COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

ELECTRONIC TARIFF FILING OF LOUISVILLE GAS AND ELECTRIC COMPANY TO REVISE ITS LOCAL GAS DELIVERY SERVICE TARIFF	))))	**CASE NO. 2024-00125**

RESPONSE OF
LOUISVILLE GAS AND ELECTRIC COMPANY
TO
THE COMMISSION STAFF'S FIRST REQUEST FOR INFORMATION

DATED MAY 14, 2024

FILED: May 30, 2024

VERIFICATION

COMMONWEALTH OF KENTUCKY)
)
COUNTY OF JEFFERSON)

The undersigned, **Tom Rieth**, being duly sworn, deposes and says that he is Vice President – Gas Operations for Louisville Gas and Electric Company and an employee of LG&E and KU Services Company, and that he has personal knowledge of the matters set forth in the responses for which he is identified as the witness, and the answers contained therein are true and correct to the best of his information, knowledge, and belief.

Tom Rieth
____
Tom Rieth

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 28th day of May 2024.

Caroline J. Dawson
____
Notary Public

Notary Public ID No. KYNP63286

My Commission Expires:

January 22, 2027

LOUISVILLE GAS AND ELECTRIC COMPANY

**Response to Commission Staff's First Request for Information
Dated May 14, 2024**

Case No. 2024-00125

Question No. 1

Responding Witness: Tom C. Rieth

Q-1. Refer to the March 29, 2024 LG&E letter to Linda Bridwell.

a. For each potential customer with whom LG&E has been in discussion regarding the delivery of renewable natural gas (RNG), provide the expected volumetric amount of RNG that will be delivered to LG&E from that customer on a daily and annual basis.

b. Explain how the revised total heating value would impact the cost of the delivery service.

A-1.

a. The table below sets forth the requested information for each potential customer with whom LG&E has actively been in discussion regarding the delivery of renewable natural gas (RNG).

Potential Customer	Daily Expected Volumetric Amount of RNG Delivered to LG&E (Mcf)	Number of Days per Year Delivering to LG&E	Annual Expected Volumetric Amount of RNG Delivered to LG&E (Mcf)
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

*Rate LGDS is a year-round, firm delivery service. The potential delivery service shown in this table for [redacted] would only be provided for one month a year, so it does not qualify for service pursuant to Rate LGDS and service would need to be provided through a special contract that would otherwise be consistent with Rate LGDS.

b. The heating value does not impact LG&E's cost to provide the delivery service.

The heating value affects the quality of the gas that is delivered to LG&E's customers. RNG has a lower heating value than the traditional natural gas that currently flows on LG&E's system. Thus, injecting RNG into the system with a heating value lower than the minimum value LG&E has proposed would reduce the heating value of the gas for customers receiving RNG. This would cause those customers to consume more gas than they otherwise would have, which would increase those customers' bills because LG&E measures and bills its end-use customers based on consumption. For example, assume a customer receives gas with a heating value of 1,035 Btu and uses approximately 58 Ccf. If the same customer receives gas with a heating value of 967 Btu, the customer would need to consume roughly 62 Ccf (7% more gas) to achieve the same level of heat. This example illustrates LG&E's purpose in revising the heating value -- to ensure that its existing customers are not adversely affected by LG&E's transportation of RNG.

LOUISVILLE GAS AND ELECTRIC COMPANY

Response to Commission Staff's First Request for Information
Dated May 14, 2024

Case No. 2024-00125

Question No. 2

Responding Witness: Tom C. Rieth

Q-2. Refer to the March 29, 2024 LG&E letter to Linda Bridwell. Explain whether LG&E is aware of any facilities capable of producing RNG that already have pipelines capable of connecting, or are already connected, to its existing pipelines. If so, provide a map indicating LG&E's pipelines and the locations of these facilities.

A-2. There are no RNG facilities connected to LG&E's gas system; nor is LG&E aware of any RNG production facilities with pipelines capable of connecting to LG&E's current facilities.

LOUISVILLE GAS AND ELECTRIC COMPANY

Response to Commission Staff's First Request for Information
Dated May 14, 2024

Case No. 2024-00125

Question No. 3

Responding Witness: Tom C. Rieth

Q-3. Refer to the March 29, 2024 LG&E letter to Linda Bridwell. Explain whether there is a minimum volume requirement that must be met by local gas suppliers before LG&E will purchase the gas.

A-3. LG&E does not presently purchase local production such as RNG for customers as a part of its gas procurement process because it is not currently a least cost supply option. The Rate LGDS tariff does not require LG&E to purchase local gas production. The Rate LGDS tariff does require the customers (producers) taking service under Rate LGDS to agree to a Maximum Daily Quantity ("MDQ") that is not less than 50 Mcf/day.

LOUISVILLE GAS AND ELECTRIC COMPANY

Response to Commission Staff's First Request for Information
Dated May 14, 2024

Case No. 2024-00125

Question No. 4

Responding Witness: Tom C. Rieth

Q-4. Refer to LG&E's proposed tariff revisions, P.S.C. Gas No. 13, First Revision of Original Sheet No. 36.

a. Explain why LG&E gas received by means other than pipeline will not be considered local gas.

b. Define "virtual pipeline."

c. Explain whether LG&E is capable of accepting gas currently by virtual pipeline. If not, describe what actions would have to be taken in order to accept local gas via virtual pipeline.

A-4.

a. Local Gas Delivery Service (LGDS) is a specific type of firm transportation service. The term "local gas," as used in the LGDS tariff, refers to gas that is produced at a location (gas well or renewable natural gas production facility) in sufficient proximity to LG&E's pipeline system that the producer would find it economically feasible to interconnect its production with an LG&E pipeline so LG&E can transport the gas produced to a delivery point. This definition of local gas mitigates reliability risks because the gas does not need to be transported (i.e., by truck) to LG&E. Also, the quality of the gas delivered to LG&E may be more consistent because the gas is produced from the same local supply area or feedstock. Because the production is connected to LG&E's system, LG&E will be able to contract and work directly with the producer to resolve reliability, operational, quality, and other concerns. Importantly, if local production is received by means other than as described in the LGDS tariff, then a separate service would be required. Also see response to Question 4(c). Once LG&E has experience receiving and transporting local production such as renewable natural gas on its system, and gains knowledge of its performance and impact on the system, LG&E is not opposed to considering whether it can receive and transport production that is delivered to LG&E by means other than a pipeline interconnection; but that type of transportation service is beyond the scope of the LGDS tariff. And LG&E

does not currently offer another tariff that would allow transportation of gas delivered by truck or any other non-pipeline transportation method.

b. A virtual pipeline is based on a modular system where bio-methane is treated, compressed (**CNG**), and stored on a mobile unit at its source location before transport. The bio-methane is then transported by truck, barge, or rail to a central injection station for entry into the natural gas pipeline network.

c. The Company is currently not capable of accepting gas by virtual pipeline. The Company has not performed an analysis to evaluate the actions necessary (i.e., required facilities, contract structure, safety, reliability and operational considerations) to accept gas production such as RNG via virtual pipelines.

LOUISVILLE GAS AND ELECTRIC COMPANY

Response to Commission Staff's First Request for Information
Dated May 14, 2024

Case No. 2024-00125

Question No. 5

Responding Witness: Tom C. Rieth

Q-5. Refer to LG&E's proposed tariff revisions, P.S.C. Gas No. 13, First Revision of Original Sheet No. 36.

a. Explain whether local gas is required to be of pipeline quality (Btu, moisture, absence of sulfur or other hazardous compounds, etc.) at the point of receipt into LG&E's pipeline facilities.

b. Define "hazardous waste" and the sources, or potential sources, of local gas produced from hazardous waste.

A-5.

a. Local gas must be processed sufficiently to evidence-based tariff quality specifications prior to introduction to LG&E's natural gas pipeline facilities. The connection of RNG or other production to the Company's pipeline network requires verification to ensure gas quality specifications are being met continuously.

b. A hazardous material is a substance or material which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and which has been so designated. Hazardous wastes are subsets of hazardous materials. The EPA defines a hazardous waste as a solid waste if it is specifically listed as a known hazardous waste or meets the characteristics of a hazardous waste. Listed wastes are wastes from common manufacturing and industrial processes, specific industries and can be generated from discarded commercial products. Characteristic wastes are wastes that exhibit any one or more of the following characteristic properties: ignitability, corrosivity, reactivity or toxicity.

Each RNG production site will be evaluated and each RNG producer must certify that gas does not contain hazardous waste and is not produced from sources or feedstocks containing hazardous waste.

LOUISVILLE GAS AND ELECTRIC COMPANY

Response to Commission Staff's First Request for Information
Dated May 14, 2024

Case No. 2024-00125

Question No. 6

Responding Witness: Tom C. Rieth

Q-6. Refer to LG&E's proposed tariff revisions, P.S.C. Gas No. 13, First Revision of Original Sheet No. 36.

a. Explain why it is necessary to exclude gas delivered by transportation methods other than a pipeline from the definition of local gas.

b. To the extent LG&E is aware, identify any other utilities that exclude gas delivered by transportation methods other than a pipeline from the definition of local gas.

A-6.

a. See the response to Question No. 4(a). The purpose of the LGDS tariff is to set forth the terms and conditions of transportation service for gas produced locally and delivered by pipeline to LG&E's system.

b. LG&E is not aware of how other utilities define "local gas" with respect to the method by which the natural gas is delivered to the utility.

LOUISVILLE GAS AND ELECTRIC COMPANY

**Response to Commission Staff's First Request for Information
Dated May 14, 2024**

Case No. 2024-00125

Question No. 7

Responding Witness: Tom C. Rieth

Q-7. Refer to LG&E's proposed tariff revisions, P.S.C. Gas No. 13, First Revision of Original Sheet No. 36.11 and First Revision of Original Sheet No. 36.12.

a. Provide an explanation of the rationale for each revision to the gas quality specifications.

b. Provide any studies LG&E performed, or relied upon, to arrive at the revised gas quality specifications.

A-7.

a. As discussed in response to Question No. 1(b), LG&E made the proposed revisions to the total heating value to more closely align with gas received from LG&E's interstate pipeline suppliers.

LG&E made the proposed revisions to the Wobbe Index and heavier hydrocarbon content due to the changes to the total heating value. The Wobbe Index is based on heating value and the specific gravity of the gas, which is dependent on the components in the gas.

LG&E made the proposed revisions to the heavier hydrocarbons to allow for blending higher Btu gas with RNG production. This change will help local producers meet the eligibility requirements of Rate LGDS, if they need to add a higher Btu gas to their production to meet the heating value and Wobbe Index requirements for this service.

LG&E increased the maximum value for oxygen to more closely align with typical values for RNG production and with industry standards.

LG&E added a proposed maximum value for nitrogen to the gas quality specification. Elevated concentrations of nitrogen may impact combustion operations, possibly causing poor flame stability, producing a flame with yellow tipping and lifting. Concentrations of nitrogen also may affect compressibility of the gas.

LG&E added or modified the maximum limits for the following trace constituents: ammonia, hydrogen, siloxanes, chlorine, fluorine, mercury, arsenic, and copper. These trace constituents have been identified in certain bio-methane production processes and can be detrimental to operations, pipeline integrity, human health, the environment, and/or end-use equipment.

b. See the attached reports from REEthink and ENTRUST. REEthink was engaged by the Company to assist with the development of the gas quality specification and verification and monitoring programs. ENTRUST was engaged to provide guidance regarding the relationship between renewable natural gas or biomethane and propane blending ratio and the blended gas heat content. Please note that while LG&E engaged consultants, the decision to propose revisions to the LGDS tariff, along with the specific revisions, was LG&E's.

Louisville Gas and Electric Company Renewable Natural Gas (Biomethane) Pipeline Gas Quality Specifications and Guidance Document for Safe Introduction to the Pipeline Network: Task 1 FINAL

7/10/2023

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c. The results within this report relate only to the topic of biomethane form of Renewable Natural Gas and its introduction to the natural gas pipeline grid.

Louisville Gas and Electric
Renewable Natural Gas (Biomethane) Pipeline Gas Quality Specifications and Guidance Document for Safe Introduction to the Pipeline Network: Task 1 FINAL

1. EXECUTIVE SUMMARY: TASK 1

REEthink, Inc. was retained by Louisville Gas and Electric (LGE) to prepare two Deliverables, as part of their effort to introduce Renewable Natural Gas (RNG, biomethane) into their extensive pipeline network. The two Deliverables are:

1) A **Task 1** Document: the *LGE Renewable Natural Gas Pipeline Quality Specification (Biomethane) and Guidance Document*, with the purpose of establishing a common framework for the introduction of RNG from a variety of biogas sources (landfill gas, wastewater treatment (WWT) sludge anaerobic digestion (AD), live animal manure (LAM) AD, AD of industrial-grade food waste, agricultural residue AD, municipal organic waste AD and combination systems) into existing LGE natural gas networks, and,

2) A **Task 2** Document: the *RNG Quality Verification and Monitoring Program*, with the purpose of creating a roadmap of testing and verification protocols, including a testing schedule, so that all RNG entering the LGE pipeline network is of the required quality, and meets the Specification detailed in Task 1.

There is a shared and important need to understand RNG quality and the potential impacts of introduced gases to pipeline networks. *RNG from all biogas waste streams should share common RNG Quality Specifications within one company*, so that there is unity and consistency throughout. In this way, RNG producers considering projects within the LGE network and its affiliates can anticipate the RNG quality required, and can design their plants to accommodate the common Specifications. The gas quality Specifications are consistent throughout the company and are not particular to the injection point conditions or the specifics of a particular project. The Specifications are considered protective of all gas pipeline systems (high pressure/high volume, low pressure/low volume). In the long term, consistency throughout the LGE network will drive costs of RNG production downwards and routinize RNG production systems, for both LGE and the producer.

Testing for specific constituents is dependent upon the source of the biogas; Verification Testing programs therefore vary by biogas origin (Task 2 of this project). *Modifications/variances/waivers to the RNG Pipeline Quality Specifications (Biomethane) and the Verification and Monitoring Program is at the discretion of LGE, based upon project circumstances, destined end-use, circumstances at point of injection, and/or other project-specific objectives or waivers.* The intent of the RNG Pipeline Quality Specifications (Biomethane) and accompanying Guidance Document (Task 1, herein) is to facilitate the use of high quality RNG into the pipeline network, without prejudice. The Guidance Document supports the RNG Pipeline Quality Specifications (Biomethane), by way of explanation of the various components in the Specification and the referenced, cited rationale for value assignment. Assignment of required constituent values is not without careful consideration; all values are referenced and supported by other industry-accepted documents, reports, published scientific papers.

The work in this Task 1 report:

- provides the Renewable Natural Gas Pipeline Quality Specifications (Biomethane) for LGE (Attachment 1),
- provides the companion RNG Guidance Document (text herein),
- provides the RNG Quality Parameters with Testing Methodology Matrix (Attachment 2), and,
- provides general definitions.

Important note, *the RNG Quality Specification produced in this work covers* ***biomethane RNG only***. Biogas is a product of biological (bio) anaerobic digestion of organic waste; biogas is cleaned or "conditioned" to produce biomethane. The Renewable Natural Gas Pipeline Quality Specifications included in this document does not pertain or apply to syngas RNG or other "RNG" products derived from alternative processes, producing other gaseous fuels. See Definitions section for further detail.

2. INTRODUCTION

Biogas is raw gas produced from the biological digestion of organic compounds; other gases not borne of microbial action may be present in biogas as well. Biogas must be cleaned sufficiently to evidence-based RNG specifications for consideration for introduction to the natural gas pipeline network. Based on the biomass source material, produced raw biogas contains constituents and compounds that may pose hazards to the pipeline network and human health and the environment. In addition, insufficiently cleaned biogas may contain trace or residual compounds that compromise the integrity and operation of gas utilization (end-use) equipment.

The quality of traditional geologically-derived natural gas is specified in gas transportation tariffs agreed upon by the supplier and the transportation system contracting for the gas. These specifications have been established in existing natural gas tariffs for gas delivered to the LGE network, through Texas Gas Transmission L.L.C and Tennessee Gas Pipeline Company, L.L.C.

Acceptance of RNG to the pipeline network is predicated upon the quality of the RNG. There are significant differences between RNG and traditional natural gas sources. These differences are due to biogas generation, source biomass or material, constituents in the raw biogas and the resulting RNG profile provided by various biogas clean up technologies. In addition, there are many constituents present in natural gas which are *not* found in RNG, such as extended hydrocarbons (various $C_2 – C_{20}$ compounds). Therefore, the Higher Heating Value (HHV) and Wobbe Number is inherently lower in RNG. The Wobbe Number is a very important parameter in natural gas acceptance and characterization.

The connection of RNG product to the pipeline grid requires additional analysis and verification of quality to ensure gas quality specifications are being met continuously. Introduction of RNG into specific points on a pipeline should be evaluated carefully, as the inherent quality of the gas presented to the end-user differs from traditional natural gas. The differences may or may not be significant to the end-user or application.

As this part of the industry continues to expand and evolve, it is important to clarify definitions and terminology. Biogas and synthetic gas (syngas) are both considered renewable natural gases. However, they are not interchangeable, and application of this document does not extent to syngas. Biogas, for which this program is currently designed, refers to gases produced through the anaerobic/biological/bacterial digestion of organic waste, and includes gas from LAM digesters, industrial-grade food digesters, municipal organics digesters, farm residual digesters, landfills and wastewater treatment sludge ADs, primarily. Syngas RNG differs from biologically-derived RNG because the process of methane production is substantially different from biological degradation of organic waste. Syngas RNG will possess a chemical/trace constituent profile which is different from RNG produced through biological degradation of organic materials (biogas), both in the raw and cleaned product. The *gas profiles are not the same*, and the RNG Quality Specifications created for biogas upgrade cannot be used for syngas, with special attention to the trace constituents profile.

3. A HIGH QUALITY RNG SPECIFICATION

RNG specifications are created from knowledge rooted in understanding the impacts/risks associated with the various "receptors" (see below) *and* referenced concentrations of specific constituents which clearly indicate impact. As mentioned previously, ONE Specification is prepared for a company, so that there is consistency and harmony throughout the system. An RNG Specification is not a "wish list" of constituents and concentrations. A proper RNG Specification is carefully constructed, and follows the criteria below, so that it is defendable, reasonable and cost-effective to instate, and is rooted in science and reality, rather than emotion, fear or uncertainty. The following six (6) points are the key elements of a good, defendable RNG Specification:

1) **Evidenced-Based**: The Specification should be rooted in science, research, modeling, and historical precedence. This is a critical aspect of a Specification, so that it covers only the constituents and parameters which are relevant to actual impacts to the identified receptors. Otherwise, the Specification may simply indicate a misunderstanding of the subject and be too broad, and difficult to defend or instate.

2) **Referenced**: The Specification should share consensus within the industry and be in line with the shared body of knowledge. A "referenced Specification" indicates a level of assurance, so that the product is created from the best available knowledge on the topic, and that other major, reputable influencers/industry bodies of expertise agree with list of constituents and the clean-up levels required.

3) **Reasonable**: The Specification should be easy to understand, be rational, be in line with applicable and high-quality research results, and be in consensus with industry and scientific experts. The applicable statement is, "Does this make sense?", or, "Are we asking the correct questions?"

4) **Justifiable**: Through the examination of databases, scientific papers, datasets, or analytical reviews, can the list of proposed compounds be justified and are the gas quality standards defendable? Why were the constituents on the list chosen? What were the cleanup values based on? What can we reasonably expect from a gas conditioning program? Is the Specification too restrictive, which will cost more money to achieve? These questions, and more, serve as a basis for the critical evaluation of a Specification.

5) **Verifiable**: This aspect of the Specification is very important in that it considers whether the proposed analytical boundaries can, in fact, be confirmed through approved methods. This parameter of the Specification ensures that the required concentrations are not outside of high-quality testing ranges. In other words, the required Specification values need to be within the constraints of appropriate analytical methods.

6) **Achievable**: The Specification should be achievable by best available demonstrated technologies for cleanup of raw biogas to quality RNG.

The Renewable Natural Gas Pipeline Quality Specifications (Biomethane) is then supported by a thorough gas quality Verification and Monitoring Program.

4. ASSESSMENT OF RNG QUALITY

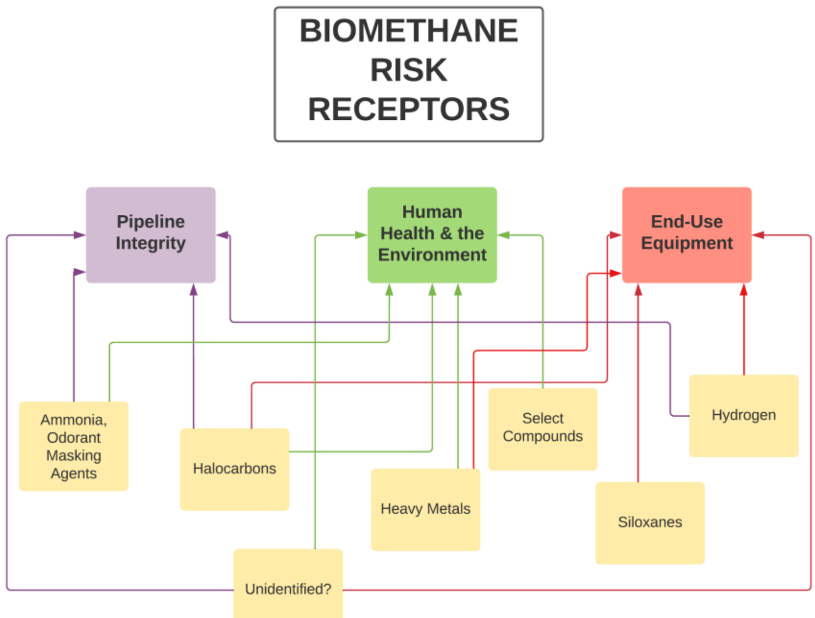
The required quality for all biomethane RNG products entering the LGE network is shown in Attachment 1, *LGE Renewable Natural Gas Pipeline Quality Specification (Biomethane)*.

Gas quality parameters have been parceled into two groups:

- Major Components
- Trace Constituents

Major components are constituents or parameters which are routinely tested by natural gas companies in accordance to the natural gas tariffs associated with the pipeline jurisdiction or local quality objectives. They include higher heating value, Wobbe Number, inert concentrations, sulfur concentrations, water content and temperature. These components are *measured routinely* in the natural gas industry, using designated on-line instrumentation, with real-time output. LGE may already have particular on-line analytical equipment and methods for use in Major Components testing of natural gas.

Trace Constituents are components or parameters which have been identified as agents of concern *specific to RNG (biomethane) supplies* from a variety of sources. The parameters include specific heavy metals, ammonia, halocarbons, siloxanes and others which have been associated with raw biogas supplies. These constituents can be detrimental to three primary "receptors": pipeline integrity, human health and the environment, and end-use equipment. Some trace constituents impact more than one receptor, as shown below:



The receptor of human health and the environment considers the gas *pre-combustion* and *post-combustion* (off-gases/emissions from combustion and impacts to indoor and outdoor air quality). Within the structure of a Specification, human health and the environment prevail as the most conservative value assigned. NOTE: as data and science advances in this area, the list of trace constituents may be modified by LGE, depending upon documented or reported relevant information.

Detailed in the RNG Verification and Monitoring Plan (Task 2 of this work), samples for trace constituent analysis are retrieved from the field and sent to third party laboratories for confirmation of gas quality. NOTE: sample collection protocols and test methods for specific components, especially within the trace constituent group, may change based upon updates in methodology, sampling protocols and new instrumentation. Alternative methods of sampling and testing for constituents must be approved by LGE. RNG producers need to be aware of the limitations of the test method and sampling protocols.

IMPORTANT: LGE does not permit RNG from sources containing hazardous waste to be delivered into its pipeline systems. This includes landfills which contain hazardous waste. Accordingly, operators, interconnecting parties, and shippers shall not knowingly deliver such gas into LGE's pipeline systems. It is the responsibility of the operator of a landfill gas receipt point to disclose whether the associated landfill is a site of hazardous waste, has ever been a site of hazardous waste, contains hazardous waste, or ever accepted hazardous waste. Hazardous waste landfills include all continuous land and structures, and other appurtenances and improvements, on the land used for the treatment, transfer, storage, resource recovery, and disposal or recycling of hazardous waste.

5. RNG QUALITY DESCRIPTIONS

5.1 Higher Heating Value and Wobbe Number

5.1.1 Overview

Higher Heating Value (HHV) or Gross Heating Value is defined as the amount of energy transferred as heat from the complete, ideal combustion of a gas with air, at a standard temperature, in which all the water formed by the reaction condenses to liquid.

Custody transfer of natural gas is generally on an energy basis. Transportation of low-calorific value gas may reduce the economic efficiency of some pipelines. As well, gas of low-calorific value may have detrimental effects on end-use equipment and may not be compatible with many systems.

Fully cleaned or "conditioned" RNG should be within the interchangeability boundaries with existing natural gas supplies (tariff) for the pipeline location. Interchangeability of a gas is defined as "the ability to substitute one gaseous fuel for another in a combustion application without materially changing operational safety, efficiency, performance or materially increasing air pollutant emissions." (NGC+, 2005). There are combustion phenomena which occur when a gas possesses a heating value which is either higher or lower than historical averages for the pipeline and customer base. These include (from AGA Report 4A, Jan '08):

- Auto-ignition (engine knock),
- Flashback,
- Lifting,
- Blowout,
- Incomplete combustion leading to carbon monoxide (CO) formation,
- Yellow tipping,
- Emissions of nitrogen oxides (NOx), unburned hydrocarbons, and CO.

The Wobbe Number (also called Wobbe Index or Wobbe) is one of the most common metrics of interchangeability; it measures the rate of energy delivered through a fixed orifice at a constant pressure. The Wobbe is calculated by dividing the higher heating value of the gas by the square root of the specific gravity of the gas relative to air. Neither heating value nor Wobbe alone can completely address combustion over the full range of natural gas. In practice, heating value and Wobbe must be examined *together* to specify an acceptable range of gas to avoid interchangeability concerns for end-use customers.

Most combustion dynamics are concerned with the upper boundary of interchangeability (at maximum heating value or Wobbe). This originated in the use of LNG within North America. Conversely, RNG possesses a heating value which falls closer to the lower boundary of interchangeability. Flame lifting, which can lead to carbon monoxide formation, and blowout are problematic with gases which possess a lower heating value and Wobbe. Given the inherently lower heating value and Wobbe of RNG compared to natural gas, flame lifting, formation of CO and blowout are the primary concerns with RNG interchange.

5.1.2 Content Limit

RNG is not similar to natural gas in its general profile; extended hydrocarbons are absent from the gas. Extended hydrocarbons, such as ethane, propane, butane, etc. boost the BTU and the Wobbe of natural gas. As such, the heating value of the RNG is based upon the percent methane in the gas. The maximum heating value for pure methane is 1,010 BTU/scf. However, this value is never realized because of the presence of concentrations of inerts (carbon dioxide, oxygen, nitrogen, etc.) which are intrinsic to RNG. Therefore, RNG will generally not reach beyond the value of 990 BTU/scf without augmentation with gases possessing higher heating value. More typically, an upper boundary is 970 – 980 BTU/scf. Essentially, the RNG conditioning unit strips the raw biogas of inert gases, boosting the concentration of methane in the resulting gas. *If a higher heating value is required for specific end-users or circumstances specific to the pipeline and customer profile, propane may be injected into the RNG, to increase the minimum required BTU and Wobbe Number. This practice is typical in Europe with RNG systems.*

Minimum required Higher Heating Value (HHV, BTU/scf) for RNG inclusion into the LGE network is 970 BTU/scf, and the minimum Wobbe number for RNG is 1314 BTU/scf. This is based upon existing natural gas pipeline tariffs pertaining to delivered gas to the LGE network (Tennessee Gas Pipeline Company, L.L.C, and, Texas Gas Transmission, L.L.C.) and recommendations cited in the California Council for Science & Technology's (CCST) Report titled: *Biomethane in California Common Carrier Pipelines: Assessing Heating Value and Maximum Siloxane Specifications: An Independent Review of Scientific and Technical Information*. As cited from this publication, a lower HHV/Wobbe risks flame lifting, formation of CO and blowout of the flame upon combustion. Wobbe Number also indicates the absence of inerts within the RNG; a required higher Wobbe Number limits the concentration of diluent and problematic inert gases (i.e., the higher the Wobbe in RNG, the less inerts).

5.1.3 Analytical Test

The heating value of a gas is determined by calculation from the molar compositional data obtained from gas chromatography (GC) using method ASTM D1945/1946, followed by ASTM 3588. The analysis and calculations are performed using an LGE-approved on-line Gas Chromatograph (GC) which continuously samples, analyzes and calculates the sampled gas properties. The Wobbe Number is calculated using the HHV and specific gravity values output from the GC.

5.2 Carbon Dioxide, Oxygen, Nitrogen, and other Inert/Diluent Gases

5.2.1 Overview

Inert and diluent gases are non-hydrocarbons; they reduce the overall heating value (HHV/Wobbe) of a methane product such as RNG. Some inerts (nitrogen, argon, helium, etc.) are not chemically reactive with the surrounding environment. However, other diluent gases may chemically react with the surrounding environment; the primary diluent in RNG is carbon dioxide, but others, such as oxygen, may be present. Landfill gas can contain significant quantities of nitrogen, depending upon the biogas extraction process. Specifications for inerts are typical in natural gas pipeline tariffs. Pipelines often group all non-hydrocarbon gases together as "total inerts", and have specific limit values for each inert gas. Control of inert concentrations in the RNG directly impacts the HHV and Wobbe Number for the gas.

Concentrations and combinations of inerts and/or diluents may impart various impacts to pipeline operations, gas facilities and end-use equipment. These are detailed in the following sections.

5.2.2 Carbon Dioxide (CO_2)

Carbon dioxide is considered a diluent and is an odorless, colorless gas. However, it reduces the overall heating value of the gas per unit volume. Carbon dioxide is non-corrosive in the absence of water, but if water is present, under certain conditions, it can form carbonic acid. Additionally, carbon dioxide can act synergistically with hydrogen sulfide and O_2, thereby enhancing the corrosion of pipeline materials.

5.2.3 Oxygen (O_2)

The presence of oxygen is critical because it increases both the effect and rate of other corrosion mechanisms. It is considered a primary driver of corrosion and concentrations in the gas are important to pipeline integrity, especially if other conditions are favorable to corrosion or are exacerbated in the presence of oxygen. In combination with free water and/or with other constituents such as carbon dioxide and hydrogen sulfide, enhanced corrosion can result. Concentrations of oxygen in RNG are particularly problematic, as oxygen can instigate or exacerbate internal pipeline corrosion. Oxygen is also problematic if there are breaches to pipeline integrity, as there is a potential for combustion.

5.2.4 Nitrogen (N_2)

Nitrogen is an inert gas that is colorless, odorless, and non-corrosive. It is usually regulated because it affects the calorific value of the gas or impacts the quality of gas used as feedstock (fuel cells, hydrogen production and natural gas liquefaction). At elevated concentrations, combustion operations may be impacted, possibly causing poor flame stability, producing a flame with yellow tipping and lifting. Concentrations of nitrogen also may affect compressibility of the gas.

5.2.5 Upper Content Limit

Content limits (maximum concentrations) for carbon dioxide, oxygen, nitrogen and total inerts in RNG for the LGE system are as follows:

Carbon Dioxide :	2.0% volume
Oxygen :	0.2% volume
Nitrogen :	2.0% volume

Total O_2+N_2 :	2.75% volume
Total Inerts (CO_2+N_2+O_2):	4.0% volume

These values are based upon and supported by natural gas tariff specifications (Tennessee Gas Pipeline Company, L.L.C, and, Texas Gas Transmission, L.L.C.) for delivered natural gas to the LGE network.

5.2.6 Analytical Tests for These Parameters (Carbon Dioxide, Oxygen, and Nitrogen)

Carbon dioxide, oxygen and other inerts can be determined by laboratory gas chromatograph analysis with a thermal conductivity detector following ASTM D1945/D1946. Tests for carbon dioxide and nitrogen are performed on-line, with continuous analysis, using approved LGE on-line instrumentation (an appropriate GC used to concurrently analyze for BTU and Wobbe) for analysis of gaseous fuels. Analysis of oxygen requires a separate on-line analyzer; a variety of high-quality instrumentation are available (e.g., Endress + Hauser/SpectraSensor OXY5500).

5.3 Hydrogen Sulfide (H_2S) and Total Sulfur

5.3.1 Overview

Total Sulfur is the sum of the contribution of sulfur by all sulfur-containing compounds in the gas and is calculated for individual sulfur-containing compounds based on relative molecular weight of sulfur in the compound. Sulfur is corrosive with or without the presence of water. The primary sulfur compound found in raw biogas is hydrogen sulfide (H_2S). It is generated from anaerobic microbial decomposition of sulfate and sulfur-containing organic matter. Additionally, some water sources contain sulfate and hydrogen sulfide.

The presence of hydrogen sulfide and other sulfur-containing compounds are regulated because of their potential corrosive and destructive nature on pipeline materials. In the presence of water, sulfur compounds can eventually form sulfuric acid, a strong acid with an aggressive corrosion potential. Corrosion is exacerbated if other compounds are also present, especially CO_2 and O_2. Hydrogen sulfide is also an irritant or potentially toxic to humans at higher levels.

5.3.2 Upper Content Limit

Content maximum limits for hydrogen sulfide and total sulfur in RNG for LGE delivery are as follows:

Hydrogen Sulfide:	0.25 grains/100scf
Total Sulfur Compounds, as sulfur:	5.0 grains/100scf

Maximum concentrations of these sulfur components is cited and supported by individual pipeline tariffs specific to natural gas delivered to LGE injection locations and contractual gas quality requirements.

5.3.3 Analytical Test for These Parameters

Hydrogen sulfide analysis can be performed in the laboratory using the method ASTM 5504, using GC/Sulphur Chemiluminescence Detector (SCD). Total sulfur analysis can be performed by ASTM 5504 using oxidative microcoulometry, using GC/SCD. Other methods are available: ASTM D6228 (GC/Pulsed Flame Photometric Detector, PFPD). Hydrogen sulfide and total sulfur are measured continuously, on-line with approved LGE instrumentation, typically using ASTM D4084 and D4468 for the analysis of hydrogen sulfide, and total sulfur using the lead acetate reaction rate method.

5.4 Water Content

5.4.1 Overview

The presence of water vapor in RNG, as with natural gas, can pose significant problems particularly associated with corrosion. Water combined with CO_2 and H_2S, under certain conditions, can form acidic mixtures which are corrosive to pipeline systems. The combination of oxygen and water is particularly impactful to corrosion potential, through a variety of mechanisms. Additionally, water vapor is limited to prevent condensation and reduce hydrate formation. Hydrates are an ice-like mixture of water and hydrocarbons formed at high pressures when high water vapor is present.

5.4.2 Upper Content Limit

The maximum content limit for water vapor in RNG delivered to LGE pipelines is 4 lbs/MMscf.

This maximum is cited in the Texas Gas Transmission, L.L.C., Fayetteville Lateral and Greenville Lateral natural gas tariff and therefore will apply to RNG injected into the LGE network, unless waivered specifically by the gas company for a specific project or RNG injection location. At no time is the maximum water vapor content to exceed a maximum of 7 lbs/MMscf, for any RNG project on the LGE network.

5.4.3 Analytical Test for This Parameter

Moisture can be tested on-line using a "chilled mirror technique" (ASTM D1142), an electronic moisture analyzer (ASTM D5454) containing sensors based on phosphorus pentoxide, aluminum oxide, or silicon among others, or an on-line detection sensor which utilizes laser technology (ASTM D7904).

5.5 Delivery Temperature

5.5.1 Overview

The effects and limitations of equipment, materials and fittings relative to gas temperatures should be considered. Temperature limitations serve to primarily protect external coatings or pipe materials, as well as downstream gas processing and handling equipment. Differences exist between metallic (steel) and non-metallic (plastic) pipeline.

5.5.2 Upper Content Limit

The temperature limits for RNG are as follows:

Not more than 120^o Fahrenheit
Not less than 40^o Fahrenheit

This temperature range is cited and supported by individual pipeline tariffs specific to LGE injection locations and contractual gas quality requirements.

5.5.3 Representative Analytical Test for This Parameter

RNG temperature can be continuously measured on-line using an LGE approved temperature measuring device.

5.6 Objectionable Matter (Sand, Dust, Gums, Oils, Liquids, Solids, Objectionable Odors, etc.)

5.6.1 Overview

Existing tariffs covering gas quality for supplies to the LGE network all contain statements addressing objectionable matter (Texas Gas Transmission, L.L.C. FERC NGA Gas Tariff, version 4.0.0., Section 6.3, #1(a); Tennessee Gas Pipeline Company, L.L.C. FERC NGA Gas Tariff, Sixth Revised Vol. No. 1, Dec. 14, 2011, Section II, 3k) Although the wording may differ in each, the general intent is that the gas must not contain sand, dust, gums, oils, particulate matter and other impurities or other objectionable substances in such quantities that may be injurious to persons or pipelines, or that may interfere with the transmission or merchantability of the gas.

Biologicals fall under the category of other objectionable substances: particulate matter. Objectionable matter, such as biologicals, dust, gums, solids, liquids, etc., can be introduced into the gas pipeline network from a variety of sources. In the case of RNG production, objectionable particulate matter may be carried along from the production process into the final RNG gas product. Specific microbes contained in RNG, as with natural gas, may induce/exacerbate pipeline corrosion (Microbially-Induced Corrosion or “MIC”). Depending upon the starting biomass, a variety of microbial populations may exist in the resulting gas stream. The amount and size of particulate matter in the RNG stream should be minimized to avoid contamination, clogging and erosion of processing plant and distribution line components. Particles including biologicals can usually be removed by filters, sedimentation or centrifugal collectors. *Research clearly indicates that the quantity of MIC-producing microbes in RNG is equal to or less than the number found in natural gas sources.*

5.6.2 Upper Content Limit

For the LGE pipeline network, tariffs for supplied natural gas state that the gas is to be “Commercially-free from odors, dust, or other solid or liquid matters…”. Biologicals fall under this category. Biological agents are considered as solid matter and can be filtered from the gas stream.

5.6.3 Analytical Test for This Parameter

Filters installed in-line after the biogas cleanup process shall be used. It is recommended that a high quality, industrial-grade, in-line filter be installed for proper filtration of microbes (bacteria) and particulate matter from the process.

An epifluorescence microscope (EM)/extended analysis (EA) corrosion coupon, or similar, can be placed in the pipe just after the point of injection to monitor and assess the conditions which induce corrosion. EM/EA analysis can identify a variety of sources of corrosion (microbial, chemical, etc.)

5.7 Ammonia

5.7.1 Overview

The presence of ammonia could impact odorization of pipeline gas (mask odorants). While typically not found in high concentrations in fully cleaned RNG, ammonia can be found in biogas particularly from LAM and WWT sludge digestion.

5.7.2 Upper Content Limit

For the LGE pipeline network, the allowable concentration of ammonia in RNG is 0.001% volume or 10 ppm. This value is supported by citation in Rule 45 and Rule 21 (state of CA) and the BNQ. The primary receptor of concern is human health and the environment, as ammonia may alter odorant smell.

5.7.3 Analytical Test for This Parameter

Gas samples are collected in glass tubes (check laboratory for preferred method), and ammonia testing is performed in the laboratory, using method OSHA ID-188 or NIOSH 6015, using Atomic Adsorption Spectroscopy (AAS). Alternatively, an impinger method may be used, collecting the gas in the field using method Mod. EPA 26 in the field, and laboratory method CTM 027, using ion chromatography.

5.8 Hydrogen

5.8.1 Parameter Overview

Hydrogen is not a typical constituent of natural gas, but it may be present in RNG. Hydrogen can be present in two forms; atomic hydrogen (H), and/or diatomic hydrogen (H_2) and each type will be discussed in turn.

Atomic hydrogen can be generated as a by-product of corrosion activity or the pipeline welding process and can be problematic when in contact with steel; hydrogen stress cracking or hydrogen embrittlement may occur. Hydrogen stress cracking is a degradation process that steel can undergo due to the extreme solubility of atomic hydrogen in the iron alloy lattice. Atomic hydrogen may result from spontaneous dissociation of molecular hydrogen. The presence of hydrogen sulfide in the gas accelerates the permeation of atomic hydrogen into the iron lattice. Other concerns are with reactions between hydrogen and sulfur and chlorine-containing compounds, especially in the presence of water, forming sulfuric and hydrochloric acids.

Diatomic hydrogen is a more stable form and less likely to react within the pipeline. However, a major concern relates to the permeability of hydrogen gas through non-metallic piping systems or mechanical connections (threads, pipe unions, flanges, etc.). If the concentration of hydrogen within RNG exceeds the normal concentration found in regular natural gas, hydrogen permeability should be considered.

5.8.2 Upper Content Limit

For the LGE pipeline network, the allowable concentration of hydrogen in RNG is 0.10 % volume percent. This is based upon the values in Rule 45 and Rule 21.

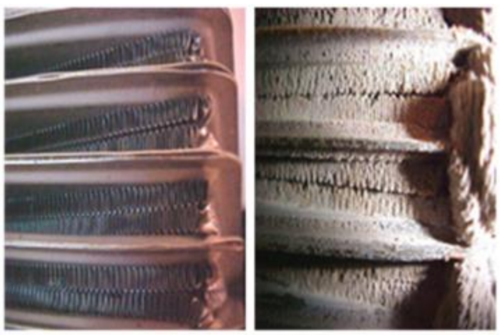
5.8.3 Analytical Test for This Parameter

Hydrogen can be determined in the laboratory from a field sample using gas chromatography with a thermal conductivity detector (ASTM D1945/D1946), GC/TCD.

5.9 Siloxanes

5.9.1 Overview

Siloxanes are a family of man-made compounds often containing oxygen and silicon (O-Si-O) bonds, with methyl (carbon and hydrogen, CH_3) groups bound to the silicon atoms. Siloxanes exist as different congeners, and are often referred to by abbreviations such as L2, D4, etc. with the number indicating the number of silicon atoms and the letter indicating the structure (linear, L or cyclic, D). Due to the increase in silicon-containing personal hygiene, health care and industrial products, the presence of siloxane in landfill and wastewater treatment waste streams has increased; they are generally not present in biogas produced from LAM, industrial-grade food waste or agricultural residues. However, if the above-mentioned wastes are mixed with wastes from municipal organics collection programs, the presence of siloxane is



increased due to erroneous admixtures with plastics and other potentially hazardous substances. As the silicon-containing waste stream is broken-down, siloxane compounds volatilize and become entrained in the biogas. When this gas is combusted under high heat and pressure, silicon dioxide is formed. This silica dust (see picture) damages internal combustion engines, turbines, and add-on air pollution control devices. Because the concern is post-combustion silica formation potential, which is proportional to mass of Si, siloxane content should be represented in mg Si/m^3 whenever possible. With regards to this trace constituent, biogas from a municipal organic waste collection program is considered on par with landfill and WWT biogas *until proven otherwise through analytical testing*.

5.9.2 Upper Content Limit

For the LGE pipeline network, the maximum allowable concentration of siloxane in RNG is 0.5 mg Si/m^3. The value is supported by citation in the California Council for Science & Technology (CCST) Report, June, 2018. This scientific and respected report, written by request of the California legislature for California gas companies, covers the HHV value and acceptable siloxane concentration in RNG. As more information becomes available, the value may be lowered over time. The primary receptor of concern is end-use equipment.

5.9.3 Analytical Test for This Parameter

A newly approved ASTM Method D8230-19: *Standard Test Method for Measurement of Volatile Silicon-Containing Compounds in a Gaseous Fuel Sample Using Gas Chromatography with Spectroscopic Detection* has been developed and approved by ASTM for general and consistent use. The method is described as follows: "This test method is primarily for gas-phase siloxane compounds present in biogas and other gaseous fuel samples at ppmv and high ppbv concentrations. It may also be applicable to low ppbv concentrations under certain circumstances." This method is being used in the industry, as it has been approved by ASTM and numerous laboratories can perform this analysis.

Sampling can be performed by Tedlar bag, sent to the laboratory and analyzed within 72 hours of sample collection. Other grab sample methods may be used upon laboratory advise; check with laboratory for preferred method of sample collection. Specific tubes have been designed for siloxane sample collection. In the laboratory, sample analysis is performed through GC/Mass Spectrometry (MS).

5.10 Halocarbons: Measurement of Chlorine (Cl^-) and Fluorine (F^-)

5.10.1 Overview

Halocarbons are organic compounds containing carbon, hydrogen, and one or more halogen element (chlorine, fluorine, or bromine, etc.). They are also considered volatile organic compounds (VOCs). Halocarbon compounds are not completely consumed upon combustion. Therefore, the elemental halogen portion (chlorine: Cl^-, fluorine: F^-, etc.) is released to the atmosphere (or inside the pipeline), where it most likely combined with a hydrogen, creating an acid (hydrochloric or hydrofluoric acid). This creates potential impacts to indoor air quality and outdoor air emissions concerns, and could impact the burner tip itself. Halocarbons could also impact pipeline integrity through the same mechanism. Various compounds within the halocarbon group possess more Cl^- or F^- (or both) per compound than others; (i.e., CFC-133 versus chloroethane). Therefore, Cl^- and F^- elements (the halogens) are considered in total versus total halocarbon concentrations.

Biogas produced from landfill and WWT sludge AD may contain a wide variety of VOCs, including halocarbons. Cleaned RNG may possess trace amounts of halocarbons and VOCs, depending upon biomass source and conditions of biogas production. Halocarbons are generally not found in LAM, agricultural residues or industrial-grade food waste. Constituents found in municipal organic waste collection programs are less clear, as analytical profiles suggest a wide variety of materials are accidently or intentionally comingled with organic materials. With regards to this trace constituent, biogas from a municipal organic waste collection program is considered on par with landfill and WWT sludge biogas *until proven otherwise through analytical testing*.

5.10.2 Upper Content Limits

For the LGE pipeline network, the maximum allowable concentration of halocarbons *is measured as total Cl^- and total F^- (sum of all):*

Total chlorine (Cl^-): 10.0 mg/m^3
Total fluorine (F^-): 1.0 mg/m^3 (*to be increased to 10.0 mg/m^3 upon approval of BNQ Reference)

These values are supported by citation from the CGA Biomethane Guidelines Document (2011) and the BNQ 3672-100/2012 (NOTE UPDATE TO FOLLOW). The CGA and BNQ documents are supported by the MarcoGaz Working Group paper and AFSSET. Analysis of RNG using the stated method allows for a calculation of the total Cl^- and F^- in the gas stream from totals of all halogenated compounds in the gas. The primary receptor of concern is human health and the environment, but other receptors are also potentially impacted.

5.10.3 Analytical Test for This Parameter

Analysis for halocarbons is through laboratory analysis by gas chromatography using GC/MS, using EPA TO-15 methodology, or an electron capture detector (ECD). Sampling may be with Summa canisters/Tedlar bags. Check with laboratory for preferred sample collection method. Concentrations of chlorine and fluorine are then calculated from total compound concentrations, based on molecular weight and percent to total compound, as follows (example calculations):

<u>Vinyl Chloride (VC) – Molecular Weight (MW) - 62.5</u>
Chlorine MW = 35.453 One chlorine in the molecule, no fluorine in the molecule
35.453/62.5 = .567
Concentration of the compound x .567 (for instance, 1 ppm VC x .567 = .567 ppm Cl, no F)
Can then convert to mg/m3: 2.56 mg/m3 = 1 ppm VC

<u>Dichlorodifluoromethane (CFC-12) – MW 120.91</u>
Chlorine MW = 70.906 (2 Cl)
Fluorine MW = 37.996 (2 F)
70.906/120.91 = .586 Cl
37.996/120.91 = .314 F
Concentration of the compound x .586 (for instance, 1 ppm CFC-12 x .586 = .586 ppm Cl)
Concentration of the compound x .314 (for instance, 1 ppm CFC-12 x .314 = .314 ppm F)
Can then convert to mg/m3: 4.95 mg/m3 = 1 ppm CFC-12

Alternatively, sampling and analysis for chlorine and fluorine may be performed through CTM 027, using USEPA Method 26/26A (modified) sampling (impinger method), analyzed by ion chromatography. This method alleviates manual calculation of total Cl^- and F^- in the sample, as only the quantity of halogens is measured.

5.11 Heavy Metals

5.11.1 Overview

Heavy metal concentrations are of particular concern when dealing with RNG generation because volatile metals may be released through the degradation of metal-containing products, batteries, etc. They are often carried by small particulate matter in the gas stream.

Heavy metals may cause toxicological and environmental problems. The primary impact from the presence of some heavy metals in the gas stream is potential corrosion of aluminum metal and alloys used to construct gas processing equipment. This is particularly problematic because heavy metals, such as mercury, may concentrate in cryogenic liquids and other processing fluids. From a human health and environment perspective, particular heavy metals can be highly toxic and impact air quality. The primary receptor of concern for arsenic and copper is human health and the environment. The primary receptor of concern for mercury is end-use equipment.

5.11.2 Upper Content Limits

Heavy metals such as arsenic, copper and mercury, as well as others, may be found in RNG specifically from landfills and WWT sludge AD.

For the LGE pipeline network, the maximum allowable concentration limits are:

Arsenic:	0.19 mg/m^3 or 0.06 ppmv
Copper:	0.60 mg/m^3 or .23 ppmv
Mercury:	0.08 mg/m^3

These RNG specification levels are referenced and cited in Rule 45 and Rule 21 for California gas utilities, with attention to emissions from burning of the gas (off-gas quality). Rule 45 and Rule 21 were based on the OEHAA Report (see References). Concentrations of these and other heavy metals may be added or removed from this list, based upon ongoing research and future studies.

5.11.3 Analytical Tests for These Parameters

Sampling for volatile metals arsenic and copper can be performed in the field using a sparger containing a mix of hydrogen peroxide and nitric acid, returned to the lab. (The sparger technique is similar to EPA Method 29 for stack gas sampling, where a known volume of gas is passed through a gas bubbler.) Samples are then tested in the laboratory using EPA Method 29 (Mod.), by Atomic Adsorption Spectroscopy (AAS)/ Inductively Coupled Atomic Plasma (ICAP).

Routine laboratory analysis for mercury can be done following ASTM D5954. This method utilizes on-site collection through gold plated glass beads, followed by lab analysis by AAS. All techniques require knowledge of the total gas sampled via a dry test meter (preferred) or rotameter.

The sampling method should extract heavy metals from the RNG at the time of gas sampling. Accurate mercury analysis cannot be performed through collection of the RNG in a cylinder and shipment to the laboratory for further analysis. As with all field sampling, it is best to refer to field sampling protocols recommended by the laboratory which is performing the analysis.

6. GENERAL DEFINITIONS

The definitions provided here are intentionally limited in scope and are offered for general information only.

- **AGA Report 4A** – A Guidance Document created to establish a common framework, as well as an industry-wide reference tool, for gas quality and measurement provisions in contracts or tariffs. It provides an explanation of terminology and examples of representative measurement and gas quality clauses for natural gas flowing through the North American pipeline grid. The primary focus is to provide technical information for use in tariff or contracts which promote the safety and reliability of gas transmission and distribution infrastructure, while maximizing supply opportunities and minimizing potential end use concerns. Furthermore, the report provides factors to consider when evaluating appropriate limits for gas quality specifications along with a discussion of available measurement technologies referenced in documents that specify custody transfer transactions.
- **Anaerobic Digestion (AD)** – see Digester.
- **Biogas** – The gas resulting from the anaerobic digestion of biomass (organic material). Depending upon the digestion process used and conditions of digestion, biogas consists of 40 – 65% methane. The remaining 35 – 60% of the biogas consists of "other" gases, with carbon dioxide being the major gas. Other trace gases include nitrogen compounds (ammonia, etc.), oxygen, water vapor, sulfur compounds (hydrogen sulfide, etc.) and other constituents, depending upon the biomass

source. Biogas is considered "raw" unless cleaned or "conditioned" to meet the requirements of end use or inclusion within natural pipeline systems. "Raw" biogas is not considered suitable for interchange within natural gas pipeline networks.

- **Biomass** – Organic materials that may be converted to gaseous fuel through anaerobic digestion (biological breakdown) or high temperature conversion (syngas/gasification). These materials may include all organic substances, but some biomass materials possess more caloric value than others, thereby producing more energy. Biomass sources vary widely and include domestic wastes, animal wastes, livestock operation residues, forest and mill residues, agricultural crops and wastes, wood and wood wastes, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes.
- **Biomethane** – Also known as a form of Renewable Natural Gas (RNG) - The portion of biogas which consists primarily of methane. Biomethane is generally extracted from raw biogas through cleanup or "conditioning", to remove "other" gases which impact gas quality. Using effective biogas cleanup (removal of gases which effect overall gas quality), biomethane can be up to 99% methane, with concentrations of "other" gases. However, "raw" biogas may contain only 40 – 65% methane. Biomethane is considered suitable for many end-use applications and may be considered suitable for inclusion in general pipeline systems, depending upon other characteristics of the gas and specific tariff requirements.
- **Co-Digestion** – Anaerobic digestion of wastes from a variety of sources, in an anaerobic digester (AD). Examples may be WWT sludge with municipal organic materials, dairy waste digestion with industrial-grade food waste or dairy waste digestion with municipal organic materials. Each co-digestion program should be examined individually for appropriate gas testing protocols.
- **Digester (Anaerobic)** – A tank, covered lagoon or other covered vessel designed to convert biomass to biogas through biological action. Digesters are common to the wastewater treatment industry as well as in farming operations for manure management and/or digestion of combined organics. Conversion of the biomass in the digester depends upon bacterial degradation or transformation of compounds, both carbon-based and others, to gaseous products, which are then present in the resulting biogas. Digesters vary in complexity and design. The maximum quantity of biogas generated from digestion of biomass is dependent upon the design of the digester (temperature and hydraulic retention time), biologically degradable fraction of the raw material and other factors. Biogas generated through anaerobic digestion of biomass in digesters requires further cleanup prior to use (interchange) within natural gas pipeline systems.
- **Gas Cleanup** – Used in reference to scrubbing raw biogas resulting from biomass conversion (anaerobic digestion or landfill digestion). The goal of the gas cleanup unit is to remove (strip) constituents within the raw biogas in order to produce a clean "RNG" product, suitable for further end use or potential inclusion within gas pipeline networks. Cleanup efficiencies for particular constituents vary between cleanup or "conditioning" units.
- **Halocarbons -** a chlorofluorocarbon or other compound in which the hydrogen of a hydrocarbon is replaced by halogens (chlorine, fluorine, bromine, etc.).
- **Halogens –** The elements fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At), which make up the seventh period in the periodic table of the elements. Compounds which consist of these elements are often used in disinfectant solutions; they are also found in Freon gases. Upon degradation, the elements may be released as gases or recombined to produce acidic solutions.
- **Heavy Hydrocarbons –** Hydrocarbons that are heavier than the methane molecule (C_1). Heavier molecular weight hydrocarbons are more prone to condense from the natural gas stream and are

the major constituents of hydrocarbon condensate. Generally, these are the C_2 – C_{20} compounds, with a focus on the butanes+ set (C_4 to C_{20}).

- **Heavy Metals –** Heavy metals refers to a group of mostly toxic metals that have high atomic weights. Some are always toxic (e.g. lead, mercury, cadmium, arsenic, chromium) and others are toxic at high concentrations (e.g. zinc, copper). They are found everywhere in the environment because they are naturally part of the earth's crust or are concentrated in waste streams due to the use of a compound that incorporates a heavy metal element. When a compound that contains a heavy metal is degraded, the element can be released as a toxic gas.
- **Industrial-Grade Food Waste** – Food waste directly derived from an industrial process, prior to contact with humans for consumption. Examples include waste food from bakeries or other food production, yogurt or other milk products, potatoes or other food products, fats, oils and greases (FOG) or other wastes from food or agricultural industries.
- **Interchangeability** – The ability to substitute one gas for another, in the context of natural gas replacement, without materially changing or influencing environmental health and safety, end use performance or pipeline integrity.
- **Landfill Gas** – Gas which is emitted from the breakdown of materials in a landfill. This gas is considered "raw" and requires upgrade for introduction to the pipeline network. Landfill gas may contain products from microbial conversion or gases which have simply volatilized and are present in the landfill gas stream.
- **Live Animal Manure (LAM)** – Manure from live animals, such as cows, cattle, pigs, etc.
- **Microbial Induced Corrosion (MIC) –** Corrosion caused by bacteria present in a pipeline network. Specific groups of bacteria can produce acids that deteriorate pipes through pitting and oxidation. MIC bacteria groupings include, but are not limited to: sulfate-reducing bacteria (SRB), acid-producing bacteria (APB), including acetic-acid producing bacteria (total group) and butyric-acid producing bacteria (total group), iron-oxidizing bacteria (IOB), denitrifying bacteria (DNB), and methanogens – microbes which produce methane (in the Archaea domain).
- **Municipal Organic Waste Collections** – Collection of biodegradable waste or compostable materials as a means to divert waste from landfills. Because the organic waste material has been in contact with humans, it is considered potentially impacted by a wide variety of organic wastes and plastics, which may be inadvertently admixed. Therefore, with respect to RNG quality, it is considered similar to WWT sludge biogas until proven otherwise through analytical testing.
- **Renewable Natural Gas (RNG)** – a general term referring to the conversion of organic materials into methane for use in the pipeline grid. Biomethane and syngas are forms of RNG.
- **RNG Verification Testing Program** – A period of time in which the gas resulting from a biomethane production process is subject to analytical testing and review, to confirm RNG quality. Such a program is advised, as the quality of biogas and biomethane varies with process design, biomass input, choice of cleanup unit and other parameters. It is advised that the Verification Program be executed prior to introduction of the RNG product to the natural gas system, so that analytical compliance may be demonstrated over a period of time.
- **Siloxane –** Any chemical compound composed of units of the form R_2Sio_2, where R is a hydrogen atom or a hydrocarbon group. A siloxane has a branched or unbranched backbone of alternating silicon and oxygen atoms, -Si-O-Si-O-Si, with side chains R attached to the silicon atoms. The word siloxane is derived from the words **sil**icon, **ox**ygen and alk**ane**. Siloxanes can be found in products such as cosmetics, deodorants, water repelling windshield coatings, food additives and

some soaps. When combusted, the siloxane molecules are reduced to silicon dust; this is extremely abrasive and damaging to internal engine components. Combustion of siloxanes also causes a glass-like build up around burner tips and on the tubes of heat exchangers. Silicon dust, resulting from the combustion of siloxanes, may pose health risks to humans and other receptors.

- **Triplicate** – Three samples, of the same stream, taken simultaneously or in parallel, using the same sampling method and technique. The results of the analyses of these samples are averaged, to produce a more accurate measurement of the parameter. The result of a single sample is not "thrown out" or excluded in the average. Triplicate sampling and the resulting data can reveal sample collection errors, problems with the analytical instrumentation and inherent variance between samples. The final value determined through averaging three sample results is more accurate than a single sample.
- **Wastewater Treatment Sludge (WWT)** – The bio-bodies and residuals of the aerobic digestion process which breaks down materials in wastewater. These materials collect at the bottom of the digester tanks, are collected and digested in AD tanks or disposed in landfills.

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13. Pipeline Research Council International, Inc. (PRCI), *Emerging Fuels – Renewable Natural Gas State-Of-The-Art*, *Gap Analysis*, *Future Project Roadmap*, MEAS-15-03, Catalog No. PR306-20604-R01, Measurement Technical Committee of PRCI, prepared by GRTgaz, December, 2020 FINAL

Attachment 1

LGE Renewable Natural Gas Pipeline Quality Specifications (Biomethane)

LGE Renewable Natural Gas Pipeline Quality Specification (Biomethane)			
PARAMETER	**ABBREVIATION**	**Tariff Limit (min./max.) or Assigned Value**	**UNIT**
MAJOR COMPONENTS			
Heating Value[1]	HV	970 min.	BTU/scf
Wobbe Number[1]		1314 min.	BTU/scf
Carbon Dioxide	CO2	2.0 max.	% vol.
Oxygen	O2	0.2 max.	% vol.
Nitrogen	N2	2.0 max.	% vol.
Total O2 + N2		2.75 max.	% vol.
Total O2 + N2 + CO2		4.0 max.	% vol.
Hydrogen Sulfide	H2S	0.25 max.	grains/100scf
Total Sulfur	S	5.0 max.	grains/100scf
Water Content	H2O	4.0 max.	lbs/MMscf
Temperature		<120° and >40°	Fahrenheit
Particulate Matter/Objectionable Materal		Commerically free of....	
TRACE CONSTITUENTS			
Ammonia[2,3]	NH3	0.001 [6]	% vol.
Hydrogen[2,3]	H2	0.1	% vol.
Siloxanes[1]	Si	0.5	mg Si/m3
Chlorine Total[4, 5]	Cl	10	mg/m3
Fluorine Total[4,5]	F	1*	mg/m3
Mercury [2,3]	Hg	0.08	mg/m3
Arsenic [2,3]	As	0.19 [7]	mg/m3
Copper [2,3]	Cu	0.6 [8]	mg/m3

FOOTNOTE REFERENCES/CONVERSIONS

[1]CCST Report, June, 2018
[2] Rule 21, PG&E
[3] Rule 45, SoCal
[4] CGA, 2011
[5]BNQ 3672-100/2012; update to follow
[6]10 ppmv
[7]0.06 ppmv
[8]0.23 ppmv
* This value will increase with the next issue of the BNQ (2023): 10 mg/m3

Attachment 2

LGE RNG Quality Parameters with Testing Methodology

LGE RNG QUALITY PARAMETERS WITH TESTING METHODOLOGY[1]							Testing Required: Biogas Source				
Gas Quality Constituent	**Reference**	**Specific Tariff Limit or Assigned Value**	**Laboratory Test Sampling Method[1]**	**Field Instrument/Laboratory Analytical Method[1]**	**Sampling Material or Devise for Laboratory Analysis**	**Comments**	**Landfill**	**WWT Sludge AD**	**Mixed Waste AD[2]**	**LAM, IGFW[3]**	**Muni. Organic Waste[4]**
High Heating Value (HHV)	Reference 5	970 BTU/scf	Online Gas Chromatography - Company Approved; Calculation	ASTM D3588	NA	Standard Procedure	X	X	X	X	X
Wobbe Number	Published Tariff	1314 BTU/scf	Calculation	ASTM D3588	NA	Standard Procedure	X	X	X	X	X
Carbon Dioxide (CO2)	Published Tariff	2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946	Steel Cylinder	Standard Procedure	X	X	X	X	X
Oxygen (O2)	Published Tariff	0.2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 in laboratory; various online for field analysis	Steel Cylinder	Standard Procedure	X	X	X	X	X
Nitrogen (N2)	Published Tariff	2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946	Steel Cylinder	Standard Procedure	X	X	X	X	X
Total O2 + N2	Published Tariff	2.75 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 plus total from O2	Steel Cylinder	Standard Procedure, add inerts	X	X	X	X	X
Total Inerts (CO2+N2+O2)	Published Tariff	4 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 plus total fror	Steel Cylinder	Standard Procedure, add all inerts	X	X	X	X	X
Hydrogen Sulfide	Published Tariff	.25 grains/100scf	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D6228/D5504/various online for field analysis	Sulfinert Steel Cylinder	Standard Procedure	X	X	X	X	X
Total Sulfur Compounds, as sulfur	Published Tariff	5 grains/100scf	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D6228/D5504/various online for field analysis	Sulfinert Steel Cylinder	Standard Procedure	X	X	X	X	X
Water Content	Published Tariff	4 lbs/MMscf	Online Analyzer	ASTM D1142 or ASTM D5454	Hygrometer	Standard Procedure	X	X	X	X	X
Delivery Temperature	Published Tariff	<120 and >40 Fahrenheit	Online Analyzer	RTD in meter tube thermo well or similar/company preference	Continuous Online	Temperature of the injection gas	X	X	X	X	X
Particulates/Biologicals	Ref. 1, 2	Commerically Free Of…				In-line filter recommended prior to gas introduction; Total corrosion can be monitored by EA/EM in-line coupon	X	X	X	X	X
Ammonia	Ref. 3, 4	0.001 vol% 10 ppmV	AAS/Ion Chromatography	OSHA ID-188 NIOSH 6015 EPA M26	Glass Tubes Glass Tubes Mod. EPA Method 26 (Impingers)	Analytical Method pairs with Sampling Method; EPA Method is impinger method	X	X	X	X	X
Hydrogen	Ref. 3, 4	0.1 Vol %	Gas Chromatography/Thermal Conductivity Detector	ASTM D1945/D1946	Tedlar Bag/Cylinder/Check with your Laboratory	Specific to pipeline integrity	X	X	X	X	X
Siloxanes	Ref. 5	0.5 mg Si/m3	Gas Chromatography/Mass Spectrometry	ASTM D8230-19	Tedlar bag - Analysis within 72 hours; Sample cylinder - check with your laboratory for holding times, options	ASTM recently approved method	X	X	(X)[6]		(X)
Halocarbons - Halogens	Ref. 6, 7, 8	Chlorine: 10 mg/m3 TOTAL Fluorine: 1 mg/m3 TOTAL to be updated	Gas Chromatography/Mass Spectrometry	EPA TO-15[5]	5-L Tedlar Bag; Summa Canisters. Impinger method in field: EPA Method 26/26A	**Impinger method preferred**. However, total Cl and F can also be quantified from TO-15 results.	X	X	(X)		(X)
Mercury	Ref. 3, 4	0.08 mg/m3	Atomic Adsorption Spectroscopy	ASTM D5954	Gold Plated Silica Beads		X	X	(X)		(X)
Arsenic	Ref. 3, 4	0.19 mg/m3 or 0.06 ppmv	Atomic Adsorption Spectroscopy/ICAP	EPA Method 29 Modified	EPA Method 29		X	X	(X)		(X)
Copper	Ref. 3, 4	0.60 mg/m3 or 0.23 ppmv	Atomic Adsorption Spectroscopy/ICAP	EPA Method 29 Modified	EPA Method 29		X	X	(X)		(X)

Specification References

Reference 1	GTI, Feb. 2009
Reference 2	GTI, Dec. 2009
Reference 3	Rule 45, SoCal
Reference 4	Rule 29, PG&E
Reference 5	CCST, 2018
Reference 6	MarcoGaz, AFSSET, 2006
Reference 7	CGA, 2011
Reference 8	BNQ 3672-100/2012 to be updated

[1] Sampling methods and analytical testing methods for trace constituents may be updated over time. Alternative methods must be approved by LGE.

[2] Mixed Waste AD=organics from a variety of sources of unknown quality (i.e, WWT sludge+muni. organic waste, etc.); must verify biogas to qualify for reduced Ver. Testing

[3] Includes LAM AD, Industrial-Grade Food Waste (IGFW) AD or a combination of these sources only.

[4] Includes collection of organics from community programs, "green bin" programs/consumer separated organic wastes.

[5] TO-15 with calculation for total chlorine and fluorine, considering molecular weight and % of total compound, unless impinger method is used.

[6] (X)=Careful examination of incoming organics to the digester; *reduced program approved ONLY if incoming organics/biogas proven free of trace constituents in LGE Specification* ; LGE may verify.

Louisville Gas & Electric Company RNG Quality Verification and Monitoring Programs: Task #2 FINAL

6/12/2023

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Louisville Gas & Electric Company
RNG Quality Verification and Monitoring Programs: Task #2
FINAL

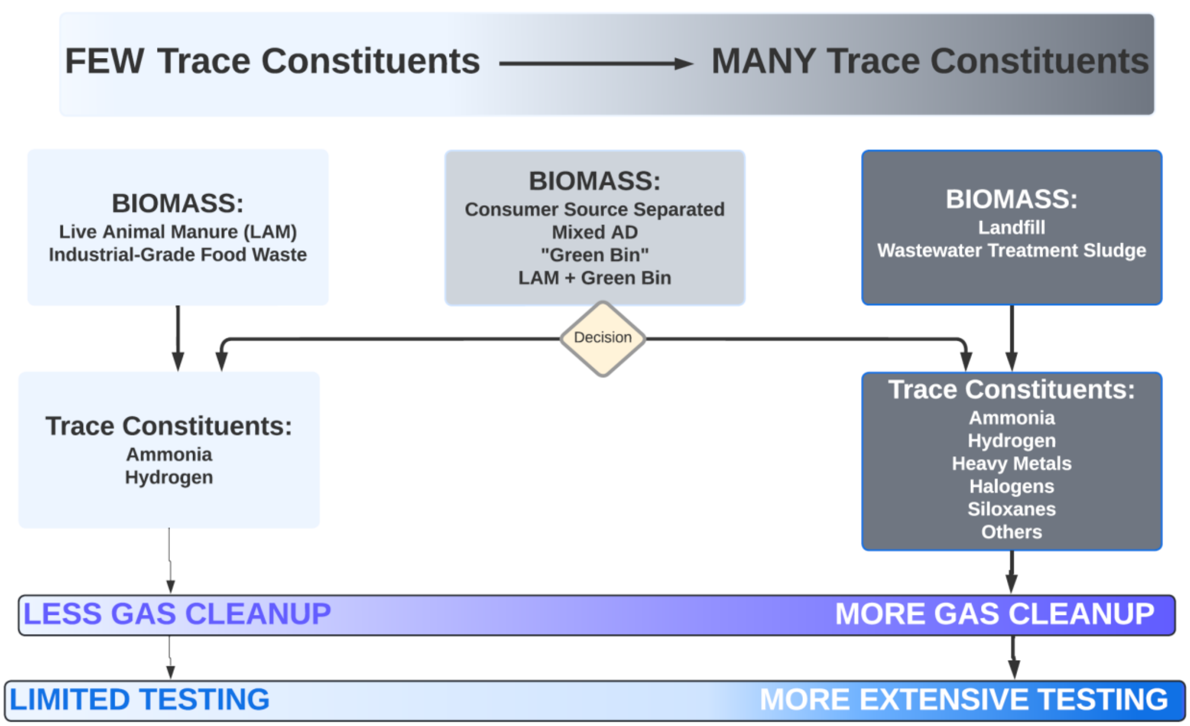
EXECUTIVE SUMMARY: TASK #2

REEthink, Inc. was retained by Louisville Gas & Electric Company (LGE) to prepare two Deliverables as part of their effort to introduce Renewable Natural Gas (RNG, biomethane) into their pipeline network. For the purposes of this Document, *biomethane* RNG only is described. The two Deliverables are:

1) A Task 1 Document: the *Renewable Natural Gas (Biomethane) Pipeline Quality Specifications and Guidance Document for Safe Introduction to the Pipeline Network*, with the purpose of establishing a common framework for the introduction of RNG (biomethane) from a variety of biogas sources (Live Animal Manure (LAM) anaerobic digestion (AD), AD of industrial-grade food waste/agricultural residues, "Green Bin" AD (GBAD), landfill gas, wastewater treatment (WWT) sludge AD, and combination systems) into existing LGE natural gas networks, and,

2) A Task 2 Document: the *RNG Quality Verification and Monitoring Programs*, with the purpose of creating a roadmap of verification and monitoring protocols, including testing schedules, so that all RNG entering the LGE pipeline network is of the required quality and meets all specifications detailed in Task 1.

Figure 1: Verification and Monitoring Program Complexity Based on Biomass Source



There is a shared and important need to understand RNG quality and the potential impacts of introduced gases to pipeline networks. RNG from all biogas waste streams should share a *common specification* (Task

1) within the company, so that there is unity and consistency throughout the company (LGE). In this way, RNG producers considering projects within the LGE network can anticipate the RNG quality required and can design their plants to accommodate the common specifications. In the long term, this will drive costs of RNG cleanup downwards and routinize RNG production systems. *Testing for specific constituents is dependent upon the source of the biogas*; Verification and Monitoring Programs therefore *vary by biogas origin* (Task 2). Modifications/variances to the RNG specifications and the Verification and Monitoring Programs are at the discretion of LGE, based upon project circumstances, destined end-use, and/or other project-specific objectives or waivers. Verification and Monitoring Programs have been created based upon the *source of the biogas* (Figure 1); it is clear that different biomass sources produce biogas of varying quality (few trace constituents to many trace constituents).

The RNG Quality Specifications are consistent within a company, but testing for trace constituents is based upon data which clearly shows that certain trace constituents are present or not present within the biogas. Landfill biogas contains far more trace constituents than farm residue AD biogas. Therefore, testing for trace constituents in cleaned farm residue RNG is limited, making the project less expensive and complicated overall. Likewise, testing of landfill RNG is more complex and expensive, due to the trace constituent profile in the gas.

The following Verification and Monitoring Programs are included in this Task 2 report:

- A Verification and Monitoring Program for Live Animal Manure (LAM) and Industrial-Grade Food Waste AD RNG (Attachment 3)
- A Verification and Monitoring Program for Landfill and WWT Sludge AD RNG (Attachment 4)

Biomass from GBAD and mixed waste AD programs, such as WWT sludge AD mixed with GBAD, should be carefully examined for assignment of the most appropriate Verification and Monitoring Program. Also included in this Task 2 report are RNG receipt requirements and instrument package obligations. The *LGE Renewable Natural Gas Pipeline Gas Quality Specification (Biomethane)* is included as Attachment 1, and the *LGE RNG Quality Parameters with Testing Methodology* are included in Attachment 2 of this document.

1. RNG RECEIPT REQUIREMENTS

1.1 In-Line Equipment Requirements

LGE should be prepared to install the following analytical equipment, or similar, to verify that the RNG from the production facility is of the quality required for introduction to the pipeline network (meets all specification requirements). The RNG producer shall have, attached to their conditioning system, their own set of analytical instrumentation and not rely on LGE's instrumentation for gas quality verification; they shall install their own system which verifies the gas PRIOR to release to LGE and the pipeline. It is the responsibility of the RNG production facility to ensure that the gas delivered to the LGE pipeline meets all specification requirements (Attachment 1). Many required tests are performed in real-time, with continuous analysis.

The intent of this equipment list is to support the use of on-line, real-time instrumentation to verify that gas quality is consistent and reproducible. Coordination and consistency between the RNG production facility and LGE is required with respect to instrumentation packages and expectations. Both LGE and the RNG producer seek to minimize discrepancies in analytical results, especially with respect to on-line instrumentation. Results from on-line analytical equipment readings will directly impact introduction of RNG to the LGE pipe; off-specification RNG will result in shut-in of RNG. The intent is for LGE and the

RNG producer to align their analytical strategy and conduct testing in harmony. Additional analytical equipment or modifications to this list are at the discretion of LGE. To be clear, a set of on-line instruments is the property of LGE, installed just prior to RNG injection to the pipeline and prior to odorization, and a set of on-line instruments is associated and owned by the RNG production facility.

On-Line, Real-time Analytical Equipment Required:

- Gas Chromatograph (GC) – 5-minute cycle; SCADA interface and programs for calculations for BTU, Wobbe, inerts (N_2, CO_2, etc.); C1-C6 measurement
- Oxygen Analyzer
- Sulfur Chromatograph (H_2S included) OR H_2S Analyzer only (laboratory testing for total sulfur)
- Water Vapor Analyzer
- Temperature Measurement

LGE Discretion (based upon RNG production facility circumstances and biogas profile):

- Redundant H_2S Analyzer
- Others as necessary

The above-mentioned additional on-line instrumentation may be necessary if major components or trace constituents in the cleaned RNG product are found to be consistently present (through laboratory testing) at levels which approach shut-in conditions. This may indicate that the conditioning unit is not robust enough to remove the constituents reliably. In order to avoid shut-in or increased laboratory testing of components, installation of additional on-line instrumentation may be necessary and is at the discretion of LGE.

The RNG producer shall install, maintain, and calibrate their above-mentioned analytical equipment according to the manufacturer's recommendations, and shall, upon request, grant LGE access to maintenance and calibration records. It is imperative that instrument calibration be timely and rigorous. On-line instrumentation serves as the basis of RNG verification, and proper calibration supports accurate reporting. The intent is for the RNG producer and LGE to harmonize their on-line instruments with regards to calibration and accuracy. Precision of the on-line instrumentation *can be* verified through sample collection and laboratory testing of split samples, if necessary; however, this is not required as part of this Program.

1.2 RNG Shut-In from Pipeline Network

All RNG entering the LGE network shall be: 1) continuously monitored for major components through on-line, real-time analysis, and, 2) tested for the presence of a set of trace constituents through scheduled, periodic field sample and off-site laboratory testing. NOTE: If, at a time when reliable on-line instrumentation for accurate measurement of specific trace compounds is available, LGE may elect to install a suitable on-line analyzer. However, *all parameters must always be within the designated analytical boundaries (Attachment 1) despite testing regime*. The shut-in procedures will be discussed in turn:

- On-line, Real-time Monitoring of RNG

With respect to on-line monitoring and analyses, RNG will be excluded from entering LGE's system ("shut-in" conditions) if any parameter, recorded in real-time, is measured outside of the specification limits (Attachment 1) for a period of testing which includes **3 consecutive test periods,** as recorded by LGE instrumentation. For the purposes of determining shut-in, all on-line parameters will be recorded at the same (or as close to the same) interval as the GC reading. For example, using a GC which records measurements at five (5) minute intervals, off-specification RNG would potentially be shut-in after a total of three (3) consecutive readings or ten (10) minutes (time zero, 5 minutes and 10 minutes). LGE's on-line instrumentation will be responsible for shut-in of RNG. The RNG producer shall be proactive in preventing off-specification RNG from entering the pipe which connects to the LGE system, in order to prevent shut-ins. It is advised that the RNG producer maintain its own automatic shut off/RNG diversion protocols, including use of flares, etc. Design of shut-in recirculation loops, pipeline evacuation schemes should be considered.

The RNG producer shall operate and maintain analytical equipment in accordance with good industry practice.

If parameters within the major components profile do not comply with RNG specifications, *where on-line, real-time monitoring is occurring on a continuous basis*, then RNG will be shut-in (see language above) until RNG production plant issues have been rectified. When the problem has been mitigated, the RNG will again be monitored continuously. RNG will be flared/diverted until there is clear assurance that the RNG quality problem has been resolved. Once the on-line instrumentation returns values which are in line with RNG specifications for a period of at least 3 consecutive test periods and up to an agreed upon time set by LGE, or until shut-in valves may be opened, the RNG may be injected into the LGE system.

- Field Sampling and Laboratory Testing

With respect to testing for trace constituents, field sampling and laboratory testing of RNG is necessary (on-line, real-time monitoring is not possible); the following protocol shall be executed. If the testing laboratory has returned results with analytical values outside the required specification limits, the RNG production plant will be immediately assessed. Refer to Table 1, below, for specification limits and immediate shut-in limit values:

1) If the value for any trace constituent is above the Specification Limit (Attachment 1), but **below** the Immediate Shut-in Limit, RNG will be immediately resampled/tested for that parameter (in triplicate, as described in Section 1.3) and RNG will not be shut-in. The RNG producer will make adjustments so that RNG quality is in line with the required Specification Limit. The intent is to allow RNG to flow into the LGE pipeline while modifications are made, in order to satisfy RNG Specifications. If, upon receipt of the second round of testing, the RNG is off-specification for the tested parameter (does not meet the Specification Limit), shut-in will occur until the production process has been corrected and the RNG quality is verified. RNG will be allowed to flow to the LGE pipeline *once the resulting value from the laboratory testing for the trace constituent meets the Specification Limit*.

2) If a value for any trace constituent is **above** the Immediate Shut-In Limit, the gas will be immediately shut-in. The RNG plant operations shall be corrected to meet the Specification Limit; RNG will be resampled as before (in triplicate) and results of testing will be expedited. RNG will be allowed to flow to the LGE pipeline *once the resulting value from the laboratory testing for the trace constituent meets the Specification Limit*.

3) However, under either scenario listed above (#1 or #2), the out-of-specification parameter will *return to a more stringent level of testing (**previous** Monitoring Period) for that trace constituent only*. The aim of this Program is to be flexible with respect to the RNG plant performance, while still maintaining high RNG quality standards.

TABLE 1: LGE RNG TRACE CONSTITUENT SHUT-IN LIMITS

PARAMETER	SPECIFICATION LIMIT*	IMMEDIATE SHUT-IN LIMIT	UNIT
Ammonia	0.001	0.003	% vol.
Hydrogen	0.1	0.3	% vol.
Siloxanes	0.5	1.0	mg Si/m3
Chlorine Total	10	25	mg/m3
Fluorine Total	10	25	mg/m3
Mercury	0.08	0.2	mg/m3
Arsenic	0.19	0.48	mg/m3
Copper	0.6	3.0	mg/m3
* This is the limit which RNG is required to consistently meet. Design of the conditioning unit is based on this value and consistent performance is expected at this level.			

For all instances (on-line testing and laboratory testing) when RNG is shut-in from LGE pipeline, the RNG producer shall promptly deliver to LGE a detailed report describing the cause of the out-of-specification parameter, steps which rectified the situation and an upgraded process/operation/maintenance plan to ensure that the situation does not occur again. Modifications to the Verification and Monitoring requirements are at the discretion of LGE.

1.3 Verification Laboratories

All trace constituent testing or testing which requires laboratory analysis (not measured through installed on-line analytical instrumentation) must be performed in accordance with good industry practice. Proper field sample collection, sample handling and preservation, sample packaging (cooling, etc.) and sample delivery must be performed with care, and individuals performing these tasks must be qualified and properly trained. A qualified sample collection team shall be contracted from an accredited laboratory/other for the field sampling process. It should be decided, before initiation of the project, where samples will be retrieved and who will collect the samples. It is highly recommended that the same sample collection team be used throughout the Verification and Monitoring program, to ensure consistency in sample collection. All samples shall be properly shipped to accredited laboratories for analysis; analyses shall be performed using the assigned methodology noted in Attachment 2 or equivalent analytical method, *if approved by LGE*. RNG producer shall inform LGE *in advance* of the time(s) and place(s) RNG producer will collect gas samples for analysis by a qualified, third-party laboratory, to allow LGE to observe such collection(s). RNG producer shall bear the cost of its own testing, and will reimburse LGE for the cost of any testing incurred by LGE. RNG producer shall provide the results of any testing to LGE at LGE's request, and LGE may audit such results.

All field samples shall be collected in TRIPLICATE. This means, for each sampling event, for each constituent, three samples are retrieved (concurrently or one right after the other in sequence). The results of the three samples are then AVERAGED. Additionally, there is NO OPTION to "throw out" one of the data points if it is excessively high or low unless it is approved by LGE. In the case of testing for components where the data is retrieved from the same analytical method, samples for these may be collected in TRIPLICATE, but tested together.

2. VERIFICATION AND MONITORING PROGRAMS

2.1 Introduction

Continuous and reliable production of high quality RNG is of upmost importance. As such, an important part of a biogas to high quality RNG project requires a period of careful examination of the product to be introduced to the natural gas pipeline grid. This period of examination serves the following purposes:

1. Provides confidence to LGE that the conditioning/cleanup system is reliable and operates consistently at high levels of performance.
2. Provides a dataset to LGE to support a level of confidence in the quality of the product delivered to the pipeline grid.
3. Provides operational security and predictability in the performance of the conditioning system.
4. Provides supportive data to both LGE and the RNG producer, so that gas quality can be verified.
5. Educates both LGE and the RNG producer as to the parameters, characteristics, and idiosyncrasies of the specific project, so that all understand and support the effort with transparency.

It is very important that LGE maintain high quality standards for gas introduced into the pipeline network. As such, major component parameters and trace constituent parameters shall be carefully examined. *Rigorous verification of gas quality should be considered as an integral part of the project rather than an unexpected "add on" to the project*. It is wise to remind the RNG producer of this program early in the planning process, so they can plan accordingly.

2.2 Goals of the Program

The LGE RNG Verification and Monitoring Program achieves 3 goals:

1) LGE is able to monitor consistent quality and routine production of the RNG product over a trial period of time (RNG Verification Phase),

2) The RNG provider/cleanup unit operator is able to verify that the product is consistent and safe for pipeline introduction, and,

3) All parties may better understand the changes required to the gas production process or gas injection system to optimize the introduction of RNG to the pipeline network.

2.3 Consideration of Biogas Source in Program Selection

This Task 2 report includes TWO Verification and Monitoring Programs; one is applicable to RNG received from projects which use "few trace constituents" biomass sources (LAM and/or industrial-grade food waste), and, one is applicable for "many trace constituents" biomass sources (landfill gas and wastewater treatment sludge AD) (See Figure 1). Some biomass sources are mixed, potentially containing few trace constituents and many trace constituents. These sources include consumer separated, municipal organic waste (Green Bin organics collection) or combined organic wastes from a variety of sources. Each is explained in turn.

2.3.1 "Few Trace Constituents" Biomass from LAM/Industrial-Grade Food Waste

Biogas generated from the digestion of waste materials from farm residues (manure from dairy, hog, sheep, feed cattle, etc., and other organic discards from farming operations), and/or industrial-grade food waste processing materials (food production wastes, slaughterhouse renderings, Fats, Oils and Grease (FOG), animal feeds, yogurt, cheese, whey production, wheat/bakery items, fruits, vegetables, potatoes and other *pre-consumer* products which are considered safe for consumption by humans or animals) is quite "clean"; in other words, few if any trace constituents are found even in raw biogas. Studies, including a study from GTI (2009), clearly show that siloxanes, selected pesticides, selected pharmaceuticals, heavy metals, halogenated compounds and problematic volatile/semi-volatile compounds are not found at levels which pose a risk to human health and the environment (NIOSH, OSHA, EPA), even in raw dairy waste biogas. It is for this reason that a more limited or reduced Verification and Monitoring Program is proposed. This Verification and Monitoring Program is NOT intended for other biogas sources, such as landfills and WWT sludge AD. Biogas from farm residues/industrial-grade food waste sources *only* do not require testing for many trace constituents because they are not present. RNG from co-mingled sources that have interfaced with humans should be additionally tested for halogens, siloxanes and heavy metals. Sourcing of biogas is very important to the success of this *reduced* Verification and Monitoring Program.

Biogas generated from the digestion of dairy or other live animal manure wastes, or co-digestion of industrial-grade food grade wastes or similar, should be highly "clean" of trace constituents which are problematic to human health and the environment, pipeline safety and end use equipment. The cleanup system (conditioning unit) has most likely been designed to accommodate a cleaner biogas source. The conditioning system will focus on removal of inert gases (carbon dioxide, oxygen, etc.) in order to increase the heating value of the gas, with accompanying systems to dry the gas (remove water) and deliver the gas at the appropriate temperature and pressure. However, and very importantly, in order to maintain a high quality of raw biogas, the digester **MUST be continuously free of any material, substance, feedstock, waste, etc. which is not of high quality**. Absolutely no wastes outside the boundary of farm residues or industrial-grade food waste can be accepted into the digester *unless assessed for appropriateness*. It is incumbent on LGE to secure an agreement with the digester company that only quality materials are accepted into the digester. LGE is to be notified by the RNG producer if the biomass material has changed, or new materials are added. The Verification and Monitoring Program for these biogas sources is reduced, in scope, time and cost.

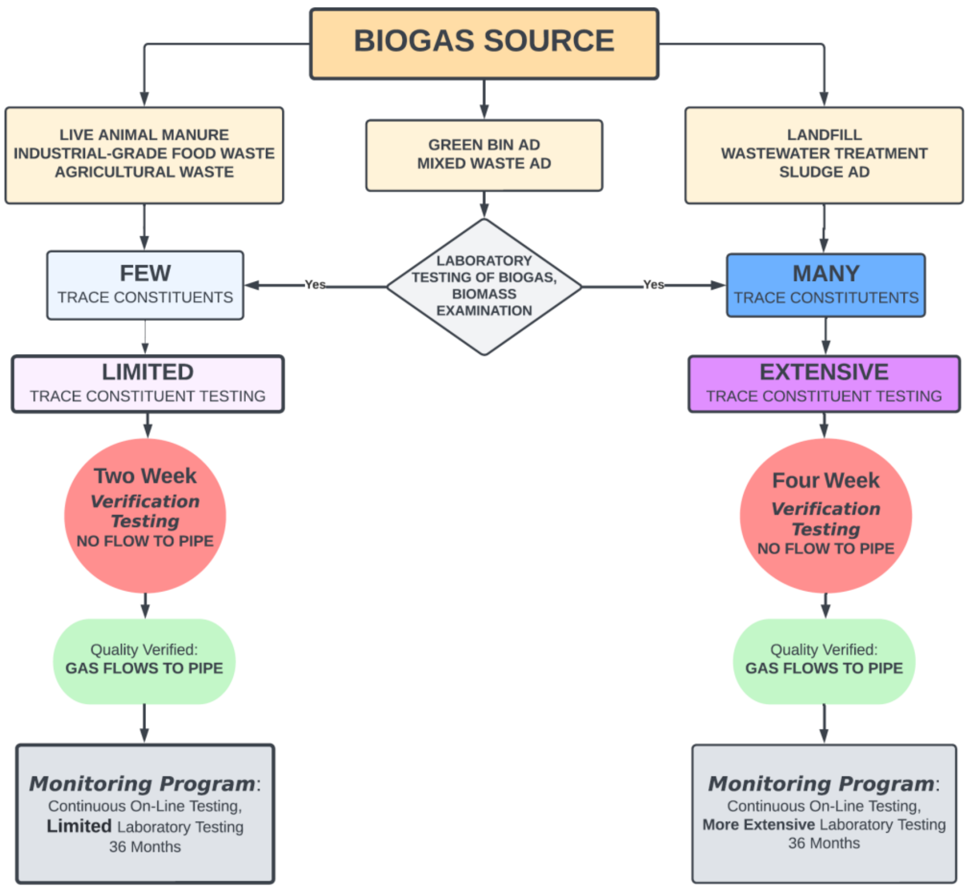
2.3.2 "Many Trace Constituents" Biomass from Landfills/WWT Sludge AD

The biogas sources of landfills and WWT sludge AD can be among the most complex raw materials to fully upgrade to pipeline quality RNG, suitable for the LGE system. Landfill gas can contain a wide variety of known and unknown constituents. Within the context of RNG production, landfill gas is particular because of its extensive trace constituent profile. Wastewater treatment sludge contains a wide variety of organics and inorganics from the processing of water which flows through the treatment plant. Anything which is flushed down toilets, released through industrial processing or collected during rain events is subject to digestion at the facility. Many compounds are present in the tank sludge; these compounds may be released during the anaerobic digestion process to produce methane. As such, biogas which is produced from wastewater treatment sludge is considered similar to landfill gas.

Hundreds of trace constituent compounds are found in landfill gas and WWT sludge AD biogas; not all of these constituents pose risk to the gas pipeline, end-use or human health and safety. It is particularly important to remove *selected sets* of trace constituents. Cleaned biogas/RNG from landfills and WWT sludge AD is NOT "free of all trace constituents." Rather, through the RNG cleanup process, the most impactful trace constituents are removed to currently-known "safe levels" or required levels. Identifying and targeting selected compounds is an evolving field. Research and field observation add to the body of data from which assessments are made. At the time of writing this document, researchers and the gas industry have limited data specific to long term impacts of RNG trace constituents on the pipeline (metal or plastic). Over time, RNG specifications may be revised and refined. Removal of trace constituents is expensive, and testing of resulting RNG is more extensive. Therefore, the industry wishes to target the most impactful trace constituents, while allowing for this new product to enter the pipeline grid safely.

A more extensive and robust Verification and Monitoring Program is designed for RNG derived from landfill biogas and WWT sludge digestion biogas.

Figure 2: Verification and Monitoring Plan by Biogas Source



2.3.3 Biomass from Green Bin Programs and Mixed Sources

Collection of waste organic materials is excellent for many reasons. Organics, despite source, will break down to methane under anaerobic (without air) conditions. However, consumer-separated organics or curbside collection programs also produce mixed results with respect to "clean organics." Municipal organic waste is defined as mixed organic wastes from "Green Bin" programs and other collection programs where interaction with humans or the public is possible. Municipal organic waste AD is often viewed similarly to landfills and WWT sludge AD because it has been shown that plastics, siloxane-containing products, and other materials co-mingled with the organics. Therefore, there are often concerns that problematic wastes (organics, metals, etc.) are inadvertently mixed with the starting biomass, and the degradation products of these mixed wastes are not as "clean" as supposed. Food scraps and organic materials collected from homes, businesses, schools, etc. and some high-grade energy crops may be impacted by products and wastes which produce trace constituents of concern. Inadvertently or purposely, other materials and undesirable wastes are mixed with the organics in the collection bins. Post-consumer, self-selected separation of organics can be problematic on many levels. Waste from general industry, including hazardous wastes of any type, municipal solid waste, personal care products, general household garbage, etc. cannot be accepted into the digester because the resulting RNG profile will change, and testing for additional trace constituents will be necessary. This is not trivial. Sourcing of biomass dictates which Verification and Monitoring Program is selected for RNG qualification. LGE risks compromise to RNG quality if biogas is not of upmost quality. Therefore, it is advised to thoroughly test the raw biogas/biomass prior to selection of the appropriate Verification and Monitoring Program. Testing of raw biogas does not necessarily indicate constituent profile in the final RNG process, however. A schematic summary is presented in Figure 2.

2.4 Overview: Phases of the Program

There are THREE distinct Phases of VERIFICATION AND MONITORING TESTING: 1) the RNG Plant Start-Up Phase (conditioning unit is running optimally and ready to be tested for performance), 2) the RNG Verification Phase (two or four weeks of rigorous RNG analytical testing, gas does not enter the pipeline), and, 3) Monitoring Periods 1 – 4 (RNG enters the pipeline continuously). The three Phases of testing, encompassing testing over a total of the first three (3) years (and beyond) of the project, are as follows:

1. **RNG PLANT START-UP PHASE** – the Phase just prior to rigorous gas testing and prior to gas entering the natural gas pipeline grid. This is the Phase during which the RNG producer is performing analytical testing of RNG, testing all components of their cleanup unit, coordinating, and harmonizing on-line analytical equipment with LGE, and preparing for the RNG Verification Phase. The time for this Phase is determined by the RNG producer, as it is the "shakedown" period for the RNG plant. The aim of this period is to assure the conditioning system is fully functioning as designed and meets all RNG quality requirements *prior* to testing by LGE. Disposal or fate of RNG produced during this time will be left to the discretion of the RNG producer, insuring that local, state, and federal regulations are being observed. The timeline for this Phase is at the discretion of the RNG producer.

   During this time, LGE may request that samples of *raw biogas* be tested for constituents listed in Attachment 1.

   Refer to Section 2.5.1. for details specific to this Phase.

2. **RNG VERIFICATION PHASE** – the first 2 or 4 weeks of RNG production; RNG is tested for complete quality by LGE, or by the RNG producer, and results shared with LGE for confirmation. The RNG production facility will concurrently monitor gas quality through on-line instrumentation and laboratory testing of samples for trace constituents. Depending upon the configuration of the analytical packages and agreement between parties, the RNG producer and LGE should compare analytical results and concur. RNG producer shall inform LGE *in advance* of the time(s) and place(s) RNG producer will collect gas samples for analysis by qualified third-party laboratories, to allow LGE to observe such collection(s). RNG producer shall bear the cost of its own testing and reimburse LGE for the cost of any testing incurred by LGE. RNG producer shall provide the results of any testing to LGE at LG&E's request, and LGE may audit such results. During this phase, gas is examined for quality, but does NOT enter the pipeline grid. In order to satisfy the requirements of this program and be prudent with RNG production, the entire RNG plant does not need to be running in order for this Phase of testing to occur, but the RNG producer

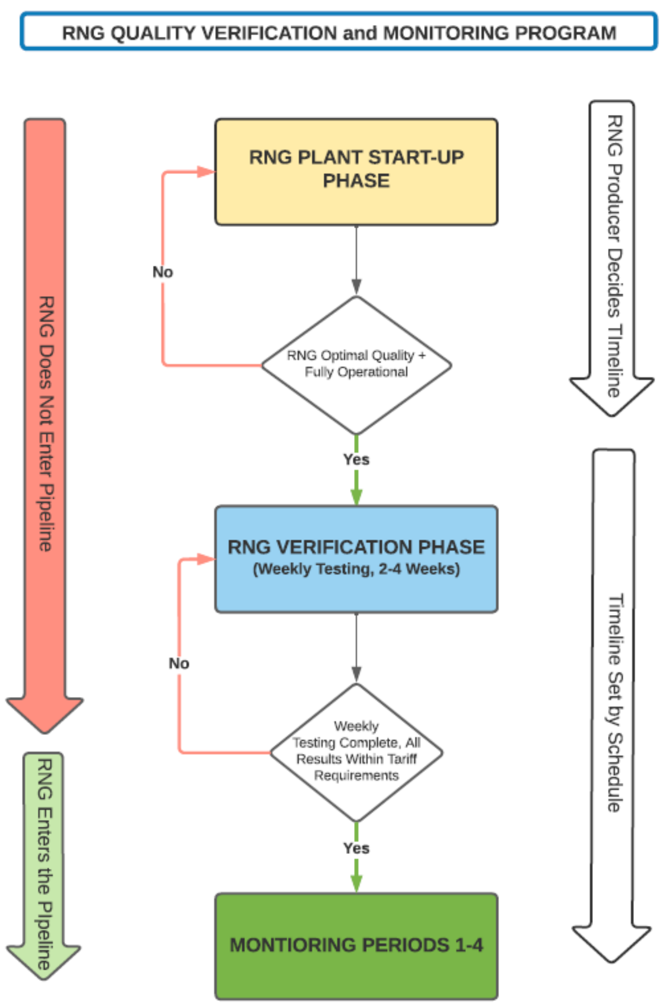
shall make reasonable efforts to produce RNG continuously with at least 70% uptime in order to be compliant with Phase. LGE requires 100% uptime for the final week of testing only. LGE may need to consider the location of the sampling port, the location of the GC and the recycle loop for RNG. Disposal or fate of RNG produced during this time will be left to the discretion of the RNG producer, ensuring that local, state and federal regulations are being observed.

Refer to Section 2.5.2. for details specific to this Phase.

3. **RNG MONITORING PERIODS**:
   a. Period 1 – Month 1 or 2 through 6 of the project
   b. Period 2 – Month 7 through 18 of the project
   c. Period 3 – Month 19 through 36 of the project
   d. Period 4 – Life of plant operations

Refer to Section 2.5.3.- 2.5.6 for details specific to these Phases. See Figure 3 for an overview of the components to the Program.

Figure 3: Three Phases of the Verification and Monitoring Program(s)



2.5 Details of RNG Plant Start-Up, Verification and Continued Monitoring Phases – Both Programs

2.5.1 RNG Plant Start-Up Phase

PRIOR to actual injection of the RNG to the natural gas pipeline grid, an **RNG PLANT START-UP** program shall be executed. This Phase applies to all biogas sources. It is during this time that the RNG producer/cleanup unit operator is completing the "shake-down" and testing of the gas conditioning unit, so that all components are performing optimally. During this Phase, the producer shall prepare and deliver to LGE an *RNG Plant Operation Document* which is comprised of the following, at a minimum:

1. A detailed description of the *anticipated RNG composition*:
   a. The anticipated RNG composition is prepared with strict adherence to the parameters of gas quality, described in the *LGE Renewable Natural Gas (Biomethane) – Pipeline Gas Quality Specifications*, Attachment 1.
   b. The description shall be the culmination of efforts towards fulfilling the requirements of the gas quality parameters, anticipating the profile of the RNG which is to be produced at the specific facility.
   c. In order to fulfill this requirement, the RNG must be fully tested for all components. The RNG producer shall consult the *LGE RNG Quality Parameters with Testing Methodology* matrix (Attachment 2). RNG producer shall inform LGE in advance of the time(s) and place(s) RNG producer will collect gas samples for analysis by third-party laboratories, to allow LGE to observe such collection(s). RNG producer shall bear the cost of its own testing, and reimburse LGE for the cost of any testing incurred by LGE. RNG producer shall provide the results of any testing to LGE at LGE's request, and LGE may audit such results.
2. A detailed list of anticipated maintenance procedures which necessitate planned RNG plant shut-down, even for a very short period of time.
3. A detailed description of contingency plans for plant disruptions, including key contact personnel, phone numbers and chains of command.
4. A listing of all gas analysis equipment and analysis cycles (time between analyses). Specifics pertaining to inspections, calibration and adjustments to the equipment on a regular basis shall be included.
5. Details of the remote transmittal of RNG quality data/flow data to LGE.
6. A detailed emergency plan, in case of system failure, fire, etc.
7. Details of the remote gas shut-in system (including process plan, schematics).
8. Details of the gas metering equipment.
9. Other details as requested by LGE, specific to the site.

RNG produced during this Phase *does not enter the pipeline* and there is no penalty to the producer/operator if the RNG does not meet specifications. Disposal or fate of RNG produced during this time will be left to the discretion of the RNG producer, insuring that local, state and federal regulations are being observed. This Phase of the venture allows the RNG producer the flexibility to fully assess the RNG Plant and modify engineering, equipment, etc. to meet the demands of the overall project. The length of time for this Phase is variable and depends upon the ability of the RNG producer to yield an RNG product which reliably meets the requirements for gas quality and provide the comprehensive above-mentioned documentation to LGE.

2.5.2 RNG Verification Phase (Two or Four Weeks of Testing)

The **RNG VERIFICATION PHASE** of the program is critical, as it is the period in which the RNG is carefully analyzed for suitability for the pipeline grid, as per the objectives specified in the *LGE RNG*

Quality Parameters with Testing Methodology matrix (Attachment 2). **Depending upon source biogas**, the schedule for testing and protocols are specified in Attachment 3 (*LAM and Industrial-Grade Food Waste AD*) or Attachment 4 (*Landfill/WWT Sludge AD*). An evaluation must be made as to the most appropriate testing program for the sources of municipal organic waste (GBAD) and mixed waste AD systems. It is important to review the biogas source before schedule selection; testing of biomass sources and thorough investigation may be necessary. During the RNG Verification Phase, RNG shall be tested EVERY WEEK (for 2 or 4 weeks, depending upon biogas source) for all parameters *listed in the matrix for that biogas source*, with continuous on-line testing and laboratory testing. The RNG Verification Phase shall include the period of time for *all analytical results to be received and reviewed by all parties*. During the RNG Verification Phase, no RNG produced by the RNG plant is available for sale or commercial use. During this time, gas is critically assessed for all parameters, but the gas *does not enter the pipeline network*. Some analyses, particularly of parameters which are listed under Major Components, will be monitored in real-time, using on-line instrumentation which records and reports continuously. Parameters which are listed in the Trace Constituents category will be sampled post-conditioning, prior to the odorization unit, and sent to accredited analytical laboratories. ALL SAMPLES WILL BE COLLECTED IN TRIPLICATE for *independent laboratory analysis*. Of note: turn-around time for some analyses can be lengthy; expedited analysis is recommended if possible.

RNG shall not enter the natural gas pipeline grid until the **full** RNG Verification Phase testing has been completed and verified by LGE, or at the discretion of LGE. If, at any time, the gas does not meet the requirements set forth in Attachment 1, testing shall continue on a weekly basis until the two or four consecutive weeks of results are in alignment with all RNG specification values and RNG shall not enter the pipeline grid. During this RNG Verification Phase, it is recommended that the RNG be flared, until the RNG Verification Phase is completed, with all sample data returned and reviewed. Attachments 3 and 4 of this Document detail the number of sampling events and samples to be retrieved and analyzed for each Phase of the program, depending upon the source biogas. It is anticipated that this RNG Verification Phase, with turn-around of samples, should take a minimum of 6-8 weeks for the biogas sources of landfill, WWT sludge AD (and GBAD/mixed waste AD, if appropriate), but the program is shortened substantially with respect to the biogas sources of LAM and industrial-grade food waste AD. LGE reserves the right to extend or shorten the testing period, depending upon sample turn-around times from the laboratories.

2.5.3 Monitoring Period 1, Month 1 or 2 – 6 (After RNG Verification)

During the **MONITORING PERIOD 1 (Month 1 or 2 – 6)**, samples are recorded continuously or samples are retrieved as per the schedules set forth in Attachments 3 and 4. For the biogas sources of LAM and industrial-grade food waste AD, sample collection is MONTHLY for 6 months; for the biogas sources of landfill and WWT sludge AD, sample collection is BI-WEEKLY, for the entire Monitoring Period. Biogas sources of GBAD and mixed waste AD must be examined for appropriateness to program guidelines. Total count for all sampling events, all parameters are noted in the Tables in Attachments 3 and 4. Please refer to Section 1.2 for details specific to shut-in and start-up conditions.

2.5.4 Monitoring Period 2, Month 7 - 18

Upon successful completion of Monitoring Period 1, the RNG will be monitored with a less stringent frequency for an additional 12 months (**MONITORING PERIOD 2**). During this Monitoring Period, for the biogas sources of LAM and industrial-grade food waste AD, laboratory testing will occur QUARTERLY; for the biogas sources of landfill and WWT sludge AD, sample collection will occur MONTHLY, with the exception of hydrogen sampling and testing, which will be on a quarterly basis (every three months). Biogas sources of GBAD and mixed waste AD must be examined for appropriateness to program guidelines. However, continuous, on-line testing will continue, as noted in the schedules (Attachments 3 and 4). Total count for all sampling events, all parameters are noted in the Tables in Attachments 3 and 4. Please refer to Section 1.2 for details specific to shut-in and start-up conditions.

2.5.5 Monitoring Period 3, Month 19 - 36

For an additional 1½ years (18 months) post Month 18 of Monitoring Period 2, laboratory testing of RNG will continue at a reduced schedule (**MONITORING PERIOD 3**). During this Monitoring Period, for the biogas sources of LAM and industrial-grade food waste AD, laboratory testing will occur BI-ANNUALLY (every 6 months); for the biogas sources of landfill and WWT sludge AD, testing will occur QUARTERLY (every 3 months) for all constituents except for mercury and hydrogen, which is tested BI-ANNUALLY. However, continuous, on-line testing will continue, as noted in the schedules (Attachments 3 and 4). Total count for all sampling events, all parameters are noted in the Tables in Attachments 3 and 4. Please refer to Section 1.2 for details specific to shut-in and start-up conditions.

2.5.6 Monitoring Period 4, Length of System Operations

MONITORING PERIOD 4 exists for the length of the time the RNG plant is in operation. For all biogas sources, on-line, continuous sampling will record all major components data in real-time in perpetuity, and trace constituent sampling will occur every year, ANNUALLY. Total count for all sampling events per year, all parameters are noted in the Tables in Attachments 3 and 4. Please refer to Section 1.2 for details specific to shut-in and start-up conditions.

IMPORTANT NOTE: RNG producer shall notify LGE of any significant upsets, expansions or process changes in the RNG production or treatment in advance of the change or immediately upon discovery. LGE will, at its sole discretion, determine whether additional sampling (or accelerated periodic sampling) for trace constituents is warranted, either based on RNG producer's notification or LGE's own observations. Upon LGE's request, RNG producer will collect samples, per the appropriate protocols outlined in this document, within 24 hours of the upset, expansion, or process change, and send them for immediate analysis, at RNG producer's sole expense. Refer, above, to language regarding to specific to shut-in conditions; shut-in conditions vary between on-line, real-time testing of components and laboratory analyzed samples. Sampling methods and analytical test methods may be modified or changed over time, based upon updates in test methods and technology. Any changes in test methods for trace constituents must be approved by LGE.

2.6 Other Considerations

1. At no time and at no point in the gas cleanup process is natural gas to be co-mingled with the RNG in order to dilute or enhance the quality of the final product to be added to the pipeline.
2. The RNG must enter the pipeline grid at the required pipeline pressure.
3. RNG will be odorized by LGE.
4. If the biomass source changes or other sources of biomass are added to the AD system, the gas should be thoroughly tested for the presence of additional trace constituents. The Verification and Monitoring Program designed for "few trace constituent" biomass is never to be used for sources which may possess compromised biomass.
5. Bacteria is categorized as a "particulate matter". Therefore, it falls under the category of Objectionable Material. As a particulate, an in-line filter is required for filtration, as is typical in natural gas operations. To monitor total corrosion, an Extended Analysis/Electron Microscope (EA/EM) Corrosion Coupon may be installed.

6. Trace constituent testing can be time consuming and costly. Please plan accordingly. Trace constituent testing can be influenced by weather and temperature, and requires trained professionals. Installation of a manifold for sample collection is recommended.
7. LGE reserves the right to alter the monitoring program, depending upon the success in maintaining a constant and high-quality gas profile over time. This applies to additional projects executed by the same RNG producer, using the same biogas source.
8. Reduction in the Verification and Monitoring Program may be considered if the RNG producer completes ONE FULL PROGRAM (3 years), with a given biomass source. A reduced Verification and Monitoring Program may be considered for that producer **only**, **using identical biomass**, on a new project with LGE.

ATTACHMENT 1

LGE Renewable Natural Gas
Pipeline Gas Quality Specification (Biomethane)

LGE Renewable Natural Gas Pipeline Quality Specification (Biomethane)			
PARAMETER	**ABBREVIATION**	**Tariff Limit (min./max.) or Assigned Value**	**UNIT**
MAJOR COMPONENTS			
Heating Value[1]	HV	970 min.	BTU/scf
Wobbe Number[1]		1314 min.	BTU/scf
Carbon Dioxide	CO2	2.0 max.	% vol.
Oxygen	O2	0.2 max.	% vol.
Nitrogen	N2	2.0 max.	% vol.
Total O2 + N2		2.75 max.	% vol.
Total O2 + N2 + CO2		4.0 max.	% vol.
Hydrogen Sulfide	H2S	0.25 max.	grains/100scf
Total Sulfur	S	5.0 max.	grains/100scf
Water Content	H2O	4.0 max.	lbs/MMscf
Temperature		<120° and >40°	Fahrenheit
Particulate Matter/Objectionable Materal		Commerically free of....	
TRACE CONSTITUENTS			
Ammonia[2,3]	NH3	0.001 [6]	% vol.
Hydrogen[2,3]	H2	0.1	% vol.
Siloxanes[1]	Si	0.5	mg Si/m3
Chlorine Total[4, 5]	Cl	10	mg/m3
Fluorine Total[4,5]	F	1*	mg/m3
Mercury [2,3]	Hg	0.08	mg/m3
Arsenic [2,3]	As	0.19 [7]	mg/m3
Copper [2,3]	Cu	0.6 [8]	mg/m3

FOOTNOTE REFERENCES/CONVERSIONS

[1]CCST Report, June, 2018
[2] Rule 21, PG&E
[3] Rule 45, SoCal
[4] CGA, 2011
[5]BNQ 3672-100/2012; update to follow
[6]10 ppmv
[7]0.06 ppmv
[8]0.23 ppmv
* This value will increase with the next issue of the BNQ (2023): 10 mg/m3

ATTACHMENT 2

LGE RNG Quality Parameters
with Testing Methodology

LGE RNG QUALITY PARAMETERS WITH TESTING METHODOLOGY[1]							Testing Required: Biogas Source			X= Testing Required	
Gas Quality Constituent	Reference	Specific Tariff Limit or Assigned Value	Laboratory Test Sampling Method[1]	Field Instrument/Laboratory Analytical Method[1]	Sampling Material or Devise for Laboratory Analysis	Comments	Landfill	WWT Sludge AD	Mixed Waste AD[2]	LAM, IGFW[3]	Muni. Organic Waste[4]
High Heating Value (HHV)	Reference 5	970 BTU/scf	Online Gas Chromatography - LGE Approved; Calculation	ASTM D3588	NA	Standard Procedure	X	X	X	X	X
Wobbe Number	Published Tariff	1314 BTU/scf	Calculation	ASTM D3588	NA	Standard Procedure	X	X	X	X	X
Carbon Dioxide (CO2)	Published Tariff	2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946	Steel Cylinder	Standard Procedure	X	X	X	X	X
Oxygen (O2)	Published Tariff	0.2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 in laboratory; various online for field analysis	Steel Cylinder	Standard Procedure	X	X	X	X	X
Nitrogen (N2)	Published Tariff	2 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946	Steel Cylinder	Standard Procedure	X	X	X	X	X
Total O2 + N2	Published Tariff	2.75 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 plus total from O2	Steel Cylinder	Standard Procedure, add inerts	X	X	X	X	X
Total Inerts (CO2+N2+O2)	Published Tariff	4 vol%	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D1945/D1946 plus total fror	Steel Cylinder	Standard Procedure, add all inerts	X	X	X	X	X
Hydrogen Sulfide	Published Tariff	.25 grains/100scf	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D6228/D5504/various online for field analysis	Sulfinert Steel Cylinder	Standard Procedure	X	X	X	X	X
Total Sulfur Compounds, as sulfur	Published Tariff	5 grains/100scf	Gas Chromatography/Thermal Conductivity Detector or online analyzer	ASTM D6228/D5504/various online for field analysis	Sulfinert Steel Cylinder	Standard Procedure	X	X	X	X	X
Water Content	Published Tariff	4 lbs/MMscf	Online Analyzer	ASTM D1142 or ASTM D5454	Hygrometer	Standard Procedure	X	X	X	X	X
Delivery Temperature	Published Tariff	<120 and >40 Fahrenheit	Online Analyzer	RTD in meter tube thermo well or similar/company preference	Continuous Online	Temperature of the injection gas	X	X	X	X	X
Particulates/Biologicals	Ref. 1, 2	Commerically Free Of…				In-line filter recommended prior to gas introduction; Total corrosion can be monitored by EA/EM in-line coupon	X	X	X	X	X
Ammonia	Ref. 3, 4	0.001 vol% 10 ppmV	AAS/Ion Chromatography	OSHA ID-188 NIOSH 6015 EPA M26	Glass Tubes Glass Tubes Mod. EPA Method 26 (Impingers)	Analytical Method pairs with Sampling Method; EPA Method is impinger method	X	X	X	X	X
Hydrogen	Ref. 3, 4	0.1 Vol %	Gas Chromatography/Thermal Conductivity Detector	ASTM D1945/D1946	Tedlar Bag/Cylinder/Check with your Laboratory	Specific to pipeline integrity	X	X	X	X	X
Siloxanes	Ref. 5	0.5 mg Si/m3	Gas Chromatography/Mass Spectrometry	ASTM D8230-19	Tedlar bag - Analysis within 72 hours; Sample cylinder - check with your laboratory for holding times, options	ASTM recently approved method	X	X	(X)[6]		(X)[6]
Halocarbons - Halogens	Ref. 6, 7, 8	Chlorine: 10 mg/m3 TOTAL Fluorine: 1 mg/m3 TOTAL to be updated	Gas Chromatography/Mass Spectrometry	EPA TO-15[5]	5-L Tedlar Bag; Summa Canisters. Impinger method in field: EPA Method 26/26A	**Impinger method preferred**. However, total Cl and F can also be quantified from TO-15 results.	X	X	(X)[6]		(X)[6]
Mercury	Ref. 3, 4	0.08 mg/m3	Atomic Adsorption Spectroscopy	ASTM D5954	Gold Plated Silica Beads		X	X	(X)[6]		(X)[6]
Arsenic	Ref. 3, 4	0.19 mg/m3 or 0.06 ppmv	Atomic Adsorption Spectroscopy/ICAP	EPA Method 29 Modified	EPA Method 29		X	X	(X)[6]		(X)[6]
Copper	Ref. 3, 4	0.60 mg/m3 or 0.23 ppmv	Atomic Adsorption Spectroscopy/ICAP	EPA Method 29 Modified	EPA Method 29		X	X	(X)[6]		(X)[6]

Specification References

Reference 1	GTI, Feb. 2009
Reference 2	GTI, Dec. 2009
Reference 3	Rule 45, SoCal
Reference 4	Rule 29, PG&E
Reference 5	CCST, 2018
Reference 6	MarcoGaz, AFSSET, 2006
Reference 7	CGA, 2011
Reference 8	BNQ 3672-100/2012 to be updated

[1]Sampling methods and analytical testing methods for trace constituents may be updated over time. Alternative methods must be approved by LGE.

[2] Mixed Waste AD=organics from a variety of sources of unknown quality (i.e, WWT sludge+muni. organic waste, etc.); must verify biogas to qualify for reduced Ver. Testing

[3] Includes LAM AD, Industrial-Grade Food Waste (IGFW) AD or a combination of these sources only.

[4] Includes collection of organics from community programs, "green bin" programs/consumer separated organic wastes.

[5]TO-15 with calculation for total chlorine and fluorine, considering molecular weight and % of total compound, unless impinger method is used.

[6] (X)=Careful examination of incoming organics to the digester; *reduced program approved ONLY if incoming organics/biogas proven free of trace constituents in LGE Specification* ; LGE may verify.

ATTACHMENT 3

LGE RNG Verification and Monitoring Program Guidelines for Injection to the Natural Gas Pipeline Grid: LAM and Industrial-Grade Food Waste AD

MAJOR COMPONENTS TABLE

TRACE CONSTITUENTS TABLE

BIOGAS SOURCES OF LIVE ANIMAL MANURE/INDUSTRIAL GRADE FOOD WASTE AD ONLY

LGE VERIFICATION and MONITORING PROGRAM GUIDELINES FOR INJECTION TO THE NATURAL GAS PIPELINE GRID - LAM and INDUSTRIAL-GRADE FOOD WASTE AD

	MAJOR COMPONENTS ONLY											
COMPONENT	HHV	WOBBE NUMBER	CARBON DIOXIDE	OXYGEN	NITROGEN	TOTAL O2 + N2	TOTAL CO2+O2+N2	HYDROGEN SULFIDE	TOTAL SULFUR	WATER CONTENT	DELIVERY TEMPERATURE	PARTICULATE MATTER
Specification Limit	970 BTU/scf Min.	1314 BTU/scf Min.	2.0% Vol.Max.	0.2% Vol.Max.	2.0% Vol. Max.	2.75% Vol. Max.	4.0% Vol. Max.	0.25 grains/100scf Max.	5.0 grain/100scf Max.	4.0 lbs/MMscf Max.	<120 and >40 Degrees F.	Commerically Free Of...
Reference Method*	ASTM D3588	ASTM D3588	ASTM D1945/D1946	ASTM D1945/D1946	ASTM D1945/1946	ASTM D1945/D1946	ASTM D1945/D1946	ASTM D6228/D5504	ASTM D6228/D5504	ASTM D1142 or ASTM D5454	RTD in meter tube thermo well	In-Line Filter as per Protocol
Sampling Method*	Online Calculation*	Online Calculation*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	
PLANT START-UP												
RNG Plant Operation Document	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
RNG VERIFICATION PHASE (Two Weeks)												
Start-up Testing WEEK 1:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	
Start-Up Testing WEEK 2:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	
No. of Start-up Sampling Events	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Check Filter at Completion**
MONITORING PERIOD 1 (MONTH 1 - 6)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 2 (Month 7 - 18)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 3 (Month 19 - 36)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 4 (Legnth of Project)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter Annually

***Approved LGE instrumentation and methodology only**

Y = Yes, continuous testing

NOTE 1 : If any parameter measured through Continuous Testing *exceeds* the tariff limit or assigned value over 3 testing periods, **immediate shut-in of the RNG will occur**. Gas must be flared, etc. by the RNG producer until the situation has been recified and the producer can verify gas quality standards. Proposed alternative test methods must be approved by LGE. LGE reserves the right to modify this program based upon testing results. Continuous testing will always remain continuous.

NOTE 2: Live Animal Manure is dairy/hog/other animal manure. Industrial Grade Food Waste is organic material derived from food production for consumption (human or animal). This food comes directly from the production facility and has not been handled by humans, etc. It is the direct residuals of food creation/processing and is pre-consumer. Agricultural residuals may be included. "Green Bin" (GBAD) and mixed waste AD programs are NOT included in this category. Green Bin programs are POST CONSUMER ORGANIC WASTE and self-segregated waste. This waste can be tested for appropriateness to this Verification and Monitoring Program, but thorough testing of organics must be performed prior to approval of this limited Verification and Monitoring Program.

BIOGAS SOURCES OF LIVE ANIMAL MANURE/INDUSTRIAL GRADE FOOD WASTE AD ONLY

LGE RNG VERIFICATION and MONITORING PROGRAM GUIDELINES FOR INJECTION TO THE NATURAL GAS PIPELINE GRID - LAM and INDUSTRIAL GRADE FOOD WASTE AD

	TRACE CONSTITUENTS	
	PARAMETER and TESTING BY THIRD PARTY LABORATORIES	
COMPONENT	**AMMONIA**	**HYDROGEN**
Specification Limit*	0.001% Vol	0.1% Vol
Analytical Method (Laboratory Testing)*	OSHA ID-188	ASTM D1945/D1946
PLANT START-UP		
RNG Plant Operation Document	Y	Y
RNG VERIFICATION PHASE (2 weeks)		
Start-up Testing WEEK 1: (1 Event x Triplicate Samples)	1	1
Start-Up Testing WEEK 2 : (1 Event per Week x Triplicate Samples)	1	1
Verification Sample Events**	**2**	**2**
MONITORING PERIOD 1 (MONTH 1 - 6)		
Monthly (Once a Month)	6	6
Total Monitoring Period 1 Sample Events**	**6**	**6**
MONITORING PERIOD 2 (Month 7 - 18)		
Quarterly (Every Three Months)	4	4
Total Monitoring Period 2 Sample Events**	**4**	**4**
MONITORING PERIOD 3 (Month 19 - 36)		
Bi-Annually (Twice Yearly)	2	2
Total Monitoring Period 3 Sample Events**	**2**	**2**
MONITORING PERIOD 4 (Length of Project)		
Annual Check **	**1**	**1**

***Approved LGE instrumentation and methodology only**

** During each sampling event, samples taken in TRIPLICATE for each parameter.

NOTE 1: RNG producer shall notify LGE of any significant upsets, expansions or process changes in the RNG production or treatment in advance of the change or immediately upon discovery. LGE will, at its sole discretion, determine whether additional sampling (or accelerated periodic sampling) for trace constituents is warranted, either based on RNG producer's notification or LGE's own observations. Upon LGE's request, RNG producer will collect samples, per the appropriate protocols outlined in this document, within 24 hours of the upset, expansion, or process change, and send them for immediate analysis, at RNG producer's sole expense. Refer to LGE RNG Verification and Monitoring Program specific to shut-in conditions; shut-in conditions vary between on-line, real-time testing of components and laboratory analyzed samples. REFER TO FULL REPORT FOR DETAILS OF TESTING: LGE RNG Verification and Monitoring Program. Sampling methods and analytical test methods may be modified or changed over time, based upon updates in test methods and technology. Any changes in test methods for trace constituents must be approved by LGE.

NOTE 2 : If the producer is able to complete one FULL LGE RNG Verification and Monitoring Program to the satisfaction of LGE, with all data in line with required gas specifications, subsequent project Verification and Monitoring Programs may be reduced for this RNG producer only and for the same biomass source. This applies to programs with same biomass source only. LGE reserves the right to reduce the Verification and Monitoring Program at any time, based on continuing high performance and adherence to the gas quality specifications. If parameters are continuously within specification values, variances may be allowed.

ATTACHMENT 4

LGE RNG Verification and Monitoring Program Guidelines for Injection to the Natural Gas Pipeline Grid: Landfill/WWT Sludge AD

MAJOR COMPONENTS TABLE

TRACE CONSTITUENTS TABLE

BIOGAS SOURCES OF LANDFILL/WWT SLUDGE AD/(GBAD, MIXED WASTE AD)

LGE RNG VERIFICATION and MONITORING PROGRAM GUIDELINES FOR INJECTION TO THE NATURAL GAS PIPELINE GRID - LANDFILL/WWT SLUDGE AD/(GBAD, MIXED WASTE AD)

	MAJOR COMPONENTS ONLY											
COMPONENT	**HHV**	**WOBBE NUMBER**	**CARBON DIOXIDE**	**OXYGEN**	**NITROGEN**	**TOTAL O2 + N2**	**TOTAL CO2+O2+N2**	**HYDROGEN SULFIDE**	**TOTAL SULFUR**	**WATER CONTENT**	**DELIVERY TEMPERATURE**	**PARTICULATE MATTER**
Specification Limit	970 BTU/scf Min.	1314 BTU/scf Min.	2.0% Vol.Max.	0.2% Vol.Max.	2.0% Vol. Max.	2.75% Vol. Max.	4.0% Vol. Max.	0.25 grains/100scf Max.	5.0 grains/100scf Max.	4.0 lbs/MMscf Max.	<120 and >40 Degrees F.	Commercially Free Of
Reference Method*	ASTM D3588	ASTM D3588	ASTM D1945/D1946	ASTM D1945/D1946	ASTM D1945/1946	ASTM D1945/D1946	ASTM D1945/1946	ASTM D6228/D5504	ASTM D6228/D5504	ASTM D1142 or ASTM D5454	RTD in meter tube thermo well	In-Line Filter as per Protocol
Sampling Method*	Online Calculation*	Online Calculation*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	Online Analyzer*	
PLANT START-UP												
RNG Plant Operation Document	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
RNG VERIFICATION PHASE (Month 1)												
Start-up Testing: WEEK 1:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	
Weekly Testing: WEEKS 2 - 4:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	
No. of Start-up Sampling Events	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Continuous**	**Check Filter at Completion**
MONITORING PERIOD 1 (MONTH 2 - 6)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 2 (Month 7 - 18)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 3 (Month 19 - 36)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter at End of Period
MONITORING PERIOD 4 (Legnth of Project)												
Continuous	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Check Filter Annually

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Y = Yes, continuous testing

***NOTE 1*:** If any parameter measured through Continuous Testing exceeds the tariff limit or assigned value over 3 testing periods, **immediate shut-in of the RNG will occur**. Gas must be flared, etc. by the producer until the situation has been recified and the producer can verify gas quality standards. Proposed alternative test methods must be approved by LGE. LGE reserves the right to modify this program based upon testing results. Continuous testing will always remain continuous.

NOTE 2: If the RNG producer is able to complete one FULL LGE Verification and Monitoring Program to the satisfaction of LGE, with all data in line with required gas specifications, subsequent project Verification and Monitoring Programs may be substantially reduced. This applies to programs with same biomass source. LGE reserves the right to reduce the Verification and Monitoring Program at any time, based on continuing high performance and adherence to the gas quality specifications. If parameters are continuously within specification values, variances may be allowed.

***NOTE 3*:** GBAD = Green Bin Anaerobic Digestion. This is the digestion of organic waste that originates from community "Green Bin" programs, etc. where interface with human consumption has occurred. Organic wastes which have come in direct contact with consumers, self-segregated wastes and community collection programs, etc. are included. This organic waste is assumed to be similar in profile with landfill/WWT sludge, **unless tested and proved otherwise**. Mixed waste AD is also included in this group. Mixed waste AD is the digestion of a combinations of biomass sources, such as WWT sludge mixed with Green Bin organics, etc.

BIOGAS SOURCES LANDFILL/WWT SLUDGE AD/(GBAD, MIXED WASTE AD)

LGE RNG VERIFICATION and MONITORING PROGRAM GUIDELINES FOR INJECTION TO THE NATURAL GAS PIPELINE GRID - LANDFILL/WWT SLUDGE AD/(GBAD, MIXED WASTE AD)

	TRACE CONSTITUENTS							
	PARAMETER and TESTING BY THIRD PARTY LABORATORIES*							
COMPONENT	**AMMONIA**	**HYDROGEN**	**SILOXANES**	**CHLORINE: TOTAL**	**FLUORINE: TOTAL**	**MERCURY**	**ARSENIC**	**COPPER**
Specification Limit*	0.001% Vol	0.1% Vol	0.5% mg SI/m3	10 mg/m3	1 mg/m3	0.08 mg/m3	0.19 mg/m3 or 0.06 ppmV	0.60 mg/m3 or 0.23 ppmv
Analytical Method (Laboratory Testing)*	OSHA ID-188	ASTM D1945/D1946	ASTM D8230-19	EPA TO-15	EPA TO-15	ASTM D5954	EPA Method 29 Modified	EPA Method 29 Modified
PLANT START-UP								
RNG Plant Operation Document	Y	Y	Y	Y	Y	Y	Y	Y
RNG VERIFICATION PHASE (Month 1)								
Start-up Testing WEEK 1: (1 Event x Triplicate Samples)	1	1	1	1	1	1	1	1
Weekly Testing WEEKS 2 - 4: (1 Event per Week x Triplicate Samples)	3	3	3	3	3	3	3	3
Verification Sample Events**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
MONITORING PERIOD 1 (MONTH 2 -6)								
Bi-Weekly (Every Other Week, Total Count)	10	10	10	10	10	10	10	10
Total Monitoring Period 1 Sample Events**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**
MONITORING PERIOD 2 (Month 7 - 18)								
Monthly (Once a Month)	12		12	12	12	12	12	12
Quarterly (Every Three Months)		4						
Total Monitoring Period 2 Sample Events**	**12**	**4**	**12**	**12**	**12**	**12**	**12**	**12**
MONITORING PERIOD 3 (Month 19 - 36)								
Quarterly (Every Three Months)	4		4	4	4		4	4
Bi-Annually (Twice Yearly)		2				2		
Total Monitoring Period 3 Sample Events**	**4**	**2**	**4**	**4**	**4**	**2**	**4**	**4**
MONITORING PERIOD 4 (Length of Project)								
Annual Check **	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

*** Approved LGE instrumentation and methodology only**

** During each sampling event, samples taken in TRIPLICATE for each parameter.

NOTE 1: RNG producer shall notify LGE of any significant upsets, expansions or process changes in the RNG production or treatment in advance of the change or immediately upon discovery. LGE will, at its sole discretion, determine whether additional sampling (or accelerated periodic sampling) for trace constituents is warranted, either based on RNG producer's notification or LGE's own observations. Upon LGE's request, RNG producer will collect samples, per the appropriate protocols outlined in this document, within 24 hours of the upset, expansion, or process change, and send them for immediate analysis, at RNG producer's sole expense. Refer to LGE Verification and Monitoring Plan specific to shut-in conditions; shut-in conditions vary between on-line, real-time testing of components and laboratory analyzed samples. REFER TO FULL REPORT FOR DETAILS OF TESTING: LGE RNG Verification and Monitoring Program. Sampling methods and analytical test methods may be modified or changed over time, based upon updates in test methods and technology. Any changes in test methods for trace constituents must be approved by LGE.

NOTE 2 : If the producer is able to complete one FULL Verification and Monitoring Program to the satisfaction of LGE, with all data in line with required gas specifications, subsequent project Verification and Monitoring Programs may be reduced substantially. This applies to programs with ***same biomass source only*** . LGE reserves the right to reduce the Verification and Monitoring Programs at any time, ***based on continuing high performance and adherence to the gas quality specifications*** . If parameters are continuously within specification values, variances may be allowed.

PROJECT #2313375.00

Renewable Natural Gas & Propane Blending:

Heat Content Calculations, Site and System Requirements, & Other Considerations

Version: 1.0

Date: April 29th, 2024

Prepared for:

Brian Lenhart and Team

Louisville Gas and Electric

Prepared by:

SIGNATURE PAGE

Project Name:	**LGE - Renewable Natural Gas & Propane Blending**		
Project Number:	2313375.00	Purchase Order:	
Report Name:	**Renewable Natural Gas & Propane Blending: Heat Content Calculations, Site & System Requirements, & Other Considerations**		
Report Date:	March 18, 2024	Version:	FINAL

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Table of Contents

I. PURPOSE & SCOPE

At the request of LGE, EN has performed calculations to demonstrate the relationship between renewable natural gas (RNG) or biomethane & propane blending ratio and the blended gas heat content.

EN notes that heat content of the RNG is not the only consideration for interchangeability. Additional processing to reduce unwanted constituents may be needed to ensure the RNG meets or exceeds minimum requirements for natural gas pipeline quality standards. The Wobbe Index should also be considered. In almost all gas end use applications, the flow of gas is regulated by flow through a hole or orifice. Gas mixtures with the same Wobbe number will deliver the same amount of heat when passing through a given orifice. Most (if not all) end use appliances are designed to operate over a specified range of Wobbe values. Additional notes and analysis are included throughout this final report.

II. BLENDED GAS HEAT CONTENT CALCULATIONS

A. HEAT CONTENT VALUES

For heat content calculations for blended gas, EN utilized heat content values for methane, ethane, and propane as reported and published by the Energy Information Administration as of September 13, 2023. The value of 1,050 Btu/scf is the assigned approximate heat content value for natural gas used by LGE. A full explanation of this value is in the Section III of this report.

B. PHASES AND GENERATION OF RNG

EN understood that RNG providers may generate “typical landfill biogas,” which has a heat content of approximately 500 Btu/scf. This value is less than half the heat content of LGE’s natural gas at 1,050 Btu/scf. The low heat content reflects the composition of biogas. In general, after water moisture and a portion of contaminants are removed, biogas may be referred to as “conditioned” and is composed of approximately 50% methane, 40% carbon dioxide, and 10% nitrogen and/or oxygen.

EN also assumed that RNG providers would further process the conditioned biogas to remove the majority of carbon dioxide and nitrogen from the mixture, generating biomethane. EN assumed that the biomethane is composed of only methane and inert gases. Because heavier hydrocarbons are not generated through biogas production methods, the heat content of the resulting biomethane and RNG ranges from 950 up to 990 Btu/scf. Heat content greater than 980 Btu/scf is uncommon without supplementation due to the absence of higher chain hydrocarbons. Additionally, LGE has established minimum requirements for the heat value content they will accept in their system, set at 967 Btu/scf in their “Rates, terms, and Conditions for furnishing Natural Gas Service, Public Service Commission of Kentucky Document.

C. HEAT VALUES FOR INITIAL RNG AND PROPANE BLENDS

The heat content of blended gas is proportional to ratio of constituents and the heat content of those constituents.

Table 1 displays calculation results of heat content of blended RNG when blending to a certain ratio (percent) of propane. The table shows blend ratios from 97.0% biomethane + 3.0% propane to 93.5% biomethane + 6.5% propane using biomethane with a heat content ranging from 950 Btu/scf to 990 Btu/scf. Additional calculated results are shown in the Appendix.

Table 1. Heat Content Achieved by Biomethane and Propane Blended at Specified Ratios

	Gas Stream Blend Ratio							
% Biomethane	97.0%	96.5%	96.0%	95.5%	95.0%	94.5%	94.0%	93.5%
% Propane	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%	6.5%
Biomethane Heat Content	Resulting Blended Gas Heat Content (Btu/scf)							
950 Btu/scf	997.0	1004.8	1012.6	1020.5	1028.3	1036.1	1044.0	1051.8
955 Btu/scf	1001.8	1009.6	1017.4	1025.2	1033.1	1040.9	1048.7	1056.5
960 Btu/scf	1006.7	1014.5	1022.2	1030.0	1037.8	1045.6	1053.4	1061.1
965 Btu/scf	1011.5	1019.3	1027.0	1034.8	1042.6	1050.3	1058.1	1065.8
970 Btu/scf	1016.4	1024.1	1031.8	1039.6	1047.3	1055.0	1062.8	1070.5
975 Btu/scf	1021.2	1028.9	1036.6	1044.3	1052.1	1059.8	1067.5	1075.2
980 Btu/scf	1026.1	1033.8	1041.4	1049.1	1056.8	1064.5	1072.2	1079.8
985 Btu/scf	1030.9	1038.6	1046.2	1053.9	1061.6	1069.2	1076.9	1084.5
990 Btu/scf	1035.8	1043.4	1051.0	1058.7	1066.3	1073.9	1081.6	1089.2

- All values are in Btu/scf unless otherwise noted. Calculations were performed using a heat value of propane as 2516 Btu/scf, per the EIA as published on September 13, 2023.

D. BLENDING SYSTEM OVERVIEW

Gas blending skids can create a user-defined volume-by-volume percentage of two gases in a well-mixed, homogenous, outlet stream. To achieve this goal, several components and a control-system is required.

A typical blending skid requires several components to produce the homogeneous downstream mixture of gases at the desired heat content. The key components of the blending skid are the gas metering, the gas quality analytic instrumentation, and the automated control valve. These components are the foundation for all blending control schemes and the most important parts of the blending skid.

1. Common Components

a. Process Piping:

Process piping transports and distributes of gases within a blending system. In RNG setups, stainless steel piping is most prevalent due to its resistance to corrosion and its ability to endure a broad spectrum of temperature and pressure levels. The specific configuration of your process piping will vary depending on the range of pressures and temperatures in question.

b. Gas Meters:

Gas meters measure the flow (also known as mass flow) both the mainstream process line and the injected gas entering the system. Coriolis and ultrasonic gas meters are most used for their high accuracy and multivariable measurements. Coriolis meters can measure multiple variables simultaneously such as, mass flow rate, volume flow rate, density, and temperature. Ultrasonic meters utilize sound waves to measure velocities and are suitable for closed systems. Another common type of gas meter is a rotary meter, commonly referred to as a positive displacement meter. Rotary meters are used in gas calibration applications, often for analytical instruments such as gas chromatographs, mass spectrometers, and gas sensors. Both meter types can provide accurate carrier gas flow rates, which play a crucial role in analyzing gas samples.

c. Automated Control Valves:

Automated control valves provide precise, remote, real-time monitoring of flow needed to achieve desired blend of gases. Automated control valves enhance system safety by allowing for rapid responses to emergency situations by diverting and isolating flow. Like natural gas applications, in RNG applications, automated control valves are highly preferred due to their ability to rapidly and remotely shut off and isolate a specific segment of pipeline in the event of an emergency, thereby minimizing potential safety hazards.

d. Pressure Regulators:

Pressure regulators maintain gas streams at the correct pressures prior to blending and within a pipeline. Pressure regulators prevent excessive pressures from causing damage to pipelines, valves, major equipment, and other infrastructure components.

e. Relief Valves:

Relief valves serve as an essential safeguard, properly venting and releasing of pressure beyond safe design thresholds, especially during emergency shutdowns. Their primary function is to prevent overpressure occurrences which could result in hazardous gas leaks, equipment damage and even explosive incidents. Relief valves play a vital role in operational integrity and safety of a piping system.

f. Flow Control Devices:

Flow control devices are essential components that work to regulate and maintain precise control of flow rates and pressures of gases. The precise and efficient control of flow rates allows for optimized process performance, consistent outputs, and energy efficiency by optimizing energy use to match demands within a system.

g. Sensors:

Pressure sensors, temperature sensors, and flow sensors monitor the system and deliver real time data on the status of the gas system. Sensors can detect the presence of leaks within a piping segment and are critical for tracking the volume of gas flow and optimizing the process. In natural gas pipelines, sensors can analyze the composition of gas to ensure quality standards are fulfilled.

h. Control System:

Programable Logic Controllers (PLCs) monitor and control the blending process through analog and/or digital signals. Parameters monitored and regulated include but are not limited to temperature, pressure, and flow rates. Human-Machine Interfaces (HMIs) complement PLCs by offering a visual representation of the process, and in some cases, the ability to adjust the process as desired. These interface systems allow operators access to essential tools for monitoring, analysis, troubleshooting, and decision making.

i. Flanges/Gaskets:

Flanges and gaskets play a vital role in ensuring the integrity of seals between different segments of process piping and components, by preventing the escape of substances of gas into the surrounding environment. Much like any mechanical piping system, the absence of components such as flanges and gaskets pose a potential danger for gas leakage and increased operational safety risks.

j. Gas Analyzers/Sampling Lines and Valving System:

Gas analyzers continuously monitor the composition of the blended gases. If a specific application only requires the analysis of the calorific value of the gas, then a calorimeter may be used. However, if an application requires analysis of gas components as well, a gas chromatograph should be used; see next component for additional detail. Depending on the system design and complexity, sampling lines and valving systems allow for automated sampling of the gas in the systems.

k. Gas Chromatograph (GC):

Gas chromatographs serve a dual purpose in the gas production process. They not only ensure that the final product aligns with regulatory standards but also enable operators to closely pinpoint the composition of the final gas product. This analysis aids in early detection of any deviations from the intended target mixture. Gas chromatographs work to ensure product quality and safety compliance.

l. Safety Devices/Interlocks:

Safety devices and interlocks such as emergency shut off valves, flame detector poles and additional safety features are critical in maintaining secure and reliable system and plant operations. Their role is to provide early triggers and activation of safety protocols in the event of flame propagation in a gas system or in the event of unintentional machinery startup within a system.

m. Blending Chamber:

A blending chamber is a mixing device where propane and natural gas are mixed to achieve desired blend. Different methods and designs are available for gas blending. Gas streams can be blended by a T-junction, where one gas stream is directly injected through a side branch into a main gas line. Alternatively, there may be instances where direct injection may take place within a side mixer initially. A side mixer ensures thorough mixing and potential gas dilution prior to direct injection into a main gas line, providing greater control further upstream.

n. Propane Vaporizer:

The use of propane vaporizers is common when equipment and system demands exceed the vaporizing capability of the propane tank. The vaporizer works to convert liquid propane to its gaseous phase by applying heat. For smaller systems, the tank is sized to allow ambient conditions to vaporize sufficient propane within the tank relative to downstream demand.

o. Heater (System Design Dependent):

As an alternative to a vaporizer, propane storage tanks may be insulated and/or heated. This design helps to ensure a minimum tank temperature which results in a minimum tank vapor pressure to drive the system for injection purposes. In systems with lower propane demands, this approach is generally more cost efficient than a vaporizer.

p. Compression (System Dependent):

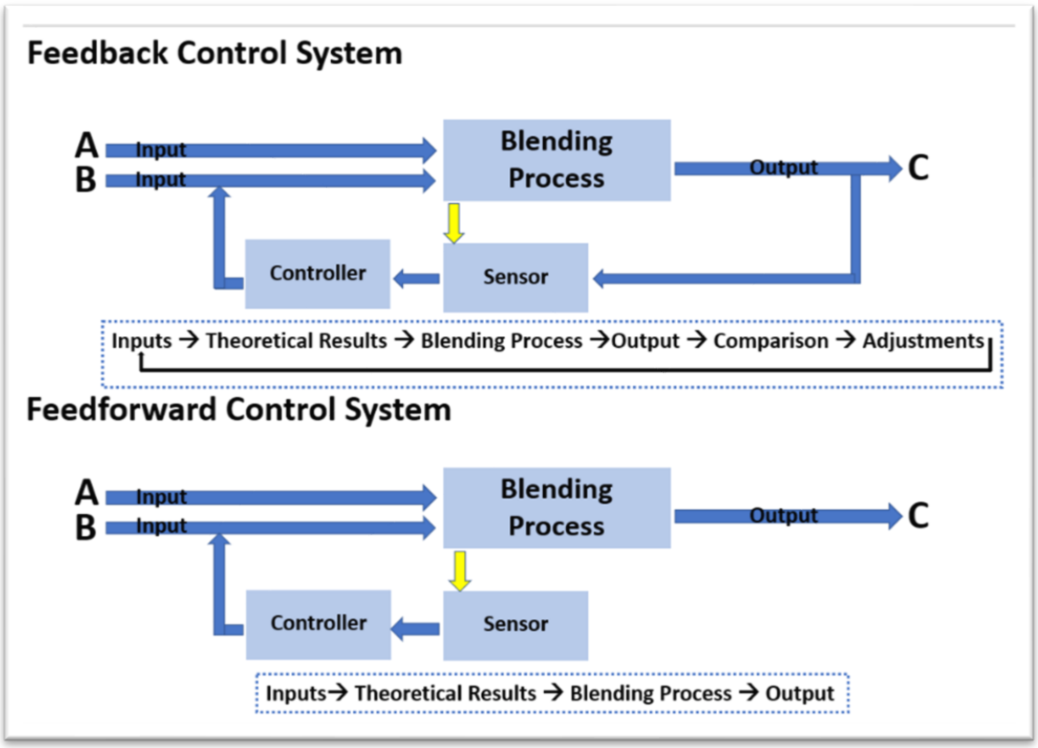
Downstream system pressure is the driver for required injection pressure. Compression can be required if the propane does not have enough vapor pressure. Instead of compression, raising the liquid tank temperature to avoid a compressor can solve this issue sometimes.

2. Control Systems

Two prevalent schemes are utilized for propane vaporization and blending control: (a) feedback control and (b) feedforward control. In general, a feedback control system uses downstream measurements in a process stream to determine the appropriate upstream inputs and then send signals to achieve those settings. By contrast, a feedforward control system relies on data from upstream sensors to anticipate potential disturbances in the overall process, transmitting this information to the control element to preemptively reduce any changes before they impact the process variable. The selection of instruments for the control system is dependent on how the data from an analytical instrument is incorporated into the control loop and when the information collected from the instrument begins to impact the control process.

In Figure 1, the difference between feedforward and feedback control systems is illustrated. In this example, “A” and “B” represent the input variables, which in a blending scenario, could signify two different gases. “C” stands for the output variable, representing the resulting blended gas. The sensor represents the component in a blending system that is responsible for gathering information about the output. Lastly, the controller is the component responsible for adjusting the blending process to achieve the desired output. In a feedback control system (Figure 1, top), an initial detection point in the system (indicated by the yellow arrow) collects primary data results for the sensor, while another detection point in the system is also linked to the sensor based on output outcomes. In contrast, in a feedforward control system (Figure 1, bottom), a single detection point for the sensor is utilized (indicated by the yellow arrow), without the presence of a second sensor for fine-tuning the blending process.

Figure 1. Comparison of Control System Flow Diagrams



a. Feedback Control System

A feedback control system uses downstream measurements in a process stream to manipulate and control the upstream inputs. The system checks if what is supposed to happen (theoretical results) matches what is really happening (actual outputs). If there is a difference, the system adjusts the mix. This information is relayed to the sensor and is used as input to control the system. As an example, in a propane and RNG blending scenario, a downstream sensor transmits signals to the propane line control meter (controller) conveying the required amount of propane for addition. Several advantages of a feedback control system include reducing non-linear system effects, sensitivity to input variations, and minimization of external noise and process disturbances which result in high accuracy. In the event of shut-ins because non-conforming gas is seen from upstream producers, feedback control enables real time responses and adjust gas pressure and volume to prevent cascading issues. These systems can play a crucial role in ensuring business continuity and risk reduction.

b. Feedforward Control System

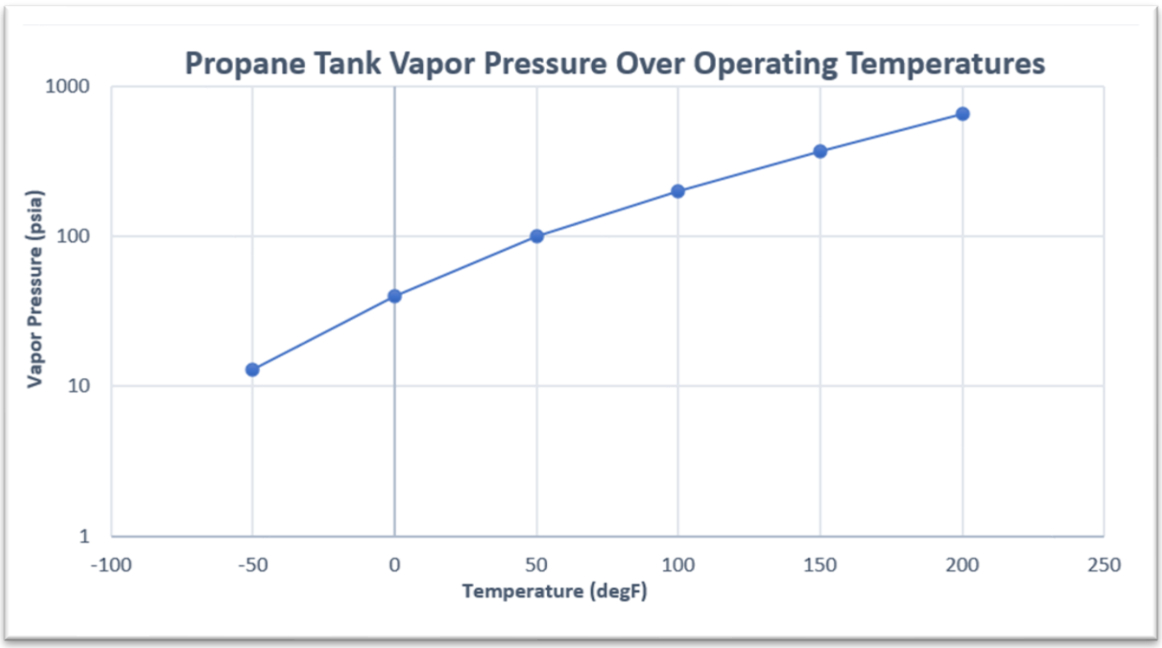
A feedforward control system relies on upstream sensors alone to collect data about the process it manages. It forecasts potential variations in process outputs based on the inputs and makes adjustments to maintain desirable outcomes. Control in a feedforward system is based only on upstream sensor readings and anticipated process results; no corrective action or feedback loop is made to the inputs if process variance occurs. Feedforward systems are engineered to address process impacts based on input variation, yet they lack a mechanism for incorporating real-time output feedback. As seen in Figure 1, there is no detection point after the blending process going to the sensor. The selection of a feedforward system in a given process depends on the desired level of risk mitigation and cost-benefit analysis. In many cases, tight process control may not be imperative for the business continuity.

3. Propane Supply and Storage

Propane is generally stored as a liquid with vapor present in the headspace of the tank. Due to this design, vaporizers may be indicated when the system demands and/or injection rate surpasses a propane tank's ability to vaporize gas. Note that one (1) gallon of propane is approximately equivalent to 36 standard cubic feet (scf) of propane gas. Accordingly, at scale for industrial or energy supply, a 1,000-gallon propane tank is equivalent to 36,000 scf of propane gas.

Often propane tanks can be sized for vaporization to occur in the tank itself without additional capital expenditures. Vapor pressure relative to the tank temperature is shown in Figure 2.

Figure 2. Graph of Propane Tank Vapor Pressure Over Various Operating Temperatures.



4. System Monitoring Equipment

System monitoring functions includes gas quality, safety, and monitoring capabilities. Gas quality equipment and instrumentation that the RNG and propane are of sufficient quality and ratios to ensure the safety and reliability of the pipeline system and infrastructure. The specific equipment needed may vary depending on the application and regulatory requirements. Some of the most crucial instruments needed for monitoring gas composition are gas analyzers. Commonly, gas chromatographs fulfill this critical function. Gas chromatographs are advanced analytical instruments that determined the constituents of the gas blend. In gas chromatography, a sample of gas is introduced into a moving gas phase (often referred to as the carrier gas). This gas phase carries the sample through a column, either packed or capillary, where the sample separates into its constituents based on interaction with the stationary phase in the column. Pressure and temperature are monitored and controlled to ensure consistent and reliable results.

Additionally, gas leak detection is crucial for safe operations. One of the most common equipment used for gas leaks, particularly in propane applications, are catalytic bead sensors. They operate on the principle of catalytic combustion. When propane encounters a heated catalytic bead, the propane oxidizes, producing heat and a change in electrical resistance. This change is detected and quantified by the instrument, which triggers an alarm if hazardous conditions are present.

Lastly, to ensure the long-term operation and efficiency of a propane blending system, it is essential to have appropriate data logging systems and control systems, including programmable logic controllers (PLCs) and supervisory control and data acquisition (SCADA) systems. These systems serve purposes for control, automation, remote oversight, as well as data analysis and reporting.

III. BLENDING CONSIDERATIONS AND ANALYSIS

A. INTERCHANGEABILITY AND WOBBE INDEX

The Wobbe Number, also commonly referred to as the Wobbe Index, is an indication of the interchangeability of fuel gases and their relative ability to deliver energy. Sometimes referred to as the interchangeability factor, it compares the combustion energy output of various fuel gases. The Wobbe Index considers not just the gas's volumetric energy value but also how quickly its molecules flow through a fixed-size orifice. The higher the Wobbe Index, the higher the heating value of that gas will flow through a given orifice. In other words, if two gases have the same Wobbe Index, then the two gases will deliver the same amount of energy (heat output) when supplied at the same pressure at a given amount of time, regardless the composition of the gas.

The Wobbe Index is calculated using the following equation:

$$\mathrm{WI} = \frac{\mathrm{CV}}{\sqrt{\mathrm{SG}}}$$

where

- "WI" is the Wobbe Index
- "CV" is the caloric value of the fuel (Btu/scf), the total heating value from combustion, and
- "SG" is its specific gravity with respect to air, representing the supply of gas.

The Wobbe Index is frequently used in the specifications of gas supply and transport utilities. Specifically, an operator can utilize the Wobbe Index of various gases to confirm minimal impact will occur when managing operational changes, such as injection of renewable natural gas (RNG). Prior to any blending operations, Wobbe Index should be calculated for the intended resulting gas mixture. The purpose of performing these types of calculations is to assess the heating value output and evaluate compatibility with end use equipment.

For instance, a potential target blend of 95% biomethane and 5% propane would have a heat content of approximately 1028 Btu/scf and specific gravity of 0.645. This example scenario would result in a Wobbe Index value of 1282. Based on this value, the blended gas would not be considered interchangeable as it would not meet the current Wobbe Index requirements as published in the current LGE tariff. The LGE tariff currently requires a Wobbe Index value of not less than 1314 and not more than 1400. In this scenario where the Wobbe Index value falls below the minimum required value specified in the RNG tariff, increasing the proportion of propane can elevate the overall Wobbe Index of the blend. Propane has a higher heating value compared to biomethane, and adjusting the blend allows for a more favorable energy content. When modifying the propane percentage in a blend, it is crucial to ensure that the heating value aligns with the project's overarching energy objectives and quality standards.

This adjustment should be made without compromising safety or compatibility with appliances. Additionally, it is essential to be aware that alterations in gas composition may have implications for contractual agreements.

IV. CONCLUSION

No universal solution exists for how operators should handle the potential impacts of RNG injection on gas quality, heat content, and gas interchangeability. Every situation is unique – from regulatory compliance in the local jurisdiction to producer relationships and interconnect agreements, from the size and complexity of the gas distribution system to the quality of biomethane produced.

Introduction of RNG directly into an operator's system has the potential to impact the gas delivered to its customers. Operators are encouraged to understand and, where possible, address direct impacts on gas quality, heat content, and gas interchangeability.

V. APPENDIX

Appendix A

Figure A1 depicts the minimum space required for a 5,000-gallon propane tank and blending skid with instrumentation buildings. The overall dimensions are 125x110', comprising of a footprint of 13,750 square feet, which is primarily driven by the NFPA 58 separation distances from the bulk propane storage tank.

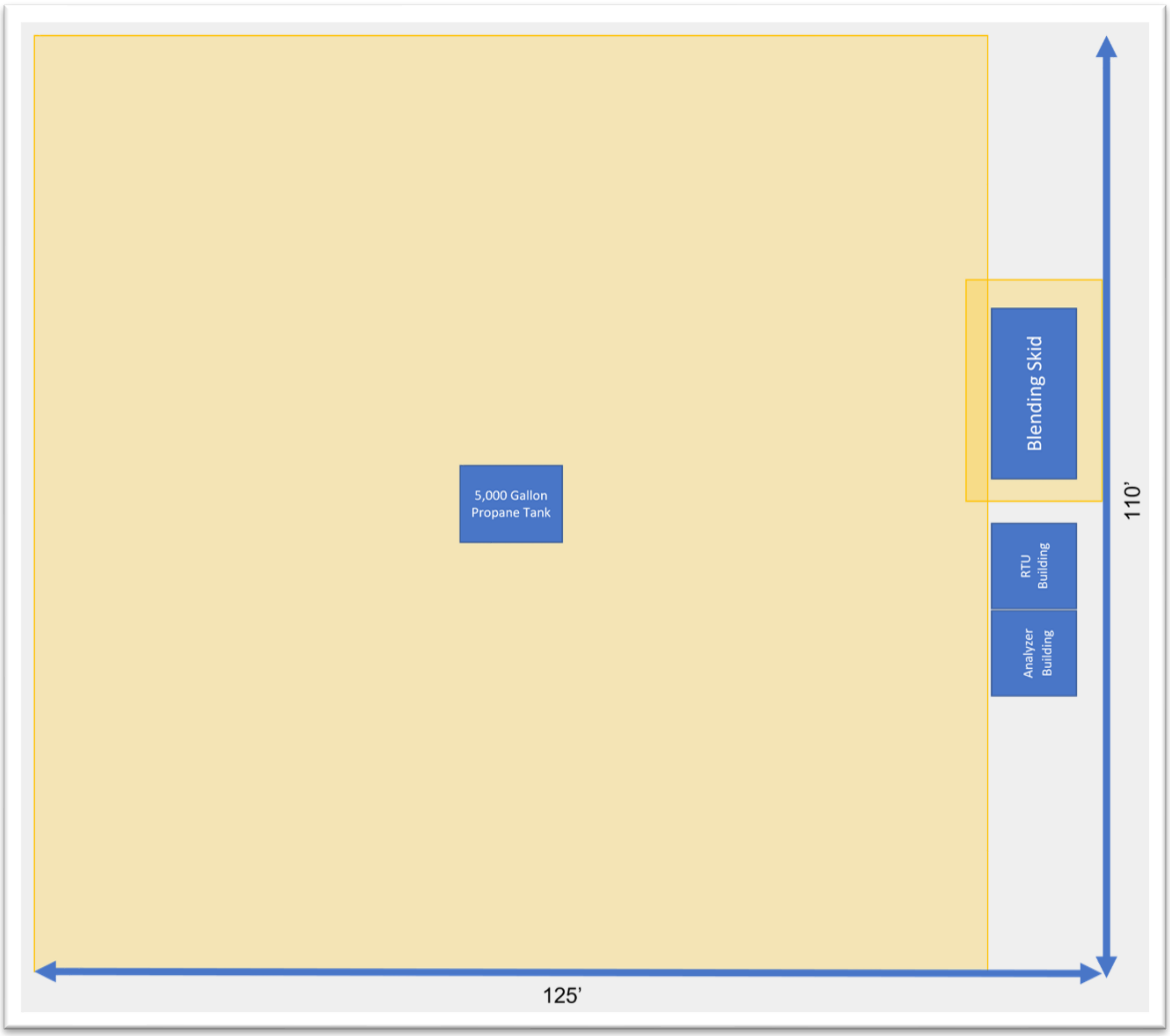


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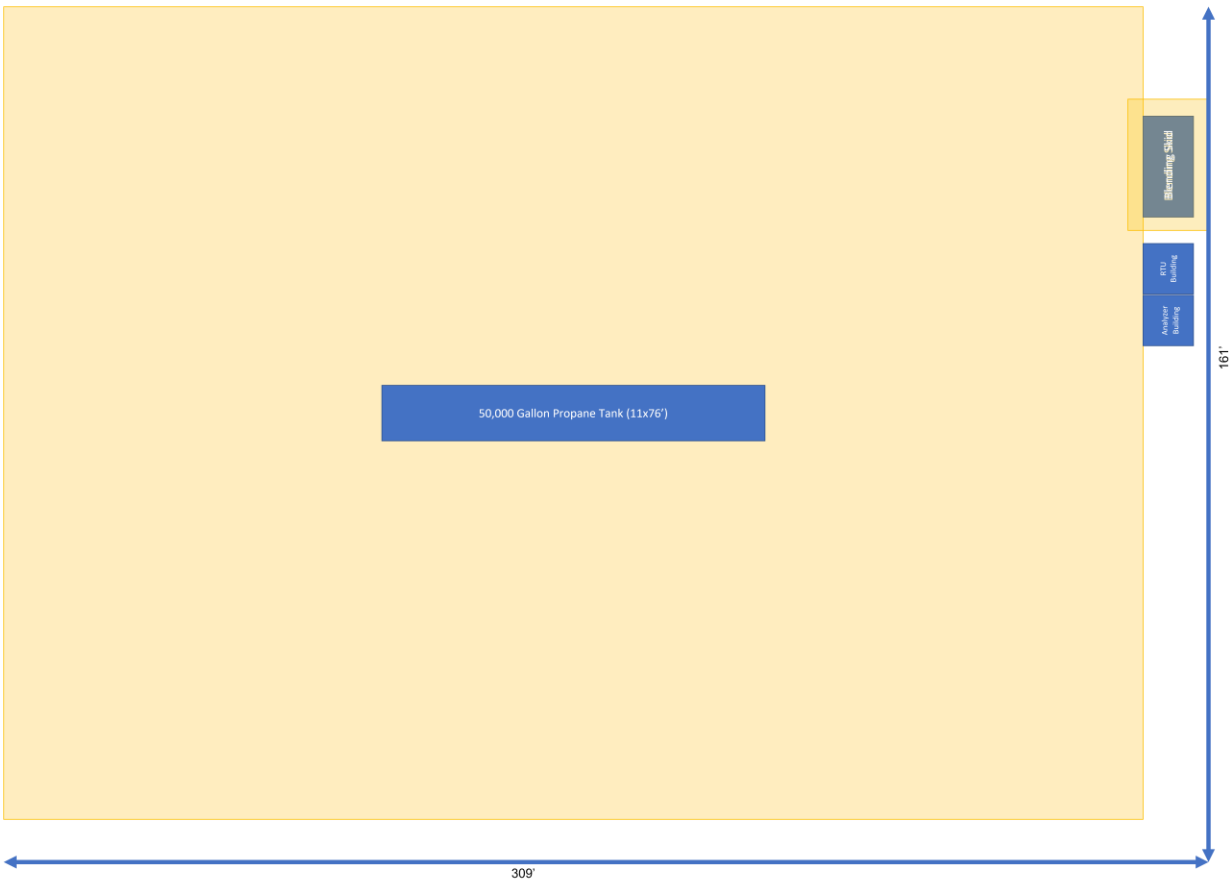
Figure A2 depicts the minimum space required for a 50,000-gallon propane tank and blending skid with instrumentation buildings. The overall dimensions are 309x161', comprising of a footprint of 49,749 square feet, which is primarily driven by the NFPA 58 separation distances from the bulk propane storage tank.



Appendix B

1. What is the ratio of biomethane and propane if LGE wants to achieve a specific heat content before acceptance as RNG?

Table B1 displays calculated blending ratios of the two gas streams, biomethane and propane, to achieve a specified heat. The table addresses six blended RNG heat contents, ranging from 1010 Btu/scf to 1060 Btu/scf at intervals of 10 Btu/scf, using biomethane with a heat content ranging from 950 Btu/scf to 990 Btu/scf. Additional calculated results are shown below.

Table B1. Blend Ratios of Biomethane and Propane for Target Heat Content

Biomethane Heat Content	1010 Btu/scf Blend		1020 Btu/scf Blend		1030 Btu/scf Blend		1040 Btu/scf Blend		**1050 Btu/scf Blend**		1060 Btu/scf Blend	
	%BM	%P	%BM	%P	%BM	%P	%BM	%P	**%BM**	**%P**	%BM	%P
950 Btu/scf	96.17	3.83	95.53	4.47	94.89	5.11	94.25	5.75	**93.61**	**6.39**	92.98	7.02
955 Btu/scf	96.48	3.52	95.84	4.16	95.20	4.80	94.55	5.45	**93.91**	**6.09**	93.27	6.73
960 Btu/scf	96.79	3.21	96.14	3.86	95.50	4.50	94.86	5.14	**94.22**	**5.78**	93.57	6.43
965 Btu/scf	97.10	2.90	96.45	3.55	95.81	4.19	95.16	4.84	**94.52**	**5.48**	93.87	6.13
970 Btu/scf	97.41	2.59	96.77	3.23	96.12	3.88	95.47	4.53	**94.83**	**5.17**	94.18	5.82
975 Btu/scf	97.73	2.27	97.08	2.92	96.43	3.57	95.78	4.22	**95.13**	**4.87**	94.48	5.52
980 Btu/scf	98.05	1.95	97.40	2.60	96.74	3.26	96.09	3.91	**95.44**	**4.56**	94.79	5.21
985 Btu/scf	98.37	1.63	97.71	2.29	97.06	2.94	96.41	3.59	**95.75**	**4.25**	95.10	4.90
990 Btu/scf	98.69	1.31	98.03	1.97	97.38	2.62	96.72	3.28	**96.07**	**3.93**	95.41	4.59

2. What is the ratio of methane, propane, and inert components in the blended gas if LGE wants to achieve a specific heat content before acceptance as RNG?

Table B2 displays calculated constituent ratios that result when two gas streams, biomethane and propane, are blended ratios to achieve a specified heat content. Instead of showing the blending ratios of the gas streams as in Table B1, this table displays what the resulting constituent concentrations would be in the blended gas. To perform these calculations, EN assumed that the biomethane is only methane and inert gas. The table addresses six blended RNG heat contents, ranging from 1010 Btu/scf to 1060 Btu/scf at intervals of 10 Btu/scf, using biomethane with a heat content ranging from 950 Btu/scf to 990 Btu/scf.

Table B2. Constituent Ratios of Methane, Propane, and Inerts when Blended for Target Heat Content

Biomethane Produced			1010 Btu/scf Blend			1020 Btu/scf Blend			1030 Btu/scf Blend			1040 Btu/scf Blend			1050 Btu/scf Blend			1060 Btu/scf Blend		
%M	%I	Heat Content	%M	%P	% I	%M	%P	% I	%M	%P	% I	%M	%P	% I	%M	%P	% I	%M	%P	% I
94.06%	5.94%	950 Btu/scf	90.46	3.83	5.71	89.85	4.47	5.68	89.25	5.11	5.64	88.65	5.75	5.60	88.05	6.39	5.56	87.45	7.02	5.52
94.55%	5.45%	955 Btu/scf	91.22	3.52	5.25	90.62	4.16	5.22	90.01	4.80	5.18	89.41	5.45	5.15	88.80	6.09	5.11	88.19	6.73	5.08
95.05%	4.95%	960 Btu/scf	92.00	3.21	4.79	91.38	3.86	4.76	90.77	4.50	4.73	90.16	5.14	4.70	89.55	5.78	4.66	88.94	6.43	4.63
95.54%	4.46%	965 Btu/scf	92.77	2.90	4.33	92.16	3.55	4.30	91.54	4.19	4.27	90.92	4.84	4.24	90.31	5.48	4.21	89.69	6.13	4.18
96.04%	3.96%	970 Btu/scf	93.55	2.59	3.86	92.93	3.23	3.83	92.31	3.88	3.81	91.69	4.53	3.78	91.07	5.17	3.76	90.45	5.82	3.73
96.53%	3.47%	975 Btu/scf	94.34	2.27	3.39	93.72	2.92	3.36	93.09	3.57	3.34	92.46	4.22	3.32	91.84	4.87	3.30	91.21	5.52	3.27
97.03%	2.97%	980 Btu/scf	95.13	1.95	2.91	94.50	2.60	2.89	93.87	3.26	2.87	93.24	3.91	2.85	92.61	4.56	2.83	91.98	5.21	2.82
97.52%	2.48%	985 Btu/scf	95.93	1.63	2.43	95.30	2.29	2.42	94.66	2.94	2.40	94.02	3.59	2.39	93.38	4.25	2.37	92.75	4.90	2.35
98.02%	1.98%	990 Btu/scf	96.74	1.31	1.95	96.09	1.97	1.94	95.45	2.62	1.93	94.81	3.28	1.92	94.17	3.93	1.90	93.52	4.59	1.89