natural ventilation.[2]

[2] There seems to be a discrepancy between NFPA 30A and IFC in that: NFPA 7.5.1 – 7.5.4 only requires ventilation for fuel dispensing areas within the maintenance facility, where IFC 2211.7.1 – 2211.7.1.2 uses similar language for CNG repair facilities assuming that indoor fueling will always be part of the repair facility even to the point of requiring the **"system shall shut down the fueling system"** if the ventilation fails. CVEF will look at getting a clarification of these requirements from IFC since it appears that IFC has assumed that fuel dispensing will always take place in the repair garage. NFPA separates indoor dispensing from repair facility requirements.

Ventilation in Pits Code Requirements:

Ventilation requirements for pits, below grade and subfloor work areas are part of the basic requirements for liquid fuels where flammable vapors may accumulate. This requirement should already be met by the existing maintenance facility. However, the codes are not harmonized as to the ventilation rate. IFC requires 1.5 cfm/sqft while NFPA requires 1.0 cfm/sqft. The local AHJ should specify the rate for each facility. The codes have no requirements specific to CNG or LNG. While experience has shown that there is a very low probability of a release of LNG liquid, the release of a cold vapor may initially be heavier than air and migrate to a subgrade area where it would quickly become buoyant and rise as a CNG release. The existing ventilation requirement for liquid fuels should be adequate for the addition of LNG to major repair facilities with approval of the local AHJ.

Table 4 – Ventilation of Pits

Subject	Liquid Fuels	CNG	LNG
Ventilation of Pits, Below-grade Work Areas and Subfloor Work Areas	**IFC 2211.3** and **NFPA 30A 7.4.5.4** Require ventilation rates of 1.5 to 1 cfm/sqft respectively for repair garages having a pit or basement where flammable vapors may accumulate.	**IFC and NFPA 30A** – No requirements specific to CNG	**IFC and NFPA 30A** – No requirements specific to LNG

Gas Detection Code Requirements

There are no requirements for gas detection in repair garages (major or minor) where odorized CNG or LCNG vehicles are maintained. However, IFC 2211.7.2 and NFPA 30A 7.4.7 both require approved gas detection systems for major repair garages servicing LNG vehicles. Specific requirements under these codes for gas detection installation and operation are similar and may require the expertise of a gas detection design engineer for optimal performance.

Table 5 – Gas Detection

Subject	Liquid Fuels	CNG	LNG
Gas Detection	**IFC and NFPA 30A** –No requirements	**IFC and NFPA 30A** – Have no requirements for gas detection for odorized CNG or odorized LCNG.	**IFC 2211.7.2, 2211.7.2.1, 2211.7.2.2, and 2211.7.2.3** Require an approved gas detection system for major repair garages for LNG vehicles where (work is done on the fuel system and the work may require use open flames or welding) **NFPA 30A 7.4.7,7.4.7.1, 7.4.7.2, 7.4.7.3 and 7.7.4.4** The requirements are essentially the same in NFPA except that it is limited to facilities where "repair of vehicle engine fuel systems" takes place

Sources of Ignition Code Requirements

The IFC does not have any specific requirements for CNG and LNG repair garages with respect to sources of ignition. IFC does provide requirements for liquid fuels in section 2211.3 restricting ignition sources from the space within the 18 inches of the floor. This is the standard requirement in the IBC, IMC and NFPA 70. These requirements already should be met by the existing facility.

In NFPA 30A 7.6.6 (see Note 2 below), the restrictions on heating equipment in major repair garages only apply to areas where ignitable mixtures may be present. The accepted practice at this time is to assume that there will be an ignitable mixture present in some areas of major repair garages. The identification of these areas is based on the expected volume of fuel released and its concentration in the facility. The quantification of a creditable release of both CNG and LNG should be done and representative computational fluid dynamic (CFD) modeling of those releases in various facility geometries is needed to determine if ignitable mixtures will be present. This is a time consuming and expensive process that is not usually done for individual maintenance facilities. The proposed research project discussed in the last section of this report

will address this issue and provide data for developing guidelines for determining the actual hazard.

Table 6 – Sources of Ignition

Subject	Liquid Fuels	CNG	LNG
Sources of Ignition – Heat Producing Appliances –	**IFC 2211.3 –** Multiple requirements on sources of ignition, primarily dealing with the type and placement of heating equipment – please see document. **NFPA 30A 7.6** – Multiple requirements on heat producing appliances – please see document	**IFC** – No specific requirements **NFPA30A 7.6.6*** Where major repairs are conducted on CNG-fueled open flame heaters or heating equipment with exposed surfaces having a temperature in excess of 750°F shall not be permitted in areas subject to ignitable concentrations of gas. **Note 1**: Minor repair garages are facilities where work is not performed on the fuel system and work is limited to exchange of parts and maintenance requiring no open flame or welding. All other garages are defined as major repair garages. **Note 2**: Determining 'areas subject to ignitable concentrations of gas' requires understanding what a creditable release of CNG (the hazard) in the facility and then determining the probability of where an ignitable may be present.	**IFC –** No specific requirements. **NFPA 30A 7.6.6*** Where major repairs are conducted LNG-fueled vehicles, open flame heaters or heating equipment with exposed surfaces having a temperature in excess of 750°F shall not be permitted in areas subject to ignitable concentrations of gas. **Note 1**: Minor repair garages are where work is not performed on the fuel system and work is limited to exchange of parts and maintenance requiring no open flame or welding. All other garages are defined as major repair garages. **Note 2**: Determining 'areas subject to ignitable concentrations of gas' requires understanding what a creditable release of LNG or LNG vapor (the hazard) in the facility and then determining the probability of where an ignitable may be present.

Electrical Classification Code Requirements

The IFC does not have any specific requirements on electrical classifications for CNG and LNG repair garages. NFPA 30A Chapter 8 includes requirements for electrical classification areas for liquid fuel vehicles that primarily address electrical classifications for pits and the space within 18 inches from the floor of the repair garage. NFPA 30A 8.2.1 classifies the area 18 inches from the ceiling for major garages that repair CNG vehicles as Class 1, Division 2. The exception to this classification is that, when an area below the ceiling has ventilation of at least 4 air changes per hour, the area is considered unclassified. While NFPA 30A is silent on classified areas for LNG in major garages, in practice LNG would see the same requirements as liquid fuels in pits and the same requirements as CNG in the 18-inch space below the ceiling.

As noted in the previous section on 'Hazard Analysis', the existing code requirements for CNG were based on the release of 150% of the contents (NFPA 30A - Annex A.8.2.1) of the largest cylinder of the vehicles in the repair facility. This release hazard was selected because of the failure of specific PRDs in service in the 1990s. The PRDs have been through several design generations since then and the last cases of premature release were over ten years ago.

A proposal has been submitted by CVEF to review the requirements in NFPA 30A 8.2.1 based on an analysis of creditable releases of CNG and LNG to determine the extent of any hazardous areas in maintenance facilities of various geometries.

The research project covered in section **Proposed Research for Code Development** will use a risk-informed process with input from quantitative risk assessment (QRA) techniques to determine what constitutes a creditable release of CNG/LNG based on experience and today's NGV technology.

Table 7 – Electrical Classifications

Subject	Liquid Fuels	CNG	LNG
Electrical Installations	**IFC Section 2211 –** No specific requirements. **NFPA 30A Chapter 8 -** Multiple electrical classifications for liquid fuel repair garages.	**IFC Section 2211 –** No specific requirements. **NFPA 30A 8.2.1*** In major repair garages where CNG vehicles are repaired or stored, the area within 18 in. of the ceiling shall be designated a Class I, Division 2 hazardous location. Exception: This requirement shall not	**IFC Section 2211 –** No specific requirements. **NFPA 30A 8.2.1*** Only covers CNG but would expect the AHJ to extend the requirement to LNG as well. See note in CNG column on assumption made for extent of hazard.

		apply where the ventilation rate is not less than 4 air changes per hour. **Note** 3 The assumption made by the code committee, as stated in Annex A.8.2.1, was that the release of CNG in the facility would be equal to 150% of the largest CNG cylinder. Since the assumption defines the hazard expected, any change in this assumption may result in future code changes.	

Preparation of Vehicle for Repair - Code Requirements

IFC 2211.5 is the only code requirement that addresses mitigation of the assumed hazards from releases of natural gas by:

- Isolating the CNG cylinders and LNG tanks from the balance of the fuel system by valve closures prior to maintenance. This reduces the quantity of fuel that could be released in fuel system piping and components due to damage or error during maintenance operations.
- Operating the NGV until it stalls due to low fuel pressure in the system can further reduce the possible release volume with the cylinder valves closed.
- IFC 2211.5 also requires that the fuel system on the NGV be tested for leakage by appropriate methods if there is a concern that the fuel system has experienced any damage. If damage is suspected the vehicle may need to be de-fueled prior to any maintenance.

Table 8 – Preparation of Vehicles For Repair

Subject	Liquid Fuels	CNG	LNG
Preparation of vehicles for repair	**IFC and NFPA 30A -** No requirement	**IFC 2211.5** Close cylinder valve prior to repairing any portion of the vehicle fuel system. Where the fuel system has	**IFC 2211.5** Close LNG tank valve prior to repairing any portion of the vehicle fuel system. Where the fuel system has been

		been damaged it shall be inspected and evaluated for fuel system integrity prior to being brought into the repair garage. Test the entire fuel system for leakage. **NFPA 30A** - No requirement	damaged it shall be inspected and evaluated for fuel system integrity prior to being brought into the repair garage. Test the entire fuel system for leakage. **NFPA 30A** - No requirement

Maintenance and Decommissioning of Vehicle Fuel Containers

These code requirements are not found under repair garages but are part of the maintenance requirements for vehicle mounted fuel storage containers. NFPA 52 (2010) should be consulted for the specific requirements. The 2013 edition of NFPA 52 is in the final stages of approval and incorporates several critical safety related changes for CNG cylinder maintenance. These changes are lessons learned from incidents involving CNG cylinder maintenance operations and are included in the table below. These requirements require development of written maintenance procedures along with certain modifications to the maintenance facility to accommodate defueling of fuel containers for fuel system maintenance and end of life decommissioning of CNG cylinders.

Table 9 – Maintenance and Decommissioning of Vehicle Fuel Containers

Subject	Liquid Fuels	CNG	LNG
Fuel System Maintenance	No specific requirements	**NFPA 52 – 2012 6.13** Repair facilities should have specific written procedures for inspection and decommissioning CNG cylinders. This set of requirements depends on properly trained personnel and the use of procedures as recommended by the cylinder and/or cylinder valve manufacturer.	The codes do not provide specific requirements for maintaining or venting LNG fuel tanks. It is recommended that the repair garage develop written procedures and training material based on the LNG tank manufacturer's instructions.
Decommissioning and defueling of fuel cylinders/tanks	No specific requirements	**NFPA 52 - 2012 6.**14 Each major repair garage should install the proper defueling facility as outlined by this section of NFPA 52. Designs for fuel recovery systems and direct atmospheric	The codes do not have specific requirements for decommissioning LNG fuel tanks. It is recommended that the repair garage develop written procedures

		venting systems should be approved by the AHJ as required. If the CNG cylinders have reached their end of life or are damaged, the cylinder should be purged with an inert gas, made unusable and scrapped according to the cylinder manufacturer's instructions.	and training material based on the LNG tank manufacturer's instructions.

Proposed Research for Code Development

Responding to the issues noted in the previous sections, CVEF, along with its partner in the proposal Sandia National Laboratory, will use their collective expertise in code interpretation, CFD modeling, sensitivity studies, hazard analysis, LNG and CNG fuel systems and facility operations to develop guidelines for modification and construction of maintenance facilities. We will analyze the existing codes, quantify the potential hazards, and develop best practices to mitigate these hazards, develop design guidance based on facility configurations and propose potential code changes. Recognizing that the existing codes were developed based on experience and 'rule of thumb' and did not use a quantitative analysis of potential hazards nor an analysis of ignitable mixtures based on leak size and facility design, Sandia will perform research in this areas as well as recommending follow on work on risk assessment.

A risk-informed process, as opposed to a risk-based process, utilizes risk insights obtained from qualitative risk assessments (QRAs) combined with other considerations to establish code requirements. The QRAs are used to identify and quantify scenarios for the unintended release of CNG/LNG, identify the significant risk contributors at different types of maintenance facilities, and to identify potential accident prevention and mitigation strategies to reduce the risk to acceptable levels. Other considerations used in this risk-informed process include the results of deterministic analyses of selected accident scenarios, the frequency of leakage events at maintenance facilities, and the use of safety margins to account for uncertainties. Please contact CVEF for additional information dbhorne@cleanvehicle.org

Guideline for Modifications

This section will discuss those steps that should be considered when determining the modifications that might be required for maintenance facilities to service CNG and /or LNG vehicles. It is important to note that each individual existing maintenance facility must be evaluated to determine any necessary modifications since the building design and activities preformed in the facility can have a significant impact on the modifications required. Just as the codes are performance, not design documents, this document does not provide specific design guidelines but does provide the steps needed for basic decisions on the modifications required to meet code and provide for safe operations.

NOTE: If the garage is designed to accommodate LNG vehicles then no additional modifications should be needed to also service CNG vehicles. If the garage is modified specifically for CNG vehicles meeting the basic code requirements, then additional modifications may be required to service LNG vehicles.

Plan Development and Coordination with AHJs

There are a number of basic questions that should be answered in order to begin development of the facility modification plan. They are:

- Does the facility meet existing code requirements for liquid fuels?
    - If not, what remedial action may be required? (i.e. ventilation etc.)
- What type of NGV will the facility maintain; CNG, LNG or both?
- Will the facility provide minor repairs, major repairs or both?
- Will the minor repair area be physically separated from the major repair area?
    - If not the entire facility may be classified as a major repair facility.
- Will the facility procedures include the venting and decommissioning of cylinders?
- Will the facility include an indoor or outdoor fueling station?
    - Note: this document does not include guidelines for fueling stations but if a station will be installed at the same times as the facility modifications then the overall plan should include that design and its possible interconnection with cylinder defueling.
- Will the facility include indoor parking for NGVs?

The answers to the questions above will help determine the scope of the potential facility modifications and the operating procedures for the facility. Before taking the next step in plan development, an inquiry should be made to the local AHJ(s) to determine the specific code documents that have been adopted and will be enforced. ICC's International Fire Code (IFC) has been adopted or is in use by 43 states, the District of Columbia and New York City. In 13 of those states, the IFC may have only been adopted by some local AHJs and not used statewide. Also, each state may adopt and enforce different editions of the respective code (IFC 2006 or IFC 2009 etc.). The codes are generally revised on a three-year cycle and AHJ adoption is usually several cycles out of date. General information on state and local adoption can be found at the ICC web site http://www.iccsafe.org/gr/pages/adoptions.aspx .
To be sure that the correct code and code edition is used the local AHJ is the best source of information.

Establishing a working relationship with the local AHJ at the beginning of the project is an important step in determining the extent of the modifications that may be required including any local concerns that may not be in the national codes. When first approaching the AHJ there are several items to consider:

- Have a completed project scope for the maintenance facility that includes the fuel types, list of maintenance activities, outline operational procedures specific to the fuel types and outline of training by fuel type for all personnel.
- Meet as early as possible with the appropriate AHJ(s) to make them aware of your project plans.
    - If AHJ is experienced with CNG/LNG installations and maintenance facility modifications, they can provide important input to the final plan development.
    - If the AHJ has no experience with NGVs or just no experience with maintenance facility modifications for CNG/LNG, you should use this as an opportunity to provide the AHJ with the background material they will need to determine the proper code requirements to enforce.
- Provide a project timeline to the AHJ(s) and add any required inspection dates as part of the timeline.
- Set up a meeting to review the final project plan and be sure to reference proposed modifications to the specific code and/or AHJ requirement.

The final plan development should, at a minimum, consider the steps discussed in the sections below in order to meet the basic code requirements.

Analysis of Existing Maintenance Facility

When modifications are anticipated for existing maintenance facilities, a review of the facilities compliance with the existing codes may be necessary. Since the existing maintenance facilities may have been built under older editions of the codes, and codes are generally not retroactive, any new modifications may require bringing the facility up to the codes now enforced for liquid fuels.

Code Compliance of Maintenance Facility for Class I and Class II Fuels

The primary concerns for code compliance for existing facilities are:

- Ventilation rate in general garage area should be between 0.75 (IMC) and 1.0 (NFPA) cfm/sqft with inlet at least 18” above the floor.
- Ventilation rate for below grade areas (pits or basement) should be between 1.0 (NFPA) and 1.5 (IFC) cfm/sqft with exhaust air taken within 12” of the floor.
- Review the IFC and NFPA documents for requirements for sources of ignition including heating appliances since their design and placement may have a significant influence on the modifications for the CNG/LNG garage.
- When the AHJ tours the facility in the initial review process, they may determine that some remedial modifications are needed to the existing facility to come into compliance with the code editions now in place.

Minor vs. Major Repair Garages

The codes discussed in the sections above *only apply* to major repair facilities. Both NFPA 30A and the IFC exempt minor repair facilities from all of the code requirements specific to CNG and LNG. There may be significant savings in the cost of modifications if the maintenance facility can be divided into separate designated areas for minor and major repair activities. This can be accomplished by either having separate buildings or separated areas within one facility. The codes are not specific in how to separate major from minor repair areas but using some of the same requirements for separating indoor fueling rooms from the repair areas may be appropriate. The codes provide some guidance for separating the minor and major repair areas within a facility, such as:

- Interior walls or partitions shall have a 2-hour fire rating and be continuous from floor to ceiling.
- For the major repair area at least one wall shall be an exterior wall and primary access shall be from the outside through the exterior wall.
- Interior access between the major and minor repair areas shall be through self-closing fire doors with the appropriate rating for the location installed as approved by the AHJ.
- The major and minor repair areas shall have separate ventilation systems as required by the codes.

If the major and minor repair areas cannot be separated, the entire maintenance garage should be modified as required to perform major repairs on CNG and/or LNG as needed.

Analysis of Maintenance Activities

An analysis of existing and anticipated maintenance activities by type and quantity may be helpful to determine if the facility can be configured into separate major and minor repair areas. Table 8 below provides guidance on classifying repairs by type. Consideration should also be given to defining additional areas that may be required for inspection and preparation of vehicles prior to entering the repair facility. Also a designated location for defueling vehicle fuel cylinders for maintenance or decommissioning should be identified.

Table 10 – Major vs. Minor Garage Activities

Code	Major Repair Activities	Minor Repair Activities
IFC 2211.7	Work on the vehicle fuel system or use of open flames or welding	All other repairs
NFPA 30A 3.3.12	Work including engine overhauls, painting, body and fender work and any repairs requiring draining vehicle fuel tanks	All work including lubrication, inspection, engine tune-ups, replacement of parts, fluid changes, brake system repairs, tire rotation and similar routine maintenance work.

Minor Repair Garages – Requirements for CNG or LNG

As noted in the sections above, the codes do not have any additional requirements for minor repair garages as a stand-alone facility or as part of a larger garage. The code requirements for the existing Class I and Class II liquid fuel garages are considered sufficient for adding both CNG and LNG vehicle minor repair operations. As covered in the section on preparation of CNG and LNG vehicles for repair, there are some precautions that are recommended to mitigate any potential hazard of a natural gas release during minor repair operations. It is also recommended that the design of existing ventilation system for the liquid fuel garage be reviewed to make sure that it meets the existing code requirements.

Ventilation

Although the codes do not require any modifications to the ventilation system, the 1cfm/sqft rate should be verified. In addition, the inlet for outside air should be at least 18" above the floor of the garage for both liquid and CNG/LNG fuels. Even though it is not required by the codes, consideration should be given to configuring the exhaust ports of the ventilation system to the highest points of the exterior walls or roof.

Major Repair Garages – Requirements for CNG

When adding CNG maintenance operations to a major repair garage, the code requirement must be evaluated to determine what types of modifications are necessary. For some code requirements, there may be more than one method to meet the requirements so an engineering analysis may be called for to determine the optimum solution. The basic difference between the minor and major repair garages is that in a major repair garage there may be a release of natural gas due to the nature of the maintenance operations. The code requirements set performance criteria to either reduce the presence of a flammable mixture and/or eliminate potential sources of ignition. For this set of requirements, it is assumed that only properly odorized CNG is present on the vehicles to be serviced. Un-odorized CNG is addressed in the section on LNG maintenance facilities.

Ventilation

NFPA 30A has no requirements for general ventilation rates for CNG major repair garages beyond the exception allowed under 'Electrical Classifications' that is covered in that section below.

The IFC has a specific requirement for continuous mechanical ventilation of CNG major repair garages of 5 air changes per hour (ACH). In garages where natural ventilation may be used, it must be approved by the AHJ as an exception to the stated requirements. The operation of the mechanical ventilation is required to be continuous, but there are two exceptions to this requirement: 1) ventilation system interlocked and controlled by a continuously monitoring natural gas detection system, or 2) ventilation system electrically interlocked with the lighting circuit for the garage.

As stated in the section on code requirements for ventilation of liquid fuel repair garages, the base ventilation rate is conservatively 1 cfm per sqft or floor area. Table 1 gives the conversion from cfm/sqft to air changes per hour (ACH) as 60/room height in feet. So for a garage with a ceiling height of 12ft, the base ventilation rate of 1cfm/sqft equals the required 5 ACH. For a ceiling height of 24ft, the cfm/sqft rate would have to increase to 2 cfm/sqft in order to maintain the same 5 ACH rate.

There are a number of decisions that must be made concerning ventilation when adding CNG to the existing liquid fuel repair facility:

- Evaluation of existing ventilation system for code compliance.
- Separation of ventilation systems for minor repair area and major repair area if in same building.
- Ventilation rates required based on building geometry and codes.
- Operate ventilation system continuously or
    - Control ventilation system by interlocking with continuously operated natural gas detection system or
    - Control ventilation system by electrically interlocking with the lighting circuit.

Note 1: There seems to be a discrepancy between NFPA 30A and IFC in that: NFPA 7.5.1 – 7.5.4 only requires ventilation for fuel dispensing areas within the maintenance facility, where IFC 2211.7.1 – 2211.7.1.2 uses similar language for CNG repair facilities assuming that indoor fueling will always be part of the repair facility even to the point of requiring the **"system shall shut down the fueling system"** if the ventilation fails.

Ventilation in Pits

There are no additional code requirements for major repair garages that add CNG maintenance operations. The ventilation already required for liquid fuel garages for pits or below grade areas are still required for continued maintenance of liquid fuel vehicles.

Gas Detection

There are no requirements for natural gas detection systems for major repair garages that add CNG maintenance operations as long as the CNG is properly odorized. The garage should predetermine that all CNG vehicles that enter the facility have been fueled with odorized natural gas. There may be some stations that supply non-odorized CNG from LNG (LCNG) or from renewable natural gas (Biogas) but they are restricted by code to only fueling CNG vehicles that have on board methane detection systems. Those vehicles should only be maintained in a garage designed for non-odorized natural gas as detailed in the section below on LNG major repair garages.

As noted above in the section on ventilation, the major repair garage may choose to install and use a natural gas detection system to control the operation of the ventilation system. If a natural gas detection system is deployed, the following should be taken into account:

- The natural gas detection system should be designed by an engineer with expertise in natural gas detection system design.

- The natural gas detection system should be *listed* in accordance with UL 2075 or *approved* by the AHJ**.**
- The natural gas detection system shall activate at 25% of the lower flammability limit (LFL).
- Upon activation the natural gas detection system shall:
    - Activate the mechanical ventilation system
    - Deactivate tall heating systems located in the major repair garage
    - Initiate a distinct audible and visual alarm in the garage
- The failure of the natural gas detection system shall:
    - Activate the mechanical ventilation system
    - Deactivate all heating systems located in the major repair garage
    - Initiate a trouble alarm in an *approved* location
- NFPA 72 National Fire Alarm and Signaling Code provide information on monitoring the detection systems for integrity.
- The natural gas detectors should be tested and calibrated as recommended by the manufacturer and approved by the AHJ.

Sources of Ignition

Both the IFC and NFPA 30A have a number of requirements addressing sources of ignition for liquid fuel garages. Only NFPA 30A has additional requirements for CNG vehicle major repair garages. The requirement is directed at restricting open flame heaters and any heating equipment with exposed surfaces with temperatures above 750 ^{o}F from any area subject to ignitable concentrations of natural gas.

The conservative approach would be to eliminate heating equipment of these types from the major repair garage. It would take an analysis of the potential credible natural gas releases and modeling of the possible concentrations of ignitable gas within the facility in order to safely place these types of heaters in safe areas. This analysis is typically beyond normal heating design work and would be subject to approval by the AHJ on a case-by-case basis.

Electrical Classification

The codes have a number of requirements on classified locations for electrical equipment in typical liquid fuel garages. Only NFPA 30A requires that the space within18 inches of the ceiling of a major CNG garage be classified as a Class 1, Division 2 classified location. This means that all electrical equipment within that area must be suitable for that classification as set forth in NFPA 70, National Electrical Code. The code does provide an exception to the requirement in that it does not apply to a facility that has a ventilation rate of at least 4 ACH.

It is important to take into account the design of the ceiling support structure to determine what modifications may be necessary for the classified location. One example would be a concrete ‘T’ beam design that may not be easily ventilated at the required rate to eliminate the classified location thus requiring modification of any electrical equipment in the 18-inch space below the ceiling. Conversely an open web steel joist structure may achieve the proper 4+ ACH eliminating the classified location.

If the classified location cannot be eliminated by ventilation, then the choice may be to either modify the electrical installation to meet Class1, Division 2 requirements or move the electrical equipment below the 18-inch classified location, which in most cases would be to attach the system to the bottom of the support structure as opposed to the ceiling.

Preparation of CNG Vehicle for Maintenance

The IFC is the only code that has requirements for vehicle preparation prior to performing maintenance operations. For CNG vehicles, the procedure is to limit the quantity of natural gas that could be accidentally released by valveing off all the fuel storage cylinders on the vehicle once it enters the repair garage. Vehicles that have cylinder-mounted solenoid valves that are tied to the ignition system of the vehicle will automatically close the valves when the engine is shut down. Vehicles that have manual valves on the cylinders must be closed by hand. A procedure to double check that all valves are closed as required should be established as part of the facilities normal operations.

The IFC also requires that if there is any suspected damage to the CNG fuel system the entire system should be checked for leaks and evaluated for fuel system integrity prior to bringing the vehicle into the repair garage. While not noted in the IFC, if there is any suspected damage to the CNG cylinder it should be inspected by a certified cylinder inspector to determine its proper disposition based on the findings of the inspection.

Maintenance and Decommissioning of Vehicle Fuel Containers

NFPA 52 requires that repair facilities have specific written procedures for inspection and decommissioning CNG cylinders. This set of requirements depends on the existence of properly trained personnel and the use of procedures as recommended by the vehicle OEM, cylinder and/or cylinder valve manufacturer. In order to properly perform maintenance on a cylinder, the cylinder must be safely vented (defueled) either returning the compressed gas back into a closed system or by atmospheric venting, both of which require making modification to the major repair garage.

NFPA 52 requires that each major repair garage install the proper defueling facility and provides specific requirements in section 6.4 of the 2010 edition of the code. Designs for fuel recovery systems and direct atmospheric venting systems should be approved by the AHJ as required. If the CNG cylinders have reached their end of life or are damaged, the cylinders should be defueled, purged with an inert gas, made unusable and scrapped according to the cylinder manufacturer's instructions.

While not covered in this set of guidelines, a CNG refueling station may be part of the overall modifications needed by the major repair garage in order to return the vehicles to service. Consideration should be given to add a natural gas recovery system to the refueling station design in order to reduce the amount of natural gas that is released to the atmosphere.

Major Repair Garages – Requirements for LNG

To add LNG maintenance operations to a major repair garage, certain code requirements should be evaluated to determine what modifications might be necessary. For some of the modifications, there may be more than one method to meet the requirements so an engineering analysis may be called for to determine the optimum solution. The basic difference between the minor and major repair garages is that in a major repair garage there may be a release of natural gas due to the nature of the maintenance operations. The code requirements set performance criteria to either reduce the presence of a flammable mixture and/or eliminate potential sources of ignition. For this set of requirements, it is assumed that LNG and /or un-odorized CNG is present on the vehicles that will be serviced. LNG and Un-odorized CNG major repair garages have additional requirements above those for odorized CNG. Proper ventilation of pits and below grade areas is required along with a continuously operating natural gas detection system. These requirements are discussed below.

Ventilation

NFPA 30A has no specific requirements for general ventilation rates for LNG major repair garages but does require that the natural gas detection system (see section below) be interlocked with the major repair garage's ventilation system.

The IFC has a specific requirement for continuous mechanical ventilation of LNG major repair garages of 5 air changes per hour (ACH). In garages where natural ventilation is used, it must be approved by the AHJ as an exception to the stated requirements. The operation of the mechanical ventilation is required to be continuous but there are two exceptions to this requirement: 1) ventilation system interlocked and controlled by a continuously monitoring natural gas detection system, or 2) ventilation system electrically interlocked with the lighting circuit for the garage.

As stated in the section on code requirements for ventilation of liquid fuel repair garages, the base ventilation rate is conservatively 1 cfm per sqft of floor area. Table 1 gives the conversion from cfm/sqft to air changes per hour (ACH) as 60/room height in feet. Therefore, for a garage with a ceiling height of 12ft, the base ventilation rate of 1cfm/sqft equals the required 5 ACH. For a ceiling height of 24ft, the cfm/sqft rate would have to increase to 2 cfm/sqft in order to maintain the same 5 ACH rate.

With the respect to ventilation, the following factors or steps should be considered when adding LNG to the existing liquid fuel repair facility:

- Evaluation of existing ventilation system for code compliance.
- Separation of ventilation systems for minor repair area and major repair area if in same building.
- Ventilation rates required based on building geometry and codes.
- Operate ventilation system continuously or
    - Control ventilation system by interlocking with continuously operated natural gas detection system or
    - Control ventilation system by electrically interlocking with the lighting circuit.

Ventilation in Pits

There are no additional code requirements for major repair garages that add LNG maintenance operations. The ventilation already required for liquid fuel garages for pits or below grade areas should be maintained and used for LNG. If it is released, LNG vapor is heavier than air at temperatures below -160^0 F. As the LNG vapor quickly warms above -160^0 F and would dissipate similar to a CNG release.

Gas Detection

There are specific requirements for natural gas detection systems for major repair garages that add LNG and/or un-odorized CNG. There may be some stations that supply non-odorized CNG from LNG (LCNG) or from renewable natural gas (Biogas) but they are restricted to only fueling CNG vehicles that have on board methane detection systems. Those vehicles should only be maintained in a garage designed for non-odorized natural gas as detailed below.

The natural gas detection system design should consider including some of the following:

- The natural gas detection system should be designed by an engineer with expertise in natural gas detection system design.
- The natural gas detection system should be *listed* in accordance with UL 2075 or *approved* by the AHJ**.**
- The natural gas detection system shall activate at 25% of the lower flammability limit (LFL).
- Upon activation the natural gas detection system shall:
    - Activate the mechanical ventilation system
    - Deactivate all heating systems located in the major repair garage
    - Initiate a distinct audible and visual alarm in the garage
- The failure of the natural gas detection system shall:
    - Activate the mechanical ventilation system
    - Deactivate all heating systems located in the major repair garage
    - Initiate a trouble alarm in an *approved* location
- NFPA 72 National Fire Alarm and Signaling Code provides information on monitoring the detection systems for integrity.
- The natural gas detectors should be tested and calibrated as recommended by the manufacturer and approved by the AHJ.

Sources of Ignition

Both the IFC and NFPA 30A have a number of requirements addressing sources of ignition for liquid fuel garages. Only NFPA 30A has additional requirements for LNG vehicle major repair garages. The requirement is directed at restricting open flame heaters and any heating equipment with exposed surfaces with temperatures above 750 ^{o}F from any area subject to ignitable concentrations of natural gas.

The conservative approach would be to eliminate heating equipment of these types from the major repair garage. It would take an analysis of the potential credible natural gas releases and modeling of the possible concentrations of ignitable gas within the facility in order to safely place these types of heaters in safe areas. This analysis is typically beyond normal heating design work and would be subject to approval by the AHJ on a case-by-case basis.

Electrical Classification

The codes have a number of requirements on classified locations for electrical equipment in typical liquid fuel garages. Only NFPA 30A requires that the space within18" of the ceiling of a major repair garage for CNG be classified as a Class 1, Division 2 classified location. LNG is not included in this requirement but it is expected that the AHJ would apply this requirement to the LNG facility as well. This means that all electrical equipment within that area must be suitable for that classification as set forth in NFPA 70, National Electrical Code. The code does provide an exception to the requirement in that it will not apply to a facility that has a ventilation rate of at least 4 ACH. Since the natural gas detection sensors would most likely be placed in this classified location, the effectiveness of the ventilation system should be factored into the system design.

It is important to take into account the design of the ceiling support structure to determine what modifications may be necessary for the classified location. One example would be a concrete 'T' beam design that may not be easily ventilated at the required rate to eliminate the classified location thus requiring modification of any electrical equipment in the 18-inch space below the ceiling. Conversely an open web steel joist structure may achieve the proper 4+ ACH eliminating the classified location.

If the classified location cannot addressed by ventilation, then the choice may be to either modify the electrical installation to meet Class1, Division 2 requirements or move the electrical equipment below the 18-inch classified location, which in most cases would be to attach the system to the bottom of the support structure as opposed to the ceiling.

Preparation of LNG Vehicle for Maintenance

The IFC is the only code that has requirements for vehicle preparation prior to performing maintenance operations. For LNG vehicles, the procedure is to: 1) Operate the LNG vehicle to reduce the pressure in the on-board LNG tank to increase the 'hold time' of the LNG tank thus extending the time that would have to expire before the pressure relief valve would need to open and, 2) limit the quantity of natural gas that could be accidentally released by valving off all the fuel storage tanks on the vehicle once it enters the repair garage. Vehicles that have tank-mounted solenoid valves that are tied to the ignition system of the vehicle will automatically close the valves when the engine is shut down. Vehicles that have manual valves on the cylinders must be closed by hand. Operate the LNG vehicle after the valves are closed to make sure there is no liquid LNG trapped in the system; this also reduces the amount of natural gas that could be released by accident. A procedure to double check that all valves are closed as required should be established as part of the facilities normal operations.

The IFC also requires that, if there is any suspected damage to the LNG fuel system, the entire system should be checked for leaks and evaluated for fuel system integrity prior to bringing the vehicle into the repair garage. The LNG tank manufacturer should be able to provide detailed instructions for leak testing, maintenance and repair of the LNG tank.

Maintenance and Decommissioning of Vehicle Fuel Containers

NFPA 52 requires that repair facilities have a specific written record of inspection and maintenance of LNG tanks. This set of requirements depends on the existence of properly trained personnel and the use of procedures as recommended by the vehicle OEM and LNG tank manufacturer. In order to properly perform maintenance on LNG tank, it must be safely defueled either returning the LNG back into a closed system at a fueling station or by atmospheric venting, both of which require modification to the major repair garage

Although the codes do not require such systems, each major repair garage should install an engineered defueling facility. Designs for fuel recovery systems and direct atmospheric venting systems should be approved by the AHJ as required. If the LNG tanks must be serviced, they should be defueled and purged with an inert gas according to the LNG tank manufacturer's instructions.

While not covered in this set of guidelines, an LNG refueling station may be part of the overall modifications needed by the major repair garage in order to return the vehicles to service. Consideration should be given to adding a natural gas recovery system to the refueling station design in order to reduce the amount of natural gas is released to the atmosphere.

Training

The facility modifications will be of no avail
Without properly trained personnel

While physical modifications to the maintenance facility will help mitigate any potential hazard from adding CNG and LNG vehicles to facility operations, proper training of personnel is critical to maintaining a safe work environment. The training program should, at a minimum, cover the following:

- The physical properties of compressed natural gas
- The physical properties of liquefied natural gas
- Hazards associated with CNG
- Hazards associated with LNG
- Operation and use of hand held flammable gas detectors
- Manufacturer's instructions for maintenance, operation and calibration natural gas detection systems installed in the garage
- OEM instructions, and recommended maintenance procedures for the onboard fuel storage system and engine fueling components for both CNG and LNG vehicles
- OEM, cylinder manufacturer and /or cylinder valve manufacturer's instructions for defueling and valve maintenance/removal for CNG cylinders

- OEM and /or LNG tank manufacturer's instructions for maintaining and defueling of LNG tanks
- OEM and/or manufacturer's instructions for maintenance and calibration of on board LNG vehicle natural gas detection systems
- CNG cylinder inspection certification by CSA Standards of at least one maintenance technician
- Consider ASE certification of CNG vehicle technicians (F1 Test)

Appendix A

Physical Properties of CNG and LNG

The Table 11 below compares some of the basic properties of typical fuels that might be found in maintenance facilities.

Table 11 – Physical Properties of Fuels

Property	Pure Methane	LNG	CNG	LPG	Diesel	Gasoline
Formula of the major chemical component(s)	CH_4	CH_4	CH_4	C_3H_8	C_3 to C_{25}	C_4 to C_{12}
Boiling Temperature, °F	-259	-259	-259	-44	370-650	80-437
Fuel Density @ 60°F [excluding RLM, LNG] (lb/gal)	1.07 (at atmospheric pressure) RLM: 3.54	3.53	1.58 (at 3500 psi)	4.22	6.7-7.4	6.0-6.5
Autoignition Temperature, °F	1202	1004	1004	850-950	600	495
Flammability Range, vol.	5% - 15%	5% - 15%	5% - 15%	2.2% - 9.5%	1% - 6%	1.4% - 7.6%
Lower Heating Value (BTU/lb)	21500	20200-21500	20200-21500	19800	18000-19000	18000-19000
Lower Heating Value (BTU/gal)	23005 RLM: 76100	72700-77400	31900-33800	84500	128400	115000
Specific Gravity @ 60°F	0.129 (at atmospheric pressure) RLM: 0.428	0.435	0.192	0.508	0.81-0.89	0.72-0.78

RLM – Refrigerated liquid methane
Source: Alternative Fuel Data Center, ALT, and Battelle

Natural Gas Properties

CNG and LNG share the same physical properties as natural gas at ambient temperatures.

- Natural gas is a mixture of hydrogen carbon and other gasses with the primary constituent being methane.
- Natural gas is a colorless and odorless gas that has odorant added by the natural gas distribution company for safety.
- Natural gas is supplied to over 70,000,000 homes and businesses in the United States and its odor (often described as smelling like rotten eggs) is familiar to a large portion of the population.
- Natural gas is non-toxic and is a simple asphyxiant that in sufficient concentrations may displace oxygen in air.
- Natural gas is lighter than air (specific gravity 0.55 to 0.65) and quickly dissipates when released.
- Natural gas has a flammability range of 5% to 15% by volume in air.
- Natural gas has an ignition temperature of 1004 º F.

CNG Properties

- CNG in the United States has typical storage pressure of 3,600 psig.
- CNG is normally compressed from natural gas supplied by a distribution company and is therefore normally odorized to the appropriate level for safety.

LNG Properties

- LNG is a cryogenic liquid made by cooling natural gas to about -260 º F at atmospheric pressure.
- LNG normally has a higher percentage of methane than the natural gas it is made from since a number of constituents in natural gas are removed such a CO_2 and odorant.
- LNG is not odorized and methane detectors are used on LNG vehicles, stations and maintenance facilities for leak detection.
- LNG vapor when released usually forms a white cloud of water vapor and becomes lighter than air at @ -160 º F and dissipates like natural gas.

Hazards Associated with Natural Gas, CNG and LNG

Natural Gas Hazards

- Natural gas is a flammable gas that will ignite in concentrations between 5% and 15% in air.
- Natural has a higher ignition temperature (1000º F) than most fuels but ignition sources must be controlled in areas where an ignitable may be present.
- Natural gas should not be allowed to accumulate in an enclosed space because if ignited it would cause a rapid deflagration with significant overpressure.

- Natural gas is a simple asphyxiant that can displace air (oxygen) in enclosed spaces.

CNG Hazards

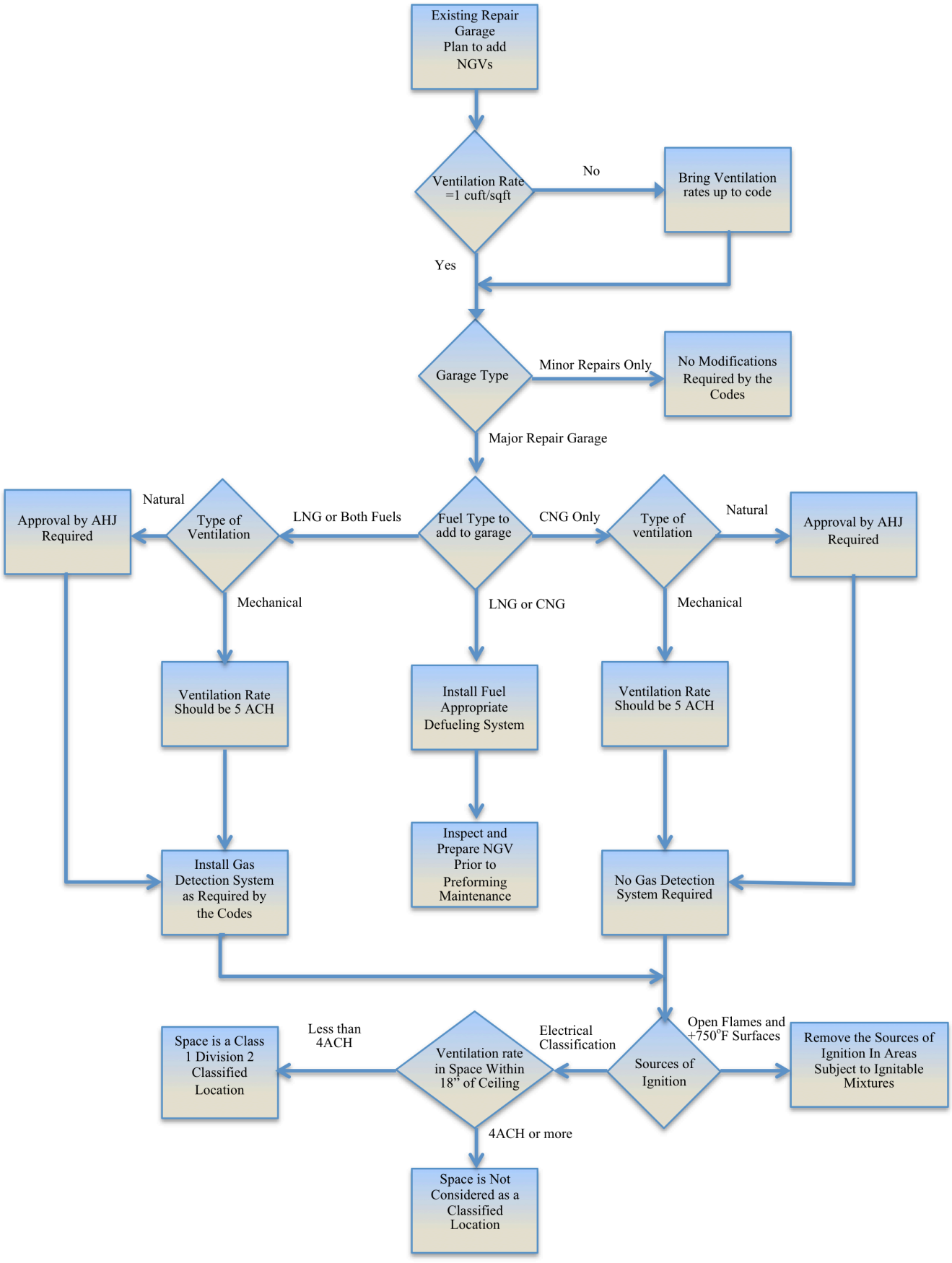
- High pressure gas releases from CNG systems may cause injury from:
  - Entrained particles in the gas stream
  - Ignition by static discharge at the leak source causing a jet or torch fire
  - High intensity noise generated by the high velocity gas stream

LNG Hazards

- Cryogenic burns to exposed skin from exposure to LNG liquid spills or cold vapor releases and direct contact to piping or fittings exposed to cryogenic temperatures.
- Since the initial release of LNG vapor is heavier than air, there is a potential that the vapor could displace air (oxygen) in pits and act as an asphyxiant.

Flow Chart for Modification Analysis

The flow shown on page 33 indicates the basic decisions that need to be made in order to determine what modifications may be required to add CNG and/or LNG vehicles to an existing maintenance facility. The decision points are discussed in more detail in the balance of the document.


Existing Repair Garage Plan to add NGVs
Ventilation Rate =1 cuft/sqft
No
Bring Ventilation rates up to code
Yes
Garage Type
Minor Repairs Only
No Modifications Required by the Codes
Major Repair Garage
Approval by AHJ Required
Natural
Type of Ventilation
LNG or Both Fuels
Fuel Type to add to garage
CNG Only
Type of ventilation
Natural
Approval by AHJ Required
Mechanical
LNG or CNG
Mechanical
Ventilation Rate Should be 5 ACH
Install Fuel Appropriate Defueling System
Ventilation Rate Should be 5 ACH
Inspect and Prepare NGV Prior to Preforming Maintenance
Install Gas Detection System as Required by the Codes
No Gas Detection System Required
Less than 4ACH
Electrical Classification
Open Flames and +750°F Surfaces
Space is a Class 1 Division 2 Classified Location
Ventilation rate in Space Within 18" of Ceiling
Sources of Ignition
Remove the Sources of Ignition In Areas Subject to Ignitable Mixtures
4ACH or more
Space is Not Considered as a Classified Location