FUEL QUALITY REPORT

BIOCNG GAS ANALYSIS

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1 INTRODUCTION

BioCNG, LLC has completed a gas composition analysis to demonstrate that the fuel produced by the BioCNG, LLC is acceptable for use in compressed natural gas (CNG) engines. The standards by which the BioCNG fuel has been compared include the Society of Automotive Engineers (SAE) J1616 Recommended Practice for Compressed Natural Gas Vehicle Fuel (See Appendix A), and the Cummins Westport fuel specifications. In addition to the standards mentioned above, BioCNG fuel was compared to a natural gas sample obtained by Air Liquide at their Delaware facility in 2007. The natural gas comparison was completed to assess the volatile organic compounds found in the BioCNG fuel versus pipeline natural gas.

The BioCNG fuel analyzed for this report is from a BioCNG installation in St. Landry Parish, LA. The BioCNG unit has been in operation at the St. Landry Parish Landfill since March 2012, and fuel is being used in Parish owned vehicles including sheriff's department patrol cars and light duty trucks. The data presented in this report was obtained during installation in of the system in February 2012 and from fuel sample collected on September 7, 2012.

To assess the quality of the BioCNG fuel several parameters were analyzed. These parameters were assessed by a combination of laboratory and field analysis. A list of the parameters that were analyzed is below:

- Fixed Gas Analysis, (methane, carbon dioxide, oxygen, and nitrogen) ASTM D1946
- Volatile Organic Compounds (VOC) EPA Method TO 15
- Siloxanes EPA Method TO 15
- Hydrogen Sulfide ASTM D5504
- Moisture Content ASTM D1142

The summary of the analysis is included in the sections that follow.

2 MAIN GAS CONSTIUENTS AND HEAT VALUE

2.1 Introduction

The main gas constituents found in BioCNG from Landfill gas include methane, carbon dioxide, oxygen, and nitrogen. BioCNG from anaerobic digesters is primarily composed of methane and carbon dioxide. Other constituents may be found in BioCNG, but are at levels of less than 0.1% and are considered trace constituents (see Section 4). The BioCNG sample from St. Landry parish was analyzed using ASTM Method D1946 (see Appendix B for analysis results). The analysis results are summarized in Table 2-1 below:

Table 2-1
St. Landry Parish Landfill BioCNG
Main Gas Constituents Summary

Gas Constituent	Quantity (% volume)	Laboratory Reporting Limit (% volume)
Methane	95.0	0.0028
Carbon Dioxide	1.6	0.028
Oxygen	ND	1.4
Nitrogen	3.2	2.8

Note:
(1) The sum of the items above do not add up to 100% due to the presence of other compounds such as VOCs, hydrogen sulfide and water vapor. For the purposes of calculating Wobbe Index, LHV and Methane Number, the 0.2% remaining was evenly distributed among the carbon dioxide and nitrogen bringing the total percentage of these gases to 1.7% and 3.3% by volume respectively.

Table 2-2 below provides data for natural gas across the United States as provided by the Gas Technology Institute. The data shows that the main gas constituent concentrations found in the St. Landry Parish BioCNG are within the range of typical concentrations of those same constituents in natural gas. The main difference is that BioCNG typically contains fewer heavy hydrocarbons (such as ethane) than natural gas.

Table 2-2
Average United States and California
Natural Gas Composition Table

Gas Constituent	Min. (% vol.)	Max. (% vol.)	CA Average (vol. %)	National Average (vol. %)
Methane	74.5	98.1	93.1	93.9
Ethane	0.5	13.3	3.4	3.2
Propane	0.0	2.6	0.7	0.7
C_4 and Higher	0.0	2.1	0.3	0.4
$N_2 + CO_2$	0.0	10.0	2.5	2.6

Source: Gas Technology Institute Presentation "Natural Gas Composition and Quality", William E. Liss and David M. Rue

2.2 Carbon dioxide

Pipeline natural gas contains small amounts of carbon dioxide. Given that the CNG corrosive environment is controlled via the limited water concentration allowed in SAE J1616, there are no limitations on the concentration of carbon dioxide for this purpose. A level of 3% by volume is recommended to help maintain stoichiometry. Based on the data shown in Table 2-2, natural gas carbon dioxide levels can exceed this recommendation. The St. Landry data shows a value of 1.6%. The BioCNG product gas carbon dioxide level can be set at a given concentration, with the system automatically adjusting operation to maintain that set level. It should be noted that according to the Cummins Fuel Quality Calculator, a fuel with 90% methane and 10% carbon dioxide will run a Cummins-Westport engine.

2.3 Nitrogen

Currently SAE J1616 does not address the nitrogen concentration in CNG fuel. Nitrogen's presence in the fuel reduces the Btu value and therefore the total nitrogen concentration must stay below a value that would preclude the fuel from meeting the minimum fuel heat content as described in Section 2.5. Data provided in Table 2-1 and Section 2.5 indicates that BioCNG achieves the minimum fuel value with the low nitrogen values detected in the gas.

2.4 Oxygen

Given that the corrosive environment in CNG fuel trains and storage vessels is controlled via the limited water concentration per SAE J1616, no limitations are required on the concentration of oxygen for the control of corrosion. SAE J1616 requirements for oxygen relate to not creating a flammable gas mixture, and BioCNG oxygen levels are consistently well below that minimum level.

2.5 Fuel Heat Content

Using the information in Table 2-1, the fuel heat content could be determined and compared to the SAE J1616 Recommended Practice and to the Cummins Westport fuel specifications.

SAE J1616 recommends a minimum Wobbe Index of 1200 for CNG. The Wobbe index is determined by dividing the high heating value of the fuel and dividing by the fuel's specific gravity. The Wobbe index calculated for the BioCNG at St. Landry Parish Landfill is 1251 Btu/scf assuming a HHV of methane of 23,880 Btu/lbm or approximately 1,003 Btu/scf (Cengel and Boles, 2002). The fuel at St. Landry Parish meets the minimum recommendation for Wobbe Index as described in SAE J1616. The SAE J1616 recommended Wobbe Index (last updated in 1994) is as follows:

> *"……The engine control systems for NGV's are presently under development. It is not well understood whether the Wobbe Index adequately characterizes these control systems. Flow through a Pintle type injector at sonic flow regimes is an example. Hence, the Wobbe Index limits may need to be reconsidered in the near future."*

SAE J1616 has not updated the Wobbe Index recommendation since the recommended practice was implemented. Therefore, it is recommended that individual engine manufacturer's fuel specifications be reviewed.

Cummins Westport analyzes the lower heat value of the fuel (LHV) and the fuel's methane number to assess fuel quality. The lower heat value is also known as the net heating value, and assumes that the latent heat of vaporization of water is not recovered during the combustion process. The LHV required for the Cummins Westport engines is 16,100 Btu/lbm. The methane number is a scale used to calculate engine knock potential in a natural gas spark ignited engine relative to reference fuels. The methane number is determined in accordance with SAE 922359. Cummins Westport requires a minimum methane number of 75 for their natural gas fired engines.

Cummins Westport provides a calculator on their website that can be used to determine the LHV of a fuel and the methane number of that fuel. BioCNG, LLC utilized the calculator and determined that BioCNG from St. Landry Parish meets the minimum requirements set forth by Cummins Westport. The LHV of the BioCNG from St. Landry Parish is 19,389 Btu/lbm, and the methane number is 108.3. A copy of the calculations from the Cummins Westport website is presented in Appendix C. A summary of the Wobbe Index, LHV and Methane Number are presented in Table 2-3.

Table 2-3
St. Landry Parish Landfill BioCNG
Fuel Heating Value Summary

Fuel Parameter	St. Landry Parish Result	Cummins Westport Requirement	SAE J1616 Recommendation
Wobbe Index	1,251 Btu/cf	None	1,200
Lower Heating Value	19,389 Btu/lbm	16,100 Btu/lbm	None
Methane Number	108.4	75	None

Notes:

(1) Wobbe Index calculation assumes a HHV of methane of 1,003 Btu/cf.
(2) LHV and Methane number were calculated using the Cummins Westport online fuel quality calculator.

3 MOISTURE CONTENT

Pipeline quality natural gas has a moisture content of approximately 7 pounds of water per million standard cubic feet of gas (7 lbs/mmscf). Pipeline natural gas utilized for CNG requires additional drying to further reduce the moisture content to prevent condensation in the fueling equipment and vehicle fueling system.. The SAE J1616 recommendation states that the pressure water dew point temperature for CNG be 10 degrees Fahrenheit below the lowest monthly dry bulb temperature recorded for the region. Fueling station dryers are designed to meet the SAE J1616 standard. BioCNG fuel exiting the treatment system is designed to be lower in moisture content than pipeline quality natural gas such that a standard fueling station dryer can be employed for final drying of the BioCNG fuel.

The BioCNG fuel at the St. Landry Parish landfill was analyzed for moisture content at the discharge of the BioCNG unit prior to the CNG fueling station dryer. An Alpha Moisture Systems model SADPminiEX portable hygrometer was used to measure the moisture content of the BioCNG. The moisture content of the BioCNG fuel was measured at a dew point temperature of -45.5 degrees F at 14.7 psia. This dew point temperature correlates to a moisture content of 4.24 lbs of water/mmscf of gas as calculated in accordance with ASTM D1142. This moisture content is less than typical natural gas and is therefore acceptable for utilization of a standard CNG fueling station drying unit.

4 TRACE CONSTITUENTS

4.1 Introduction

Raw biogas contains small amounts of trace constituents, typically measured in the parts per million or parts per billion ranges. The trace constituents of concern for BioCNG fuel are sulfur compounds, and siloxanes. These trace constituents can damage engines through corrosion and abrasion. Both Cummins Westport and SAE J1616 have set limits for hydrogen sulfide and total sulfur compounds. Cummins Westport has set additional standards to address siloxanes. Neither Cummins Westport or SAE J1616 has set limits on the VOC concentrations within CNG, however, pipeline natural gas was compared to BioCNG fuel to demonstrate that BioCNG fuel is similar with regard to VOC concentrations. Each of the trace constituents is discussed in detail in the following sections.

4.2 Hydrogen Sulfide and Sulfur Compounds

At the St. Landry Parish facility, hydrogen sulfide was the only sulfur compound analyzed for the BioCNG fuel. In biogas, hydrogen sulfide makes up the majority of the sulfur found in biogas, typically greater than 95%.

SAE J1616 and Cummins Westport have maximum total sulfur limits, and Cummins Westport has an additional requirement for hydrogen sulfide. One item to note regarding SAE J1616 is that the recommended practice states that due to low water content of the gas, the potential for corrosion is limited and no limitations on hydrogen sulfide are required. With that said SAE J1616 does recommend a maximum total sulfur limit to avoid excessive exhaust catalyst poisoning.

The test method recommended by both SAE J1616 and Cummins Westport is ASTM D4084 for hydrogen sulfide. For total sulfur, Cummins Westport recommends the CARB Method 16, which is similar to EPA Method 16. For the St. Landry Parish BioCNG facility, ASTM D5504 was used to determine the hydrogen sulfide concentration of the BioCNG. In the future, hydrogen sulfide testing will be done utilizing both EPA method 15 and ASTM D4084. The results of the hydrogen sulfide test indicate that the BioCNG fuel meets the requirements of both the SAE J1616, and Cummins Westport fuel specifications, see Table 4-1 below for a summary and comparison of results.

Table 4-1
St. Landry Parish Landfill BioCNG
Sulfur Concentration Summary

Sulfur Component	St. Landry Parish Result	St. Landry Parish Laboratory Reporting Limits	Cummins Westport Maximum Concentration	SAE J1616 Maximum Concentration
Hydrogen Sulfide	Non Detect (EPA Method 15)	0.56 ppmv	0.0006% by vol. = 6 ppmv (ASTM D4084)	No Limit due to low moisture content, if tested use ASTM D4084
Total Sulfur	Not Tested	NA	0.001% by wt. ≈ 6 ppmv (CARB Method 16)	1 grain per 100 cubic feet ≈ 17 ppmv

Notes:

(1) SAE J1616 4.2 states the following: Given that the corrosive environment is controlled via the limited water concentration per 3.1, no limitations are required on the concentration of hydrogen sulfide for this purpose. However, the total content of sulfur compounds, including odorants, should be limited to 1.0 grain per 2.83 m^3 (100 ft^3) [8 to 30 ppm mass] to avoid excessive exhaust catalyst poising.

4.3 Siloxanes

Siloxanes are compounds that have a variety of uses; some of the products where siloxane may be found include cosmetics, deodorants, soaps, food additives, and in water repellants. When disposed of in a landfill or anaerobic digestion system, siloxanes volatilize and become part of the biogas stream. During the combustion process siloxane compounds break down, and one of the resulting compounds is silicon dioxide. Silicon dioxide is hard and abrasive and can build up inside of engines and cause wear on moving parts. Due to the damaging effects of siloxanes on internal combustion engines, the BioCNG system is designed to remove siloxanes from the biogas stream. Since siloxanes are not found in pipeline natural gas, a standard has not been set forth through SAE, however, Cummins Westport, realizing that biogas is being used as a vehicle fuel has set forth a total siloxane concentration standard of 0.0003% by volume. The BioCNG fuel at the St. Landry Parish Landfill was tested for siloxanes to demonstrate that the BioCNG fuel siloxane content is below acceptable levels. The results of the analysis are presented in Table 4-2 below:

Table 4-2
St. Landry Parish Landfill BioCNG
Siloxane Concentration Summary

Siloxane Component	St. Landry Parish Result (EPA Method TO15)	St. Landry Parish Laboratory Reporting Limit	Cummins Westport Maximum Concentration	SAE J1616 Maximum Concentration
Hexamethyldisiloxane (L2, MM)	Non Detect	0.084 ppmv	No Individual Standard	No Standard
Hexamethylcyclotrisiloxane (D3)	Non Detect	0.084 ppmv		
Octamethyltrisiloxane (L3, MDM)	Non Detect	0.084 ppmv		
Octamethalcyclotetrasiloxane (D4)	Non Detect	0.084 ppmv		
Decamethyltetrasiloxane (L4, MD2M)	Non Detect	0.084 ppmv		
Decamethylcyclopentasiloxane (D5)	Non Detect	0.420 ppmv		
Dodecamethylpentasiloxane (L5, MD3M)	Non Detect	1.7 ppmv		
Total Siloxane	Not Tested	Not Applicable	0.0003% by vol. = 3 ppmv	No Standard

4.4 VOCs

Volatile organic compounds, or VOCs are found in both natural gas and biogas, however, no standard exists for VOCs by either Cummins Westport or by SAE J1616. BioCNG, LLC did however test the BioCNG fuel at the St. Landry Parish Landfill for VOC levels using EPA Method TO14/15. These results were compared to a similar test completed by Air Liquide, Inc. in 2007 on a sample of natural gas from their Delaware manufacturing facility (see Appendix D). The comparison of the natural gas to the BioCNG indicates that the BioCNG has less VOCs present than natural gas. Table 4-3 below shows the comparison of results between St. Landry Parish BioCNG and pipeline natural gas.

Table 4-3
St. Landry Parish Landfill BioCNG
VOC Comparison to Natural Gas Summary

Volatile Organic Compound	St. Landry Parish Result (ppbv)	Air Liquide Natural Gas Result (ppbv)
Dichlorodifluoromethane (R-12)	ND	ND
1,2-Chloro-1,1,2,2-Tetrafluoroethane	72	ND
Chloromethane	ND	36653.64
Vinyl Chloride	13	ND
1,3-Butadiene	Not Analyzed	ND
Bromomethane	ND	372.88
Chloroethane	ND	ND
Trichloromonofluoromethane	12	118.25
1,1-dichloroethene	ND	76.95
1,1,2-trichloro-1,2,2-trifluoroethane	ND	ND
Ethanol	Not Analyzed	409.46
Carbon Disulfide	Not Analyzed	ND
Isopropyl alcohol	Not Analyzed	ND
Methylene chloride	ND	ND
Acetone	670	ND
t-1,2-dichloroethene	ND	129.16
Hexane	Not Analyzed	40685.71
Methyl-t-butyl ether (MTBE)	210	354.79
1,1-Dichloroethane	34	ND
Vinyl acetate	ND	2225.62
cis-1,2-dichloroethene	ND	ND
Cyclohexane		18542.04
Chloroform	ND	3982.69
Ethyl Acetate	Not Analyzed	7522.65
Tetrahydrofuran	Not Analyzed	4944.84
1,1,1-trichloroethane	ND	ND
Carbon Tetrachloride	ND	55.26
2-Butanone	84	ND

.

Table 4-3 (Continued)

Volatile Organic Compound	St. Landry Parish Result (ppbv)	Air Liquide Natural Gas Result (ppbv)
Heptane	Not Analyzed	40709.24
Benzene	ND	38614.20
1,2-dichloroethane	ND	ND
Trichloroethylene	ND	174.08
1,2-dichlopropane	ND	ND
Bromodichloromethane	ND	132.41
1,4-dioxane	Not Analyzed	49.88
cis-1,3-dichloropropene	ND	ND
Toluene	22	15833.75
4-Methyl-2-pentanone(MIBK)	130	1077.63
t-1,3-dichloropropene	ND	ND
Tetrachloroethylene	ND	ND
1,1,2-trichloroethane	ND	ND
Dibromochloromethane	ND	ND
1,2-dibromoethane	ND	ND
2-Hexanone	ND	ND
Ethylbenzene	370	892.42
Chlorobenzene	ND	ND
m/p-Xylene	ND	4385.79
o-Xylene	ND	1114.34
Styrene	ND	38.11
Tribromomethane	ND	40.64
1,1,2,2-tetrachloroethane	ND	ND
1-ethyl-4-methylbenzene	Not Analyzed	ND
1,3,5-trimethylbenzene	ND	356.89
1,2,4-trimethylbenzene	ND	340.61
1,3-dichlorobenzene	ND	ND
1,4-dichlorobenzene	ND	ND
Benzyl chloride	ND	ND
1,2-dichlorobenzene	ND	ND
1,1,2,3,4,4-hexachloro-1,3-butadiene	ND	ND
1,2,4-trichlorobenzene	ND	ND
4-Ethyl Toluene	ND	Not Analyzed

5 CONCLUSION

Based on the research completed by BioCNG, LLC at the St. Landry Parish, and the results of the natural gas analysis provided by Air Liquide, the BioCNG system produces a fuel that meets or exceeds the SAE J1616 Recommended Practice and the Cummins-Westport fuel specifications.

LIMITATIONS

The work product included in the attached was undertaken in full conformity with generally accepted professional consulting principles and practices and to the fullest extent as allowed by law we expressly disclaim all warranties, express or implied, including warranties of merchantability or fitness for a particular purpose.

The work product herein (including opinions, conclusions, suggestions, etc.) was prepared based on the situations and circumstances as found at the time, location, scope and goal of our performance and thus should be relied upon and used by our client recognizing these considerations and limitations. Cornerstone shall not be liable for the consequences of any change in environmental standards, practices, or regulations following the completion of our work and there is no warrant to the veracity of information provided by third parties, or the partial utilization of this work product.

REFERENCES

Anderson, Charlie. *Halogens and Carcinogens in Pipeline Natural Gas.* Air Liquide MEDAL, a division of Air Liquide Advanced Technologies U.S., LLC. March 17, 2012.

Cengal, Yunus A. and Boles, Michael A. *Thermodynamics and Engineering Approach, Fourth Edition.* New York, NA: McGraw-Hill, 2002. Print.

Cummins-Westport, Inc.

Gas Technology Institute

APPENDIX A

SAE J1616 RECOMMENDED PRACTICE FOR COMPRESSED NATURAL GAS VEHICLE FUEL

SURFACE VEHICLE RECOMMENDED PRACTICE

An American National Standard

Recommended Practice for Compressed Natural Gas Vehicle Fuel

Foreword—This document has been changed to comply with the SAE Technical Standards Board format. Definitions have changed to Section 3. All other section numbers have changed accordingly.

1. ***Scope***—Compressed Natural Gas (CNG) is a practical automotive fuel, with advantages and disadvantages when compared to gasoline. It has a good octane quality, is clean burning, easy to meter, and generally produces lower vehicle exhaust emissions. CNG is used to fuel internal combustion engines. Natural gas is normally compressed form 20 690 to 24 820 kPa (3000 to 3600 psig) to increase its energy density thereby reducing its on-board vehicle storage volume for a given range and payload.

   The properties of natural gas are influenced by (1) the processing of natural gas by the production and transmission companies and (2) the regional gas supply, storage, and demand balancing done by distribution companies often in concert with pipeline companies to maintain uninterrupted service throughout the year, e.g., peakshaving with propane-air (see U.S. Bureau of Mines Publication 503).

   Information on the properties of distribution system natural gas and its variability has been included in Figure 1 and can be found in GRI-92/0123. The analysis in this reference summarizes the expected composition of natural gas in 26 cities. Composition can vary hourly under certain operating conditions in certain areas of the country. Thus the data should generally be considered representative for the areas mentioned with due consideration for local variation.

   Natural gas is comprised chiefly of methane (generally 88 to 96 mole percent) with the balance being a decreasing proportion of non-methane alkanes (i.e., ethane, propane, butanes, etc.).

   Other components found in natural gas are nitrogen (N_2), carbon dioxide (CO_2), water, oxygen, and trace amounts of lubricating oil (from compressors) and sulfur found as hydrogen sulfide (H_2S) and other sulfur compounds. Before entering the transmission system, it is processed to meet limits on hydrogen sulfide, water, condensibles of heavier hydrocarbons, inert gases such as carbon dioxide and nitrogen, and energy content. Mercaptan odorants (e.g., tertiary butyl mercaptan) are added by local distribution companies (LDC's) for safety reasons to detect the presence of natural gas which otherwise would be odorless.

   Water content and other corrosion precursors, heavier hydrocarbons which may condense within the fuel container, particulate matter, oil and energy content need to be controlled in order to minimize corrosion and provide satisfactory low-temperature vehicle operation, performance, and emissions levels.

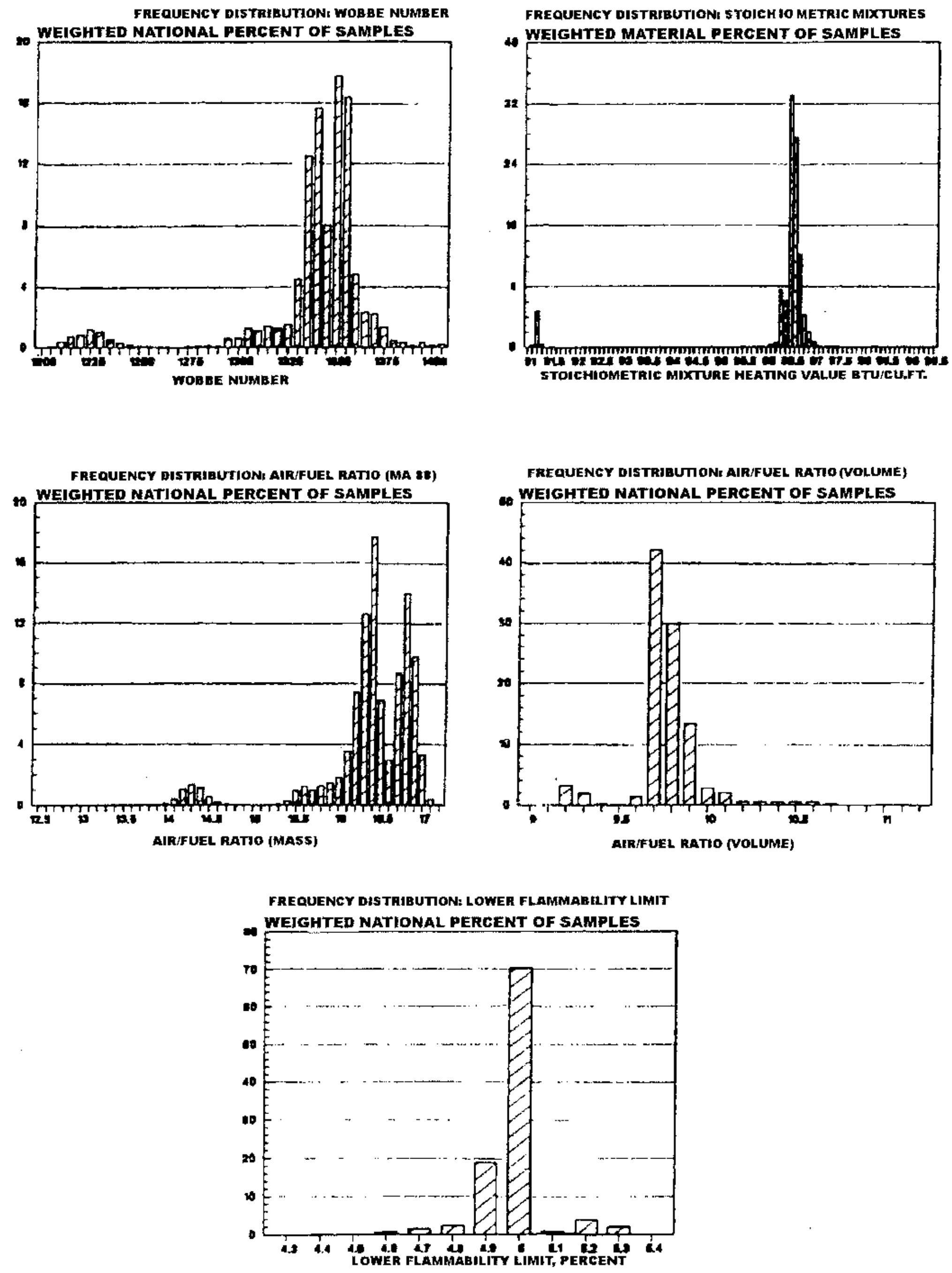


FIGURE 1—NATIONAL WEIGHTED DISTRIBUTIONS

The provisions contained in this SAE Recommended Practice are intended to protect the interior surfaces of the fuel container and other vehicle fuel system components such as fuel injector and exhaust catalyst elements from the onset of corrosion, poisoning, the deposition of liquids or large dust particles, or the formation of water, ice particles, frost, or hydrates. The provisions contained in this document are not intended to address the composition of natural gas as delivered to a fueling station, but rather at the outlet of the fueling station as delivered into the containers on the vehicle. Limits on gas composition constituents currently not included in this document may be added when data are available to substantiate them.

1.1 **Purpose**—This document presents the more important physical and chemical characteristics of compressed natural gas vehicle fuel and describes pertinent test methods for defining or evaluating these properties.

In order for compressed Natural Gas Vehicles (NGVs) to effectively provide satisfactory and safe operation for users, there is a need to address specific issues relative to the use of natural gas as a vehicle fuel. The two primary areas relate to (1) compressed storage of natural gas and (2) vehicle fuel system and engine performance issues. These provisions have been derived through a joint effort of the SAE TC-7 Natural Gas Vehicle Task Force and the Technology Committee of the Natural Gas Vehicle Coalition.

NOTE—This document is intended as a guide and is subject to change to keep pace with experience and technical advances. The following are separate documents that are not part of the document, but are added as an Informative Appendix (Appendix A).

Background Statement—Summarizes the development of the maximum water content provision for SAE J1616.

Excerpts from ANSI AGA/NGV2—Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers
Bibliography of SAE Publications and Other Publications.
Rationale Document for SAE J1616.

2. *References*

2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE Publications—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE Paper 902069—Ambient Temperature and Driving Cycle Effects on CNG Motor Vehicle Emissions, Gabelle, P., Crews, W., Perry, N., Lenning, J., Knapp, K. T., Ray, W.D., Snow, R.
SAE Paper 920593—The Impact of Natural Gas Fuel Composition on Fuel Metering and Engine Operational Characteristics, King, S.R.

2.1.2 ANSI Publication—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI AGA/NGV2, 1992—Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers

2.1.3 ASHRAE Publication—Available from ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329.

ASHRAE Handbook

2.1.4 ASTM Publications—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 1142-90—Test Method for Water Vapor Content of Gaseous Fuels by Measurement of Dew Point Temperature
ASTM D 1945-91—Test Method for Analysis of Natural Gas by Gas Chromatography
ASTM D 3588-91—Standard Method for Calculating Calorific Value and Specific Gravity "Relative Density" of Gaseous Fuels
ASTM D 4084-88—Test Method for Analysis of H_2S in Gaseous Fuels (Lead Acetate Reaction Method)

2.1.5 Administration Publication—Available from National Climatic Data Center, Federal Building, Asheville, NC 28001.

Climatography of the U.S. No. 20, Climatic Summaries for Selected Sites, 1951–80
Comparative Climatic Data for the United States through 1991, U.S. Dept. of Commerce's National Oceanic and Atmospheric Administration

2.1.6 GRI Publications—Available from Gas Research Institute, 8600 West Byr Mawr Avenue, Chicago, IL 60631.

GRI-91/1011,92/0123—Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States, Final Report, March 1992, Liss, W.E. and Thrasher, W.R.
GRI-92/0150—Effect of Gas Composition on Octane Number of Natural Gas Fuels, Kubesh, J.
Gas Engineers Handbook, Industrial Press Inc., New York, 1965

2.1.7 NFPA Publication—Available from National Fire Protection Agency, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 52 1992 Edition—Compressed Natural Gas (CNG) Vehicular Fuel Systems

2.1.8 U.S. Bureau Of Mines Publication—Available from U.S. Bureau of Mines, Department of the Interior, 1849 C Street NW, Washington, DC 20250.

U.S. Bureau of Mines Publication 503, Copyright 1952

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 GRI Publication—Available from Gas Research Institute, 8600 West Byr Mawr Avenue, Chicago, IL 60631.

GRI 92/0158, 1992—Proceedings of the Gas Research Institute Natural Gas Vehicle Fuel Composition Workshop Held February 13, 1992, Rosemont, IL

2.2.2 ISO Publications—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 6326-2-1981—Gas analysis—Determination of sulfur compounds in natural gas—Part 2: Gas chromatographic method using and electrochemical detector for the determination of odoriferous sulfur compounds
ISO 6570-3-1989—Natural gas—Determination of potential hydrocarbon liquid content—Part 3, Volumetric method
ISO 6977-1983—Natural gas—Detection of water and methanol content, gas chromatograph method

3. *Definitions*

3.1 **Dew Point Temperature**—The temperature, referenced to a specific pressure, at which water vapor or other vapor phase components begin to condense.

3.2 **Pressure Water Dew Point (At Container Pressure)**—The water dew point temperature of the gas at the maximum anticipated pressure in the fuel storage container(s) of the CNG vehicular fuel system (usually measured in the fueling station storage container(s) prior to pressure reduction). When presenting or referencing dew point, the value shall be given in terms of the container pressure; e.g., –20 °C, (–4 °F) dew point at 24 820 kPa (3600 psig).

3.3 **Pressure Hydrocarbon Dew Point (At Container Pressure)**—The hydrocarbon dew point temperature of the gas at the maximum anticipated container(s) pressure of the CNG vehicular fuel system (usually measured in the fueling station storage container(s) prior to pressure reduction). When presenting or referencing dew point, the value shall be given in terms of the container pressure; e.g. –20 °C (–4 °F) dew point at 24 820 kPa (3600 psig).

3.4 **Micrometre**—A metric measure with a value of 10^{-6} m or 0.000001 m (also referred to as "micron"). The ANSI spelling of "micrometre" for dimension and "micrometer" for the measuring tool is used in this document.

3.5 **(PPM)**—Represents parts per million and can be given on a volume or mass basis. The abbreviation shall be ppm (v/v) for volume, or m/m for mass: e.g., 1.0 ppm (v/v), which corresponds to 1.0 m^3 (CO_2 or other limited constituent) per million (1 000 000) m^3 of natural gas at standard conditions of pressure and temperature. There are numerous "standard conditions" in use in the gas industry. For purposes of this document, the values being adopted by ISO of 101.325 kPa (14.7 psig) and 288.15 K (15 °C or 59 °F) are used.

3.6 **Specific Gravity**—Also known as relative density, is the ratio of the density of natural gas (kg/m^3) to the density of air measured at standard conditions of pressure and temperature.

3.7 **Wobbe Index (WI)**—Also known as Wobbe Number (WN), is a measure of fuel energy flow rate through a fixed orifice under given inlet conditions.

4. ***Properties Related to Containers and Vehicle Fuel System Corrosion***—Natural gas for vehicle fuel use is typically stored in a high-density gaseous state at CNG fueling stations at peak tank pressures of 24 820 to 34 480 kPa (3600 to 5000 psig) and on board vehicles at peak tank pressures of 20 690 to 24 820 kPa (3000 to 3600 psig) in cylinders made of metal (e.g., steel or aluminum), metal liners with resin-reinforced filament winding, or non-metallic liners with resin-reinforced filament winding. It is essential that all safety factors must provide adequate safety margin for rupture pressure as well as resistance to corrosion, fatigue, fire, vibration, and mechanical damage. Cylinder failures can be caused by corrosion or corrosion-related damage, i.e., stress corrosion cracking (essentially hydrogen embrittlement) or corrosion fatigue.

Specific fuel components can impact cylinder integrity. The most critical potential issue is crack growth due to corrosion fatigue. This process occurs due to the combined action of corrosion agents in natural gas—hydrogen sulfide, carbon dioxide, water (or water vapor)—and the pressure cycling associated with periodically expending and replenishing the fuel storage cylinder. Complementary discussion of issues related to compressed gas storage is available in Appendix A.

4.1 **Pressure Water Dew Point Temperature**—The pressure water dew point temperature of the fuel should be compatible with the specific geographical location in which the vehicle will operate and should be set such that condensation of water will not occur in the storage cylinder at the maximum operating container pressure. The local dew point temperature of the fuel should be defined as 5.6 °C (10 °F) below the monthly lowest dry-bulb temperature as found in U.S. Dept. of Commerce's National Oceanic and Atmospheric Administration Publication: "Comparative Climatic Data for the United States through 1991," at the maximum operating container pressure. Data for specific states/cities can be found in the Department's "Climatography of the U.S. No. 20: Climatic Summaries for Selected Sites, 1951–80." The margin of 5.6 °C (10 °F) is intended to provide some allowance for expansion cooling as gas flows throughout the fuel system components. Expansion cooling will generally lead to greater temperature decreases than 5.6 °C (10 °F). Hence, freezing in the fuel system may occur if the fuel gas is not extremely dry. It should be noted that current hydromatic devices have been found to be inherently inaccurate below 1.6×10^5 kg/m^3 (1 lb/mmscf). Future engineering development programs are expected to better define the appropriate specification in this regard.

The fuel provider or station operator should determine the most appropriate method to maintain the pressure water dew point limit. Future changes to NFPA-52 will address specific safety requirements.

Pressure water dew point is determined by ASTM D 1142-90.

4.2 **Hydrogen Sulfide Concentration**—Given that the corrosive environment is controlled via the limited water concentration per 3.1, no limitations are required on the concentration of hydrogen sulfide for this purpose. However, the total content of sulfur compounds, including odorants, should be limited to 1.0 grain per 2.83 m^3 (100 ft^3) [8 to 30 ppm mass] to avoid excessive exhaust catalyst poisoning.

Hydrogen sulfide concentration is determined by ASTM D 4084-88.

4.3 **Carbon Dioxide Concentration**—Given that the corrosive environment is controlled via the limited water concentration per 3.1, no limitations are required on the concentration of carbon dioxide (CO_2) for this purpose. However, a limit of 3.0% CO_2 by volume is recommended to help maintain stoichiometry.

Carbon dioxide concentration is determined by ASTM D 1945-91.

4.4 **Methanol Concentration**—No methanol shall be added to natural gas at the CNG fueling station. Methanol can cause corrosion of natural gas cylinders and deterioration of fuel system components. Methanol is not needed if the pressure water dew point temperature of the stored gas is controlled to the recommended limits.

There is no applicable test method for determining methanol concentration at this time.

4.5 **Oxygen Concentration**—Given that the corrosive environment is controlled via the limited water concentration per 3.1, no limitations are required on the concentration of oxygen for the control of corrosion. At no time shall the oxygen level produce a mixture within the flammability limits of the fuel. Flammability limits at ambient conditions are readily known and published in documents such as the Gas Engineers Handbook. Information about flammability limits at the temperature and pressure conditions to which the onboard cylinders or ground storage containers are subjected have not been documented. Current auto industry experience indicates closed-loop engine controls can be used to maintain stoichiometry using pipeline quality gas.

Oxygen concentration is determined by ASTM D 1945–91. Flammability limits can be calculated using U.S. Bureau of Mines Publication 503.

4.6 **Particulate and Foreign Material**—Particulate concentration should be minimized to avoid contamination, clogging, and erosion of fuel system components. The fuel should be processed with a filter rated at 5 μm (micron) nominal (i.e., 98% efficiency) particle size. CNG fuel delivered to the vehicle should have particulate matter content equal to or less than 5 μm in size.

There is no applicable test method for determining particulate concentration at present.

4.7 **Oil Content**—Lubricating oils are often present in natural gas at trace levels due to carryover from pipeline compressors, or on-site fueling station compressors. Excessively high levels of lubricating oil entrained or absorbed in natural gas can condense and may create vehicle operational problems (e.g., liquids in the fuel pressure regulator). Additional data are required to determine acceptable lubricating oil levels as well as standardized test procedures for quantifying lubricating oil content. However, it must be understood that levels adversely affecting NGV performance are unacceptable by definition. Lubricated compressor oil levels should be monitored, and coalescing filters may be installed downstream of the compressor discharge to control oil.

4.8 **Pressure Hydrocarbon Dew Point Temperature**—Some locally distributed natural gases may contain mixtures of propane and air used to meet peak demand requirements. Propane therefore is the predominant condensable hydrocarbon of concern. Propane has a comparably low vapor pressure and if present in significant quantities will form a liquid phase at elevated pressures and low temperatures. Fuel variability due to revaporization of this liquid condensate at reduced tank pressures can lead to reduced vehicle performance. To minimize these occurrences, the composition of natural gas should be such that the original gaseous storage volume will form less than 1% of a liquid condensate at the lowest ambient temperatures and gas storage pressures between 5517 to 8275 kPa (800 to 1200 psig) at which maximum condensation occurs, depending on gas composition.

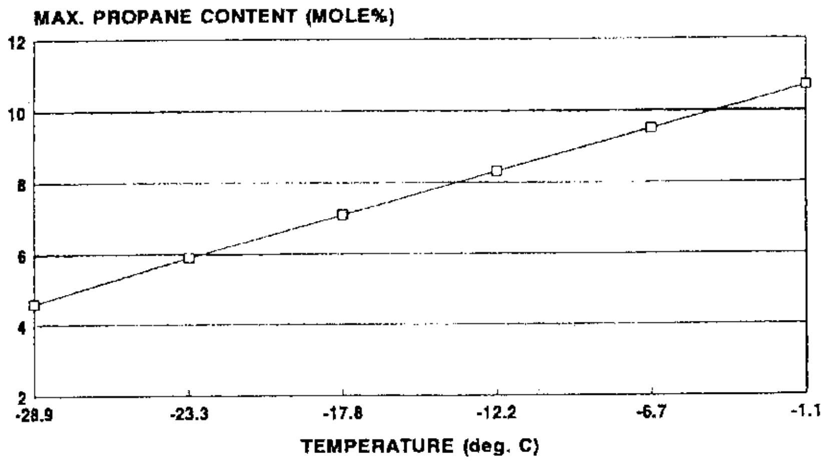
Figure 2 shows the maximum allowable concentration of propane in mole percent that corresponds to a 1% liquid condensation volume for various low ambient temperatures and gas storage pressure conditions. The amount of propane shall be compatible with the specific geographical region or temperatures in which the vehicle will operate and shall be set such that less than 1% hydrocarbon condensate will form at the dry-bulb temperatures as found in U. S. Department of Commerce Publications: "Comparative Climatic Data for the United States Through 1991." Data for specific states/cities can be found in the Department's "Climatography of the U.S. No. 20: Climatic Summaries for Selected Sites, 1951–80."

Propane concentration is determined by ASTM D 1945–91.

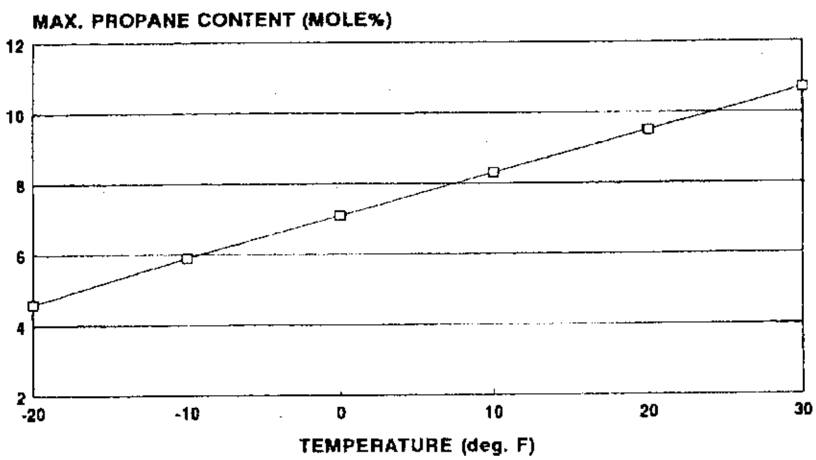
4.9 **Natural Gas Odorant**—Natural gas introduced into any CNG fueling station or vehicle shall have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 of the lower limit of flammability. This is approximately 1.0% gas in air by volume.

5. ***Vehicle Fuel System and Engine Performance***—Some chemical and physical properties not currently limited by this document are important considerations in vehicle fuel system, and engine performance. Theoretical and laboratory results cannot fully define all pertinent fuel properties that impact engine operation characteristics. A complete list of fuel properties requires a more substantial level of field experience. Currently, there is insufficient field data on NGV's to specify limits on all properties. However, laboratory results do indicate how certain parameters impact engine operational characteristics and future fuel composition limits are anticipated. An overview of the characteristics of natural gas as an engine fuel is provided in SAE Paper 902069.

5.1 **Engine Performance**—SAE Paper 920593 describes in detail the causes and effects of varying composition on fuel metering and engine operational characteristics.



PRESSURE RANGE OF 55-80 ATMOSPHERES



PRESSURE RANGE OF 800-1200 PSI

FIGURE 2—MAXIMUM PROPANE CONTENT (MOLE % PROPANE IN GAS FOR MAX. 1% HC CONDENSATION)

5.1.1 WOBBE INDEX—Natural gas can be characterized by Wobbe Index (WI). The Wobbe Index is a measure of the fuel energy flow rate through a fixed orifice under given inlet conditions. Mathematically, the Wobbe Index is expressed as shown in Equation 1:

$$WI = \frac{\text{(dry, higher heating value)}}{\text{(specific gravity)}^{1/2}} \quad \text{(Eq. 1)}$$

Dry denotes essentially no water vapor in the gas fuel. A change in Wobbe Index may affect the power output and performance of the engine. Since most present natural gas metering systems are based on orifices, variations in Wobbe Index of the gas will produce similar variations in the air-fuel ratio. Variability in this parameter most significantly impacts engines that are not equipped with closed-loop controls.

In recommending a Wobbe Index range, it is important to consider the practicality of supplying gas meeting a narrow criteria. As documented by Liss and Thrasher in GRI-91/1011, 92/0123, major gas pipelines already maintain reasonably tight control over Wobbe Index of delivered gas. Figure 1 shows the Wobbe Index distribution for a national sample. As the figure shows, there are essentially two distributions: one between 1200 and 1250 and the other between 1300 and 1420. Alterations or further tightening of these ranges for NGV use would not be practical, given foreseen NGV fuel demand.

At this time, a Wobbe Index range of 48.5 to 52.9 MJ/m^3 (1300 to 1420 BTU/ft^3) is recommended; however, a Wobbe Index range of 44.7 to 46.6 MJ/m^3 (1200 to 1250 BTU/ft^3) has been found to be acceptable for use on current equipment in high altitude areas. The recommended range, typical of most natural gas, would allow maximum variation from nominal air-fuel ratio of about ±3.7%, which is comparable to the range in variation in gasoline density, and should not present significant control problems. The engine control systems for NGV's are presently under development. It is not well understood whether Wobbe Index adequately characterizes these control systems. Flow through a Pintle type injector at sonic flow regimes is an example. Hence, the Wobbe Index limits may need to be reconsidered in the near future.

The Wobbe Index of natural gas can be determined through the measurement of heating value and specific gravity (i.e., relative density) by ASTM D 3588–91. Wobbe Index is then calculated using Equation 1.

5.1.2 KNOCK RATING—The resistance of a fuel to autoignition (sometimes referred to as detonation or combustion knock) is a fundamental fuel characteristic. No recognized test method presently exists for determination of the Motor Octane Number (MON) of natural gas. A methodology has been developed by Southwest Research Institute (SAE Paper 920593 and GRI 92/0150) which shows a close correlation between hydrogen - carbon ratio and MON antiknock performance. The results of these analyses suggest that the MON of natural gas ranges from 115 to 124.

5.2 Driveability—The Pressure Water Dew Point criterion as specified is expected to be adequately rigorous to eliminate operational problems that the presence of condensed water can cause. Use of natural gas with high water content can result in the formation of water, ice particles, frost, or hydrates at low ambient temperatures. If permitted to enter the vehicle fuel system, this may interfere with consistently smooth natural gas flow, and has been known to result in driveability problems due to clogging or freeze up of gas lines, fittings, valves, regulators, fuel injectors, and the like.

PREPARED BY THE SAE FUELS AND LUBRICANTS TECHNICAL COMMITTEE 7—FUELS

APPENDIX A

A.1 ***Informative Background Statement***—Initially, the NGV Coalition's Fuel Cylinder Task Group had recommended in ANSI AGA/NGV2 a water vapor criteria of –45.6 °C (–50 °F) or lower pressure water dew point. The Task Group had agreed that the coverage in the proposed NGV2 standard is predicated entirely on absense of liquid water, i.e., a pressure water dew point of –45.6 °C (–50 °F) or lower. The Task Group's recommendation was based on existing industry design experience for compressed gas cylinders, which is mandatory by DOT cylinder regulations and exemptions. In addition, the Task Group's consideration involved review of pertinent compressed gas cylinder corrosion research performed by Southwest Research Institute (U.S.) and Powertech Labs (Canada). This review of corrosion research also involved reports from the National Association of Corrosion Engineers (NACE).

Over the course of several meetings, the Gas Composition Subcommittee and the Fuel Cylinder Task Group arrived at an acceptable compromise to the –45.6 °C (–50 °F) criterion, which then appeared in proposed NGV2 and the Society of Automotive Engineer's proposed Recommended Practice for Compressed Natural Gas Vehicle Fuel Composition, SAE J1616. It was acknowledged that the present specification of 5.6 °C (10 °F) below the 99% winter design temperature was more realistic and feasible as a criterion than a –45.6 °C (–50 °F) water pressure dew point specification. With this compromise, the Task Group's goal of establishing a suitable internal environment for NGV2-certified containers was realized.

Subsequently, the Coalition's Gas Composition Subcommittee considered local seasonal or monthly adjustment of the pressure water dew point criterion, and agreed that the ASHRAE 99% winter design temperature reference should be replaced with the lowest dry-bulb temperatures found in the U. S. National Oceanic and Atmospheric Administration Publication: "Comparative Climatic Data for the United States Through 1991."

The ANSI AGA/NGV2 Standard is included in NFPA 52-1992, under vehicle fuel container coverage. The NGV2 Standard has been approved by ANSI to ensure approval of its proposed reference in NFPA 52-1992. In addition, SAE J1616 is included in NFPA 52-1992 as an informational, non-mandatory text "Note,", under "gas quality" coverage. The "gas quality" coverage in NFPA 52-1988 was retained for the 1992 edition.

Several vehicle OEM's are unanimous in pressing for at least as tight or a tighter limit in the context of the gas composition Recommended Practice, SAE J1616, to protect NGV fuel system components, particularly fuel injectors, from the internal formation of condensed water, ice, or frost.

A.2 ***Excerpts from ANSI AGA/NGV2 Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers "Rationale Document" Pertinent to SAE J1616***—The dew point limit is intended to relieve NGV operators in warm climates of the extreme water vapor limits needed in colder areas. The ASHRAE Handbook is an authoritative publication, readily available, upon which to base a location-specific standard. The 99.0% winter design temperature is exceeded during 99.0% of the total hours of the months of December, January, and February. Natural gas storage containers have considerable thermal mass, and the lowest container temperature cannot be below atmospheric ambient unless gas has been withdrawn. The margin of 5.6 °C (10 °F) is intended to allow for expansion cooling of the container.

It is intended that the pressure used for the dew point determination be the "service pressure," as defined in NGV2 as follows:

"Service pressure. The settled pressure post adjustment per ASHRAE at a uniform gas temperature of 21 °C (70 °F) and full gas content. It is the pressure for which the equipment has been constructed, under normal conditions. Also referred to as nominal pressure or working pressure."

In addition, methanol injection at the fuel station is prohibited because of the corrosive effects of methanol and the extreme difficulty of monitoring the methanol content in the compressed gas. The methanol delivered in the pipeline is not considered sufficient to harm the cylinders, but much greater amounts might be added at the fueling compressor. Methanol injection will not be necessary to prevent hydrate formation if the dew point is controlled.

The water content of natural gas stored in NGV2 containers must be controlled to prevent the formation of liquid water in the container. The proposed NGV2 standard permits significant economic advantages when compared to the existing DOT specifications and exemptions for gas cylinders, but these advantages, and their regulatory acceptance, depend upon an interior service environment free of liquid water.

The Task Group has editorially revised the gas composition coverage to correlate with the proposed SAE Recommended Practice on Natural Gas Vehicle Fuel. In the absence of an ASTM natural gas fuel specification, the SAE Recommended Practice, once approved by SAE probably will be referenced by the three major automakers in their NGV owner manuals. These will probably require compliance to ensure the continued validity of warranties for the NGV's which they will produce and sell.

The NGV2 Standard required only periodic visual external inspection as assurance that the container condition has not deteriorated at an unsafe level. The hydrostatic expansion retest is excluded from NGV2 because neither general corrosion nor undetected overheating which would cause a reduction in the pressure retention capability of the container are expected. These two sources of strength loss are the reasons for the inclusion of the hydrostatic expansion retest for DOT cylinders. The presence of liquid water in the container raises the issue of general corrosion and therefore coverage tolerant of the presence of water would require the addition of hydrostatic expansion retest to NGV2.

The NGV2 Standard requires no internal visual inspection during the 15-year service life. This is somewhat more ambitious than the 10-year retest/reinspection interval for DOT-3AA steel cylinders used in dry gas service. Twenty-two years experience with the 10-year retest interval in dry gas service has shown that interior deterioration is not a problem with the current DOT restriction of –46.7 °C (–52 °F) dew point. This experience forms the basis for the NGV2 reinspection criterion.

The NGV2 standard requires only 5000 fatigue cycles to the maximum allowable working pressure plus 13 000 cycles to service pressure. The total of 18 000 cycles is the estimate of worst case service fatigue cycles and contains no additional safety factor. Present DOT specification cylinders have cycle lives on the order of 50 000 at maximum allowable operating pressure and 500 000 at service pressure. The two most common composite compressed natural gas cylinders, E8725 and E8965, have demonstrated cycle lives in excess of 20 000 and 50 000 at these same pressures. The presence of liquid water in the NGV2 containers raises the issue of corrosion fatigue and will require the application of fatigue safety factors of between four and twenty. Increasing the fatigue requirements to allow for liquid water corrosion fatigue will drive up the cost of all except plain metal containers, limiting the weight benefits and feasibility of the lighter composite designs.

The NGV2 standard reduces the safety factor for metal and hoop wrapped metal containers from 2.5:1 to 2.25:1. This 10% reduction corresponds to the safety factor of DOT 3AA "+" marked cylinders and DOT-3HT high tensile steel aircraft cylinders. Although DOT specifications do not require that only dry gas be used in "+" marked 2.25:1 safety factor cylinders, the reinspection criteria requires removal from 2.25 safety factor service if local or pitting corrosion are present. Water accumulation in compressed natural gas containers may be expected to cause such corrosion.

The Task Group is aware of no definitive study of the effects of methanol injection on local corrosion, general corrosion or corrosion fatigue of compressed natural gas containers. Industry experience with methanol fuel systems give cause for concern regarding methanol attack in both metallic and nonmetallic compressed natural gas containers. Existing NGV fueling technology requires the use of methanol injection to achieve reliable mechanical operation in the presence of liquid water. Methanol is not needed if the pressure dew point of the stored gas is controlled.

The final issue concerns the potential for use of higher strength, more efficient steels in compressed natural gas cylinders. Today, there are DOT industrial gas cylinders in service with minimum tensile strengths 50% greater than the minimum tensile strength of DOT-3AA cylinders. These more efficient designs cannot be contemplated as long as the gas contained may be wet.

The conclusion of the Task Group is that substantial cost and weight penalties will result from modifications to the NGV2 standard unless the gas to be stored is dry. In addition, the corrosion damage mechanisms are not well defined, and a large investment in both basic and specific research would be necessary to establish adjustment factors between design qualification tests performed with noncorrosive fluids and actual service with a corrosive wet gas. The variability of natural gas quality, both geographically and seasonally, further complicates any such research effort.

Gas quality assurance is not easy from either a Quality Assurance (QA) system standpoint or a technical analysis standpoint. Neither the individual fuel station operator nor the gas distribution company supplying the fuel station can by themselves maintain a complete QA program. Therefore, such a QA program must be the joint responsibility of both parties. The QA program could condition the gas either before or after compression, but monitoring of the quality should be done after compression to detect contamination by defective cooling systems on the compressors. In all cases, the responsibility for maintaining the dispensed gas at the required dew point should rest with the party responsible for final sale of the gas dispensed into a container covered by the NGV2 standard.

As a result of the reference change from ASHRAE winter design temperature to the monthly lowest dry-bulb temperature reference, the ANSI AGA/NGV2 standard will need to be revised to be consistent with SAE J1616.

A.3 ***Bibliography***—The following publications are provided for information purposes only and are not referenced in this document.

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"Control of Corrosion Fatigue in NGV Fuel Cylinders," Hudak, S., GRI Report-89/0239.

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SAE J1616 Issued FEB94

Rationale—The changes are as follows;

General—Like most emerging industries, the use of compressed natural gas for automotive fuel does not spring fully developed into the market place. The technology is still evolving as evidenced by development of dedicated engines and vehicles. Earlier NGVs were converted from existing gasoline models and often were bi-fuel units. Nevertheless, the industry is growing and has reached proportions where guidelines, standards, and specifications are necessary. Standards for fuel containers and components (NFPA 52, ANSI AGA/NGV1 and NGV2) already exist. This SAE J1616 Recommended Practice is an early attempt to address the natural gas fuel itself.

Safety along with performance have been paramount considerations. At the same time, the technical and economic impositions of overly stringent requirements cannot be such as to adversely affect viability. While a conservatively safe approach has been the rule, several provisions have caused controversy within the natural gas and automotive industries. The numerous revisions of this document over the past three years attest to that fact. Input from all sides has been considered and factored in, including comments in response to the SAE Technical Committee 7 — Fuels, four different letter ballots. This rationale explains the reasoning behind the provisions of the document.

Scope—The document specifically relates to compressed natural gas intended for use as a vehicular fuel. Scope should answer questions of what compressed natural gas is, how and when its chemical and physical properties vary, and why a recommended practice is needed. This information was previously contained within the text of the document, but has been condensed under Scope. Detailed specifics are better addressed in other sections of the document concerning water content, corrosion, and formation of liquids. As the need for limits on all gas composition constituents cannot be supported by scientific evidence, some constituents are not addressed in SAE J1616 at this time.

Purpose—This section makes clear the need for defining the fuel parameters and the means for evaluating them. It also clarifies the status of the Recommended Practice as a guide, not a standard. It is anticipated that a standard will evolve, but experience and more technical knowledge in some areas are needed. It is the best available information at this time.

The NOTE contained within the PURPOSE clearly explains the relationship between the Recommended Practice and Appendix A. This device is used by ISO to provide users with important information, and has been adopted here. Informational References are located in Appendix A under A.3.

References

2.1 Applicable Documents—Only references that pertain to the requirements relating to the chemical and physical properties of natural gas should be in the body of the document.,

2.2 Related Publications—These references are for information only and are not referenced in the document.

3. *Definitions*—Definitions should be in a separate section and not the text of the document.

4. Properties Related to Containers and Vehicle Fuel Systems Corrosion—Certain information has been included in the document Scope. An attempt is made to reduce redundancy, but emphasize the importance of the corrosion issue.

4.1 Pressure Water Dew Point Temperature—The intent regarding water limits is to preclude problems of corrosion and performance while maintaining consistency with the ANSI AGA/NGV2 Container Standard. It is essential to maintain consistency between all NGV Standards until or unless provisions are proved faulty. Then all must be changed, improved, and updated to maintain continuity. Harmonization of NGV2 with ISO and the Canadian B-51 standards is in progress.

Fueling station operators are given some leeway in the means to stay within these limits. Controlling the water content from the outlet of fueling stations and into the fuel system of the vehicle is considered a basic requirement because it mitigates the potential for many adverse problems in the corrosion and performance areas.

Climate and therefore ambient temperature varies by region as well as by season or month. No reference is made to dryers or other specific equipment because to do so would be excessively prescriptive. The means of controlling water content are within the prerogative of the operators.

The gas and auto industries have initiated research to characterize CNG fuel composition effects on NGVs and fueling components. The data obtained will be used to establish or revise composition limits included in this document.

4.2 Hydrogen Sulfide Concentration—"Effects of Natural Gas Contaminants on Stress Corrosion of Compressed Natural Gas Fuel Storage Cylinders,": Paper #98, The NACE Annual Conference and Corrosion Show, Lyle, F.E., March 1991, page 10. "When the dew point of the natural gas entering a steel cylinder is below the lowest anticipated cylinder temperature at the highest anticipated cylinder pressure, no limitations are required on the concentrations of other corrosive contaminants." See A.3

Control of water level content in the CNG fuel precludes the need for extraordinary measures to reduce trace constituents below levels normally found in pipeline gas. Such measures for reducing levels of hydrogen sulfide, carbon dioxide, and oxygen would be much more difficult and expensive than water removal.

4.3 Carbon Dioxide Concentration—See rationale in 3.2. Also the Rationale for the approved American National Standard ANSI AGA/NGV2 states, "the limits on Carbon Dioxide are not present in the coverage because they are unnecessary if liquid water is excluded from the container."

However, to adequately maintain stoichiometry a 3% volume limit has been recommended.

4.4 Methanol Concentration—No quantitative limit is stated because no data is available from pipelines.

It is expected that any methanol added at the refueling station would be greatly in excess of pipeline quantities and highly undesirable.

4.5 Oxygen Concentration—See Rationale in 3.2.

GRI-91/1011, 92/0123—Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States, the study of gas compositions in the United States, shows oxygen levels in natural gas to be very low, in the order of 1.0% or less by volume. Except when and where propane air peakshaving is used, higher concentrations are not encountered. The prescriptions on propane in Section 3.8 plus technical problems in compressing propane-air mixtures rules out the possibility of more than 2.0% oxygen being present in CNG vehicle fuel. Although the actual flammable limits for on board CNG are not known, it was deemed inadvisable to put a limit on oxygen concentration. At atmospheric conditions, the flammable range of natural gas is 5 to 15% in air by volume. Thus, the oxygen concentration is between 19.9 and 17.9% by volume for flammability to occur in air at atmospheric pressure.

Prior work, taken from the Gas Engineers Handbook, pages 2/73 to 2/75 states that "The lower limit stays relatively constant, while the upper limit rises with increases in the initial pressure." Data is only given to 2000 psig, but at that level, the upper flammable limit is given as 59.0% gas in air. A plot of the data shows the curve becoming asymptotic with a conservatively projected value of 70.0% gas in air at a container pressure of 3600 psig. Even then, the 30.0% air component at 6.3% oxygen, 23.7 nitrogen, would be well above the 1 to 2% oxygen concentration foreseen in CNG vehicle fuels. Moreover, auto industry experience indicates closed-loop control adequately maintains stoichiometry with CNG vehicle fuels.

4.6 Particulate and Foreign Material—The best solution was deemed to call for a prescribed particle size believed to be acceptable and attainable. This limit is applicable to the fuel being delivered to the NGV.

4.7 Oil Content—No limit is stipulated because there is no data to support a limit and no applicable test method for determining oil concentrations. There are conflicting opinions that (a) carry-over oil is a corrosion suppressant, and (b) that carry-over oils is in a form that precludes any lubrication or coating benefit.; Clearly an excessive oil level is undersirable and can be controlled with coalescing filters installed downstream of the compressor discharge. More research is needed in this field.

4.8 Pressure Hydrocarbon Dew Point Temperature—Figure 2 is based on engineering estimates that simplify more complex calculations. It may benefit a utility that peakshaves with propane-air to further investigate their specific fuel compositions and temperatures before making decisions involving significant investments.

4.9 Natural Gas Odorant—New cylinders adsorb odorants, and dehydrators remove odorants as well. Additional data are needed to determine an acceptable, measurable limit and test procedure.

5. Vehicle Fuel System and Engine Performance—This section deals with physical properties which stem from the gas composition and affect the Vehicle Fuel System and Engine Performance. Due to the rapid growth of an NGV industry, research and development in some of these areas has lagged behind the need. The NGV Coalition, OEM companies, and the gas industry are endeavoring to meet these needs. Meanwhile, it is necessary to list these areas with the best information available at this time.

5.1 Engine Performance—Several referenced documents (SAE Paper 920593 and GRI 92/0150) and numerous related publications bear on this subject. Much work was done by Southwest Research Institute under Gas Research Institute auspices. Two of the major properties of natural gas in this context, namely, Wobbe Index and Knock Rating have been listed. No provisions relative to emissions have been included because definitive data relative to gas composition is not available. This is a major area in need of research.

5.1.1 Wobbe Index—As might be expected, equipment manufacturers want the fuel composition to be as uniform as possible. Conversely, fuel suppliers desire to keep their existing practices intact to the maximum extent. As always, there must be compromise. Wobbe Index is a prime property of natural gas relative to energy content. The recommendation for a WI of 1300 to 1400 BTU/ft^3 was made with the knowledge that it covers the vast majority of natural gas distributed in the United States. But it is qualified in the expectation that WI as low as 1200 BTU/ft^3 will prove acceptable based on prior experience in areas at high altitude (i.e., 5000 ft elevation or more).

Presently, there are compressed natural gas vehicles operating satisfactorily in all areas covered by the extended Wobbe Index range. Lacking information that documents the need for a narrower range or data specifying a particular set of narrower limits, it is prudent to retain the Wobbe Index range now existing in the country. Respondents possessing such information are encouraged to present it for review. If it is shown that need exists for additional research to clarify appropriate limits for Wobbe Index (or equivalent parameter) this question will be added to the agenda of the gas and auto industries' Standards Research Support Group.

The term "Wobbe Index" has been adopted by ISO in all their standards. It was deemed appropriate to use this term in the document although "Wobbe Number" is recognized and acceptable.

5.1.2 Knock Rating—The Octane Rating of gasoline fuels is a fundamental parameter for evaluating their ability to resist knock. A means for determining the octane rating of natural gas, known to be high, is a necessity. In the absence of such means, which requires development of an ASTM standard, the presently available basis for estimating MON ratings of natural gas compositions was used. The GRI Report 92/050, performed by Southwest Research Institute, gives the basis for citing a minimum value of 115 MON for natural gas. A recommendation will be submitted to ASTM and the Standards Research Support Group for development of a MON rating methodology for future incorporation in SAE J1616.

As a further result of the GRI supported work at Southwest Research Institute, a linear correlation was determined to exist between Methane Number and Octane Rating for natural gas. Therefore, it was decided to use only the universally recognized parameter of Octane Rating in the document rather than introducing to the automotive industry a new and unknown term.

Rationale for Test Methods—Test Methods have been included in the appropriate gas composition sections to minimize referencing.

Rationale for Appendix A—In light of comments from SAE Technical Committee 7 — Fuels, it was decided to make a clear division concerning the document and informational material. This device is used in ISO International Standards and adopted for the SAE document.

Relationship of SAE Standard to ISO Standard—Not applicable.

Application—Compressed Natural Gas (CNG) is a practical automotive fuel, with advantages and disadvantages when compared to gasoline. It has a good octane quality, is clean burning, easy to meter, and generally produces lower vehicle exhaust emissions. CNG is used to fuel internal combustion engines. Natural gas is normally compressed form 20 690 to 24 820 kPa (3000 to 3600 psig) to increase its energy density thereby reducing its on-board vehicle storage volume for a given range and payload.

Reference Section

SAE Paper 902069—Ambient Temperature and Driving Cycle Effects on CNG Motor Vehicle Emissions, Gabelle, P., Crews, W., Perry, N., Lenning, J., Knapp, K. T., Ray, W.D., Snow, R.

SAE Paper 920593—The Impact of Natural Gas Fuel Composition on Fuel Metering and Engine Operational Characteristics, King, S.R.

Gas Engineers Handbook, Industrial Press Inc., New York, 1965

ANSI AGA/NGV2, 1992—Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers

ASHRAE Handbook

ASTM D 1142-90—Test Method for Water Vapor Content of Gaseous Fuels by Measurement of Dew Point Temperature

ASTM D 1945-91—Test Method for Analysis of Natural Gas by Gas Chromatography

ASTM D 3588-91—Standard Method for Calculating Calorific Value and Specific Gravity "Relative Density" of Gaseous Fuels

ASTM D 4084–88—Test Method for Analysis of H_2S in Gaseous Fuels (Lead Acetate Reaction Method)

Climatography of the U.S. No. 20, Climatic Summaries for Selected Sites, 1951–80

Comparative Climatic Data for the United States through 1991, U. S. Dept. of Commerce's National Oceanic and Atmospheric Administration

GRI-91/1011,92/0123—Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States, Final Report, March 1992, Liss, W.E. and Thrasher, W.R.

GRI-92/0150—Effect of Gas Composition on Octane Number of Natural Gas Fuels, Kubesh, J.

GRI 92/0158, 1992—Proceedings of the Gas Research Institute Natural Gas Vehicle Fuel Composition Workshop Held February 13, 1992, Rosemont, IL,

NFPA 52 1992 Edition—Compressed Natural Gas (CNG) Vehicular Fuel Systems

U.S.Bureau of Mines Publication 503, Copyright 1952

ISO 6326-2-1981—Gas Analysis—Determination of Sulfur Compounds in Natural Gas—Part 2, Gas Chromatographic Method Using an Electrochemical Detector for the Determination of Odoriferous Sulfur Compounds

ISO 6570-3-1989—Natural Gas—Determination of Potential Hydrocarbon Liquid Content—Part 3, Volumetric Method

ISO 6977-1983—Natural Gas—Detection of Water and Methanol Content, Gas Chromatograph Method

Developed by the SAE Fuels and Lubricants Technical Committee 7—Fuels

SAE J301—Effective Dates of New or Revised Technical Reports—The final approval date for Fuels and Lubricants technical reports is shown following the J-report number. This approval date is the date of final approval by the Fuels and Lubricants Division. It is effective immediately subsequent to divisional approval for *newly Issued Standards, Recommended Practices, and Information Reports*, and also for *revised Information Reports* and the *SAE J1146 Recommended Practice*. In the case of *revised* or *cancelled Standards or Recommended Practices* (used to define product quality), and 18-month optional grace period exists before they become fully effective.

APPENDIX B

ST. LANDRY PARISH LANDFILL BIOCNG LABORATORY ANALYSIS RESULTS

AirTECHNOLOGY Laboratories, Inc.

September 28, 2012

ACLASS ACCREDITED DoD ELAP
ADE-1461
EPA Methods TO-3, TO14A,TO15 SIM & Scan, ASTM D1946

nelac
LA Cert 04140
EPA Methods TO3, TO14A, TO15, 25C/3C, RSK-175
TX Cert T104704450-09-TX
EPA Methods TO14A, TO15

Cornerstone Environmental Group
ATTN: Steve Wittman
8413 Excelsior Dr., Suite 160
Madison, WI 53717

LABORATORY TEST RESULTS

Project Reference: St. Landry Parish; CNG 002-004
Lab Number: D091103-01

Enclosed are results for sample(s) received 9/11/12 by Air Technology Laboratories. Analyses were performed according to specifications on the chain of custody provided with the sample(s).

Report Narrative:

- Unless otherwise noted in the report, sample analyses were performed within method performance criteria and meet all requirements of the NELAC Standards.
- The enclosed results relate only to the sample(s).

Preliminary results were e-mailed to Steve Wittman on 9/28/12.

ATL appreciates the opportunity to provide testing services to your company. If you have any questions regarding these results, please call me at (626) 964-4032.

Sincerely,

Mark Johnson
Operations Manager
MJohnson@AirTechLabs.com

Note: The cover letter is an integral part of this analytical report.

Client: Cornerstone Environmental Group
Attn: Steve Wittman
Project Name: St. Landry Parish
Project No.: CNG 002-004
Date Received: 09/11/12
Matrix: Air
Reporting Units: ppbv

EPA Method TO15

Lab No.:	D091103-01							
Client Sample I.D.:	Sample #1 5957							
Date Sampled:	09/07/12							
Date Analyzed:	09/26/12							
QC Batch No.:	120925MS2A1							
Analyst Initials:	VM							
Dilution Factor:	8.4							
ANALYTE	Result ppbv	RL ppbv						
Dichlorodifluoromethane (12)	ND	8.4						
Chloromethane	ND	17						
1,2-Cl-1,1,2,2-F ethane (114)	72	8.4						
Vinyl Chloride	13	8.4						
Bromomethane	ND	8.4						
Chloroethane	ND	8.4						
Trichlorofluoromethane (11)	12	8.4						
1,1-Dichloroethene	ND	8.4						
Carbon Disulfide	52	42						
1,1,2-Cl 1,2,2-F ethane (113)	ND	8.4						
Acetone	670	42						
Methylene Chloride	ND	8.4						
t-1,2-Dichloroethene	ND	8.4						
1,1-Dichloroethane	34	8.4						
Vinyl Acetate	ND	42						
c-1,2-Dichloroethene	ND	8.4						
2-Butanone	84	8.4						
t-Butyl Methyl Ether (MTBE)	210	8.4						
Chloroform	ND	8.4						
1,1,1-Trichloroethane	ND	8.4						
Carbon Tetrachloride	ND	8.4						
Benzene	ND	8.4						
1,2-Dichloroethane	ND	8.4						
Trichloroethene	ND	8.4						
1,2-Dichloropropane	ND	8.4						
Bromodichloromethane	ND	8.4						
c-1,3-Dichloropropene	ND	8.4						
4-Methyl-2-Pentanone	130	8.4						
Toluene	22	8.4						
t-1,3-Dichloropropene	ND	8.4						

18501 E. Gale Avenue, Suite 130 ♦ City of Industry, CA 91748 ♦ Ph: (626) 964-4032 ♦ Fx: (626) 964-5832

Client: Cornerstone Environmental Group
Attn: Steve Wittman
Project Name: St. Landry Parish
Project No.: CNG 002-004
Date Received: 09/11/12
Matrix: Air
Reporting Units: ppbv

EPA Method TO15

Lab No.:	D091103-01			
Client Sample I.D.:	Sample #1 5957			
Date Sampled:	09/07/12			
Date Analyzed:	09/26/12			
QC Batch No.:	120925MS2A1			
Analyst Initials:	VM			
Dilution Factor:	8.4			

ANALYTE	Result ppbv	RL ppbv						
1,1,2-Trichloroethane	ND	8.4						
Tetrachloroethene	ND	8.4						
2-Hexanone	ND	8.4						
Dibromochloromethane	ND	8.4						
1,2-Dibromoethane	ND	8.4						
Chlorobenzene	ND	8.4						
Ethylbenzene	370	8.4						
p,&m-Xylene	ND	8.4						
o-Xylene	ND	8.4						
Styrene	ND	8.4						
Bromoform	ND	8.4						
1,1,2,2-Tetrachloroethane	ND	17						
Benzyl Chloride	ND	8.4						
4-Ethyl Toluene	ND	8.4						
1,3,5-Trimethylbenzene	ND	17						
1,2,4-Trimethylbenzene	ND	17						
1,3-Dichlorobenzene	ND	8.4						
1,4-Dichlorobenzene	ND	8.4						
1,2-Dichlorobenzene	ND	8.4						
1,2,4-Trichlorobenzene	ND	17						
Hexachlorobutadiene	ND	8.4						

ND = Not Detected (below RL)
RL = Reporting Limit

Reviewed/Approved By: [signature]
Mark Johnson
Operations Manager

Date 9/27/12

The cover letter is an integral part of this analytical report

AirTECHNOLOGY Laboratories, Inc.
18501 E. Gale Avenue, Suite 130 ♦ City of Industry, CA 91748 ♦ Ph: (626) 964-4032 ♦ Fx: (626) 964-5832

Client: Cornerstone Environmental Group
Attn: Steve Wittman
Project Name: St. Landry Parish
Project No.: CNG 002-004
Date Received: 09/11/12
Matrix: Air
Reporting Units: ppbv

EPA Method TO15

Lab No.:	D091103-01							
Client Sample I.D.:	Sample #1 5957							
Date Sampled:	09/07/12							
Date Analyzed:	09/26/12							
QC Batch No.:	120925MS2A1							
Analyst Initials:	VM							
Dilution Factor:	8.4							
ANALYTE	**Result ppbv**	**RL ppbv**						
Hexamethyldisiloxane (L2, MM)	ND	84						
Hexamethylcyclotrisiloxane (D3)	ND	84						
Octamethyltrisiloxane (L3, MDM)	ND	84						
Octamethylcyclotetrasiloxane (D4)	ND	84						
Decamethyltetrasiloxane (L4, MD2M)	ND	84						
Decamethylcyclopentasiloxane (D5)	ND	420						
Dodecamethylpentasiloxane (L5, MD3M)	ND	1,700						

ND = Not Detected (below RL)
RL = Reporting Limit

Reviewed/Approved By: [signature]
Mark Johnson
Operations Manager

Date 9/27/12

The cover letter is an integral part of this analytical report

LCS/LCSD Recovery and RPD Summary Report

QC Batch #: 120925MS2A1

Matrix: Air

EPA Method TO-14/TO-15

Lab No:	Method Blank		LCS		LCSD						
Date Analyzed:	09/26/12		09/25/12		09/26/12						
Data File ID:	25SEP014.D		25SEP012.D		25SEP013.D						
Analyst Initials:	DT		DT		DT						
Dilution Factor:	0.2		1.0		1.0			Limits			
ANALYTE	Result ppbv	Spike Amount	Result ppbv	% Rec	Result ppbv	% Rec	RPD	Low %Rec	High %Rec	Max. RPD	Pass/ Fail
1,1-Dichloroethene	0.0	10.0	10.3	103	10.6	106	2.4	70	130	30	Pass
Methylene Chloride	0.0	10.0	10.4	104	10.7	107	3.3	70	130	30	Pass
Trichloroethene	0.0	10.0	9.3	93	9.5	95	1.5	70	130	30	Pass
Toluene	0.0	10.0	11.2	112	11.4	114	2.1	70	130	30	Pass
1,1,2,2-Tetrachloroethane	0.0	10.0	9.4	94	9.5	95	1.2	70	130	30	Pass

RPD = Relative Percent Difference

Reviewed/Approved By: [signature] Date: 9/27/12

Mark Johnson
Operations Manager

The cover letter is an integral part of this analytical report

Client: Cornerstone Environmental Group
Attn: Steve Wittman
Project Name: St. Landry Parish
Project No.: CNG 002-004
Date Received: 09/11/12
Matrix: Air
Reporting Units: ppmv

ASTM D5504

Lab No.:	D091103-01							
Client Sample I.D.:	Sample #1 5957							
Date Sampled:	09/07/12							
Date Analyzed:	09/13/12							
QC Batch No.:	120913GC3A1							
Analyst Initials:	VM							
Dilution Factor:	2.8							
ANALYTE	Result ppmv	RL ppmv						
Hydrogen Sulfide	ND	0.56						

ND = Not Detected (below RL)
RL = Reporting Limit

Reviewed/Approved By: [signature] Date 9/21/12
Mark Johnson
Operations Manager

The cover letter is an integral part of this analytical report

QC Batch No.: 120913GC3A1
Matrix: Air
Units: ppmv

QC for Sulfur Compounds by ASTM D5504

Lab No.:	Method Blank		LCS		LCSD			
Date Analyzed:	09/13/12		09/13/12		09/13/12			
Analyst Initials:	VM		VM		VM			
Datafile:	13sep006		13sep004		13sep005			
Dilution Factor:	1.0		1.0		1.0			
ANALYTE	Results	RL	% Rec.	Criteria	% Rec.	Criteria	%RPD	Criteria
Hydrogen Sulfide	ND	0.20	111	70-130%	109	70-130%	2.1	<30

ND = Not Detected (Below RL)
RL = Reporting Limit

Reviewed/Approved By: [signature]
Mark J. Johnson
Operations Manager

Date: 9/21/12

The cover letter is an integral part of this analytical report

Client: Cornerstone Environmental Group
Attn: Steve Wittman
Project Name: St. Landry Parish
Project No.: CNG 002-004
Date Received: 09/11/12
Matrix: Air
Reporting Units: % v/v

ASTM D1946

Lab No.:	**D091103-01**							
Client Sample I.D.:	**Sample #1 5957**							
Date Sampled:	**09/07/12**							
Date Analyzed:	**09/18/12**							
QC Batch No.:	120918GC8A1							
Analyst Initials:	MJ							
Dilution Factor:	**2.8**							
ANALYTE	**Result % v/v**	**RL % v/v**						
Carbon Dioxide	**1.6**	0.028						
Oxygen/Argon	**ND**	1.4						
Nitrogen	**3.2**	2.8						
Methane	**95**	0.0028						

ND = Not Detected (below RL)
RL = Reporting Limit

Reviewed/Approved By: [signature]
Mark Johnson
Operations Manager

Date 9-27-12

The cover letter is an integral part of this analytical report

AirTECHNOLOGY *Laboratories, Inc.*
18501 E. Gale Avenue, Suite 130 ♦ City of Industry, CA 91748 ♦ Ph: (626) 964-4032 ♦ Fx: (626) 964-5832

QC Batch No.: 120918GC8A1
Matrix: Air
Units: % v/v

QC for ASTM D1946

Lab No.:	Method Blank		LCS		LCSD			
Date Analyzed:	09/18/12		09/18/12		09/18/12			
Analyst Initials:	MJ		MJ		MJ			
Datafile:	18sep015		18sep012		18sep013			
Dilution Factor:	1.0		1.0		1.0			
ANALYTE	**Results**	**RL**	**% Rec.**	**Criteria**	**% Rec.**	**Criteria**	**%RPD**	**Criteria**
Oxygen/Argon	ND	0.50	97	70-130%	95	70-130%	1.2	<30
Nitrogen	ND	1.0	99	70-130%	98	70-130%	0.2	<30
Methane	ND	0.0010	116	70-130%	117	70-130%	1.1	<30
Carbon Dioxide	ND	0.010	100	70-130%	103	70-130%	2.8	<30

PQL = Practical Quantitation Limit
ND = Not Detected (Below RL).
RL = PQL X Dilution Factor

Reviewed/Approved By: [signature] Date: 9-28-12
Mark J. Johnson
Operations Manager

The cover letter is an integral part of this analytical report

APPENDIX C

CUMMINS-WESTPORT ON-LINE FUEL CALCULATOR

Westport

Natural Gas Academy
Natural Gas Academy Videos
Learn About Natural Gas
Natural Gas as Fuel
Compressed Natural Gas
Liquefied Natural Gas
Biomethane
Fuel Quality Calculator
Vehicle Fuel Systems
Fuel Providers
Fuel Stations
Incentives
Links

Fuel Quality Calculator

Cummins Westport natural gas engines can operate on CNG, LNG or biomethane that meets Cummins published fuel specifications.

Customers should note that pipeline natural gas fuel quality can vary on a regional and seasonal basis. LNG fuel quality may change if it is held in storage for extended periods of time. Consult your fuel provider on a regular basis to ensure that natural gas fuel quality, in particular, the methane number, meets engine requirements.

The minimum methane number requirement for the C, B and L Gas Plus engines is 65 or greater. The ISL G requires a minimum methane number of 75 or greater.

To ensure the fuel you are using meets the required specifications, we've provided an online calculator for your reference. This specification covers the natural gas fuel requirements for the following Cummins Westport automotive spark-ignited natural gas engine models:

ISL G • L Gas Plus • C Gas Plus • B Gas Plus

To use this online calculator, fill in the Fuel Composition values so that the total equals 100%. The Results will be calculated automatically. Methane Number, Lower Heating Value, and Sulfur Content criteria must be met to pass a given fuel for a specific engine. **Contact your Cummins Westport representative** for complete details on the fuel standard and fuel testing specifications.

Fuel Composition			
Methane	CH_4	95	%
Ethane	C_2H_6	0	%
Propane	C_3H_8	0	%
Butane	C_4H_{10}	0	%
Pentane	C_5H_{12}	0	%
Hexane	C_6H_{14}	0	%
Heptane	C_7H_{16}	0	%
Octane	C_8H_{18}	0	%
Carbon Dioxide	CO_2	1.7	%
Nitrogen	N_2	3.3	%
Oxygen	O_2	0	%
Sulfur	S_2	0	%
Hydrogen	H_2	0	%
Hydrogen Sulfide	H_2S	0	%
Siloxanes	Si	0	%
Total (must be 100%)		100.00	%

Results for ISL G   Results for B/C Gas

Methane Number	Methane Number
108.4	108.4

Additional Results

Lower Heating Value: (min. 16,100 BTU/lbm)	19389	PASS
Sulfur % Weight: (max. 0.001% weight)	0.000	PASS
Hydrogen % Volume: (max. 0.03% volume)	0	PASS
Hydrogen Sulfide % Volume: (max. 0.0006% volume)	0	PASS
Siloxanes % Volume: (max. 0.0003% volume)	0	PASS

APPENDIX D

AIR LIQUIDE – DELAWARE PLANT NATURAL GAS VOC ANALYSIS

AIR LIQUIDE
MEDAL
a division of
Air Liquide Advanced Technologies U.S. LLC

HALOGENS AND CARCINOGENS IN PIPELINE NATURAL GAS

Charlie Anderson
MEDAL, a division of Air Liquide Advanced Technologies U.S. LLC
305 Water St
Newport, DE 19804

17 March 2012
Rev 0

Introduction

Air Liquide developed a patented biogas upgrading technology in 2005 aimed at landfill gas and has since accumulated more than a dozen applications across the US. During the first years of operation, a lot of focus was placed on contaminant removal. In 2006, as a reference point, a sample was taken of pipeline natural gas feeding the Air Liquide - MEDAL plant in Newport, Delaware. This was the same gas as used by industry and residential users in the Delaware area.

Sampling Procedure and Laboratory

A cleaned and evacuated summa canister was received from RTP Labs. This canister was connected to a 90 PSIG natural gas line feeding a boiler. The canister was connected by way of SS tubing and a small needle valve to control flow and pressure. A compound gage was used to monitor the pressure into the canister, first confirming that the canister was initially under vacuum and then allowing the canister to be filled to about 10 psig and not over pressured. The canister was then sent back to RTP Labs where a TO-15 analysis was done.

Results

The TO-15 lab report is presented below.

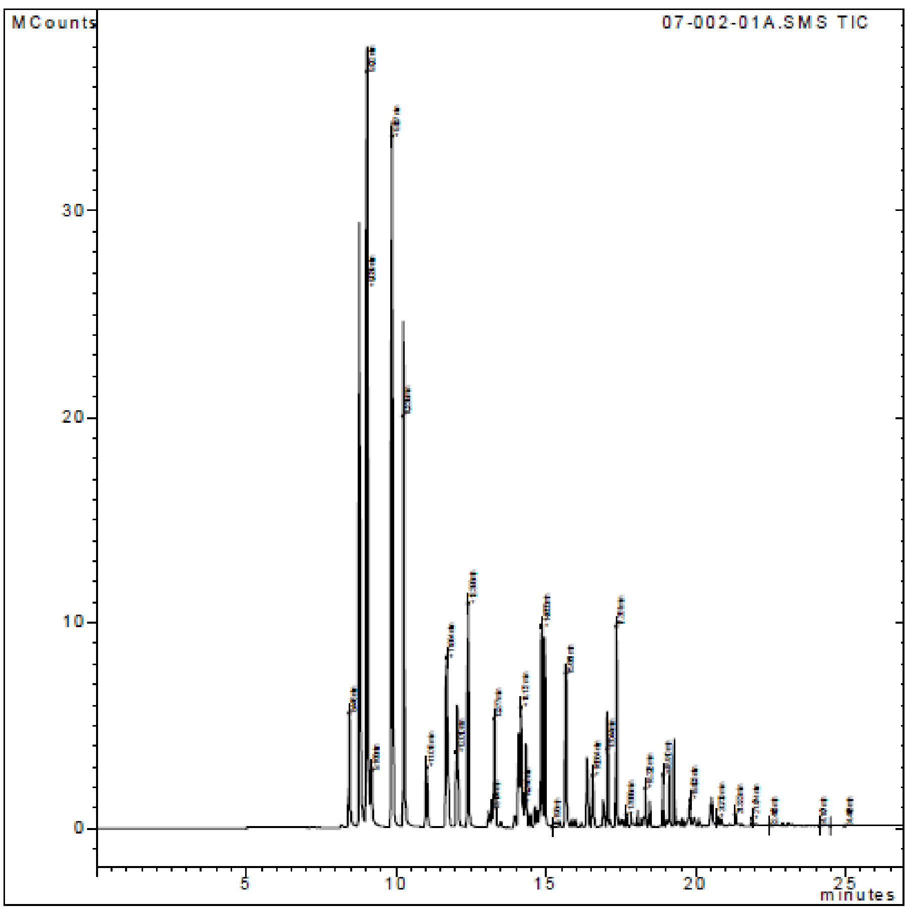
Research Triangle Park Laboratories, Inc.
8109 Ebenezer Church Road
Raleigh, NC 27612

919 510-0228 Telephone
919 510-0141 Fax

ACCREDITED IN ACCORDANCE WITH nelac

Web Site: www.rtp-labs.com

RTPLabs
NELAC Accredited NJ# NC003



Research Triangle Park Laboratories, Inc.
8109 Ebenezer Church Road
Raleigh, NC 27612

919 510-0228 Telephone
919 510-0141 Fax

Web Site: www.rtp-labs.com

RTPLabs
NELAC Accredited NJ# NC0

EPA Method TO-15 GC/MS VOLATILE ORGANICS ANALYSIS REPORT

Data File: c:\varianws\wsdatafiles\voc031406\07-002-01a.sms Acquisition Date: 1/10/2007 16:3
Comment: Air Liquide/ 12/22/06; Pipeline; 1mL; DF 500

CAS NO.	COMPOUND	CONCENTRATION	UNITS	Method Detection Lim
75-71-8	Dichlorodifluoromethane (Freon 12)	Not Found	ppbv	0.3
76-14-2	1,2-Chloro-1,1,2,2-Tetrafluoroethane	Not Found	ppbv	0.2
74-87-3	Chloromethane	36853.64	ppbv	0.1
75-01-4	Vinyl chloride	Not Found	ppbv	0.2
106-99-0	1,3-Butadiene	Not Found	ppbv	0.3
74-83-9	Bromomethane	372.88	ppbv	0.2
75-00-3	Chloroethane	Not Found	ppbv	0.2
75-69-4	Trichloromonofluoromethane	118.25	ppbv	0.2
75-35-4	1,1-dichloroethene	76.95	ppbv	0.2
76-13-1	1,1,2-trichloro-1,2,2-trifluoroethane	Not Found	ppbv	0.2
64-17-5	Ethanol	409.46	ppbv	0.2
75-15-0	Carbon disulfide	Not Found	ppbv	0.3
67-63-0	Isopropyl alcohol	Not Found	ppbv	0.2
75-09-2	Methylene chloride	Not Found	ppbv	0.1
67-64-1	Acetone	Not Found	ppbv	0.3
156-60-5	t-1,2-dichloroethene	129.16	ppbv	0.3
11-05-3	Hexane	40685.71	ppbv	0.3
1634-04-4	Methyl-t-butyl ether (MTBE)	354.79	ppbv	0.3
75-34-3	1,1-Dichloroethane	Not Found	ppbv	0.4
108-05-4	Vinyl acetate	2225.62	ppbv	0.5
156-59-2	cis-1,2-dichloroethene	Not Found	ppbv	0.3
110-82-7	Cyclohexane	18542.04	ppbv	0.3
67-66-3	Chloroform	3982.69	ppbv	0.3
141-78-6	Ethyl Acetate	7522.65	ppbv	0.3
109-99-9	Tetrahydrofuran	4944.84	ppbv	0.4
71-55-6	1,1,1-trichloroethane	Not Found	ppbv	0.3
56-23-5	Carbon Tetrachloride	55.26	ppbv	0.5
78-93-3	2-Butanone	Not Found	ppbv	0.3
142-82-5	Heptane	40709.24	ppbv	0.2
71-43-2	Benzene	38614.20	ppbv	0.2
107-06-2	1,2-dichloroethane	Not Found	ppbv	0.3
79-01-6	Trichloroethylene	174.08	ppbv	0.2
78-87-5	1,2-dichloropropane	Not Found	ppbv	0.3
75-27-4	Bromodichloromethane	132.41	ppbv	0.2
123-91-1	1,4-dioxane	49.88	ppbv	0.2
10061-01-5	cis-1,3-dichloropropene	Not Found	ppbv	0.2
108-88-3	Toluene	15833.75	ppbv	0.3
108-10-1	4-Methyl-2-pentanone (MIBK)	1077.63	ppbv	0.2
1006-02-6	t-1,3-dichloropropene	Not Found	ppbv	0.2
127-18-4	Tetrachloroethylene	Not Found	ppbv	0.05
79-00-5	1,1,2-trichloroethane	Not Found	ppbv	0.2
124-48-1	Dibromochloromethane	Not Found	ppbv	0.2
106-93-4	1,2-dibromoethane	Not Found	ppbv	0.2
591-78-6	2-Hexanone	Not Found	ppbv	0.2
100-41-4	Ethylbenzene	892.42	ppbv	0.3
108-90-7	Chlorobenzene	Not Found	ppbv	0.2
1330-20-7	m/p-Xylene	4385.79	ppbv	0.7
95-47-6	o-Xylene	1114.34	ppbv	0.3
100-42-5	Styrene	38.11	ppbv	0.1
75-25-2	Tribromomethane	40.64	ppbv	0.3
79-34-5	1,1,2,2-tetrachloroethane	Not Found	ppbv	0.2
622-96-8	1-ethyl-4-methylbenzene	Not Found	ppbv	0.2
108-67-8	1,3,5-trimethylbenzene	356.89	ppbv	0.2
95-63-6	1,2,4-trimethylbenzene	340.61	ppbv	0.3
541-73-1	1,3-dichlorobenzene	Not Found	ppbv	0.2
106-46-7	1,4-dichlorobenzene	Not Found	ppbv	0.3
100-44-7	Benzyl chloride	Not Found	ppbv	0.2
95-50-1	1,2-dichlorobenzene	Not Found	ppbv	0.3
87-68-3	1,1,2,3,4,4-hexachloro-1,3-butadiene	Not Found	ppbv	0.2
120-82-1	1,2,4-trichlorobenzene	Not Found	ppbv	0.3

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TENTATIVELY IDENTIFIED COMPOUNDS

EPA Method TO-15 **GC/MS VOLATILE ORGANICS ANALYSIS REPORT**

Data File: c:\varianws\wsdatafiles\voc031406\07-002-01a.sms **Acquisition Date:** 1/10/2007 16:33
Comment: Air Liquide/ 12/22/06; Pipeline; 1mL; DF 500

Number of TICs 8

CAS NO.	COMPOUND NAME	Retention Time	Estimated Concentration,	
78-77-3	Propane, 1-bromo-2-methyl-	9.17	4897.75	ppbv
619-99-8	Hexane, 3-ethyl-	11.6	53421.50	ppbv
625-74-1	Propane, 2-methyl-1-nitro-	14.2	4612.80	ppbv
625-74-1	Propane, 2-methyl-1-nitro-	16.5	10440.18	ppbv
3728-54-9	Cyclohexane, 1-ethyl-2-methyl-	16.9	6805.92	ppbv
921-47-1	Hexane, 2,3,4-trimethyl-	18.3	6664.96	ppbv
625-74-1	Propane, 2-methyl-1-nitro-	18.4	4758.27	ppbv
625-74-1	Propane, 2-methyl-1-nitro-	18.9	7661.00	ppbv
1072-85-1	BFB (IS)	20.5	10.00	ppbv

Discussion of Results

Halogens

It is interesting to note that this gas contained significant concentrations of halogen compounds, mostly chlorine containing molecules. While this was at first surprising, further consideration would suggest this should be typical. The halogen compounds found were:

Chloromethane	**36,653 ppb**
Bromomethane	**373 ppb**
Trichlorofluoromethane	**118 ppb**
1,1-Dichloroethene	**77 ppb**
trans-1,2-Dichloroethene	**129 ppb**
Chloroform	**3,982 ppb**
Trichloroethene	**174 ppb**
Bromodichloromethane	**132 ppb**
Tribromomethane	**41 ppb**

The dominant halogen compound was Chlormethane, a naturally occurring substance. Considering that natural gas is in deposits deep underground, at high pressures and temperatures, often in contact with brines, the formation of halogen compounds should not be surprising.

Carcinogens

Benzene causes cancer and in particular bone marrow failure. OSHA sets limits of 1 ppm for 8 hour exposures, 5 ppm for 15 minutes. A very nasty substance indeed.

The pipeline gas sample was found to contain the following amounts of benzene and benzene compounds:

Benzene	**38,614 ppb (39 ppm)**
Ethyl benzene	**892 ppb**

Geologic gas almost always contains significant quantities of aromatics, commonly referred to as BTEX. Benzene, Toluene, Ethyl-benzene and Xylene. Quite common in gasoline also.

Safety Concern?

Should Halogens and Carcinogens in natural gas be of concern? Probably not directly, considering that the unburned gas is not inhaled, only combustion products at worst. The combustion products of Benzene would still be essentially CO_2 and H_2O. For the Halogens, the Cl and Br would of course survive combustion. This is not known to be a problem.

Other Data?

Air Liquide has made these results public in an attempt to bring a sense of proportion to the worries about landfill derived biomethane. If you have contaminant analysis of pipeline natural gas and would like to share, please contact Charlie Anderson, charlie.anderson@ airliquide.com, +1 302 225-2102.