

White Paper on Natural Gas Interchangeability and Non-Combustion End Use

**NGC+ Interchangeability Work Group
February 28, 2005**

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

1.0 Introduction

1.0.1 The Federal Energy Regulatory Commission (FERC) has undertaken an initiative to examine and update natural gas interchangeability standards. FERC's initiative results from the confluence of several events and issues. Liquefied natural gas (LNG) imports have begun to rise, and forecasts are for future imports to be a significant percentage of total North American supply. Regasification terminals have regained active status and are expanding. The National Petroleum Council's 2003 report "Balancing Natural Gas Policy – Fueling the Demands of a Growing Economy" presented projections for LNG imports to increase from 1 percent of our natural gas supply in 2003 to as much as 14 percent by 2025. This report also recommended that FERC and DOE "update natural gas interchangeability standards."¹ The characteristics of natural gas supply in North America have evolved over time as conventional sources are depleted, and new sources in the Rockies, Appalachians and the Gulf of Mexico are developed. Direct receipt of unprocessed gas by transmission pipelines has grown and also contributed to the change in the natural gas composition. Finally, the United States has also experienced prolonged periods of pricing economics that make it more profitable to leave some natural gas liquids (NGL's) in the natural gas stream as Btu's rather than process the gas and extract the NGL's for petrochemical feedstock and other traditional markets. These issues are exacerbated by North American natural gas supply being unable to meet current or projected demand.

1.0.2 The transition from historical gas compositions to the evolving gas supply profile presents specific technical challenges throughout the stakeholder value chain. Consequently, FERC undertook the challenge to begin addressing these issues in its annual Natural Gas Markets Conference (PL03-6-000) on October 14, 2003 and a technical conference on gas quality issues (PL04-3-000) on February 18, 2004. There are also several proceedings before FERC that highlight these issues on an individual basis. As part of their process, FERC recognizes and has encouraged the industry to develop a process to identify the issues in a comprehensive fashion and wherever possible, to recommend courses of action developed by consensus. A group of stakeholders, under the leadership of the Natural Gas Council, hereafter known as the NGC+, formed a technical work group to address the hydrocarbon liquid dropout issues specific to domestic supply and another technical work group to address the interchangeability issues associated with high Btu LNG imports.

1.0.3 Interchangeability 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.

Interchangeability is described in technically based quantitative measures, such as indices, that have demonstrated broad application to end-uses and can be applied without discrimination of either end-users or individual suppliers.

¹ Executive Summary, Page 64

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

2.0 Objective

2.1 The objective of this white paper is to define acceptable ranges of natural gas characteristics that can be consumed by end users while maintaining safety, reliability, and environmental performance.² It is important to recognize that this objective applies equally to imported LNG and domestic supply.

2.2 The NGC+ commissioned the Work Group on Interchangeability to examine the issues related to maintaining adequate and reliable gas supplies for consumers in a manner that will enable system integrity, operational reliability and environmental performance.

3.0 Background

3.1 Development of North American Natural Gas Industry

3.1.1 Interchangeability has been an issue since the 1930s and 1940s when natural gas began to replace manufactured gas (gas derived from coal and oil) in street lighting and other applications. In the traditional sense, gas interchangeability is simply defined as the ability to substitute one gaseous fuel for another without impacting combustion performance. However, the term interchangeability in the NGC+ effort has taken on a more general definition that includes the ability to substitute one gas for another without materially impacting historical utilization, including utilization in the industrial sector as “feedstock.”

3.1.2 Interchangeability remained an issue throughout the twentieth century, but mostly on a regional basis as new domestic supplies became available. In the areas where the gas supply changed significantly with time or by region, gas utilities managed the interchangeability issues in various ways, including Btu stabilization (nitrogen or air blending) and appliance readjustment. In addition, several LDC's studied regional impacts of interchangeability extensively as new LNG imports containing varying levels of higher hydrocarbons were planned and/or introduced into the North American supply infrastructure. Now, interchangeability has risen as a national issue as more non-traditional domestic supplies coupled with increases in global LNG imports that are planned to play a more significant role in meeting demand.

3.2 Development of Natural Gas End Use

3.2.1 Natural gas and NGLs found a ready market in the burgeoning petrochemical industry that began its rapid growth as part of the war effort associated with WWII and accelerated even faster after 1952. The regional growth of the interstate pipeline system in the 1950's and 1960's coupled with relatively low cost natural gas encouraged the installation of gas burning equipment (furnaces, hot water heaters, stoves, etc.) in residential and

² Performance applies to material increases in air pollutants from gas-fired equipment that cannot be addressed cost effectively with additional emissions control technology.

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

commercial settings. In general, gas-burning equipment from this period through the 1980s was designed to optimize combustion by creating near stoichiometric conditions, i.e.-chemically equivalent amounts of air and natural gas.³ As a result, properly installed and maintained equipment from that period is tolerant of fluctuations in the underlying gas quality related to seasonal demand patterns. Generally, inter- or intrastate pipeline supply meets the majority of non-peak natural gas demand and is supplemented with storage and propane-air mixtures during the peak usage periods. A number of appliance studies from the 1920s to the 1980s evaluated the limits of interchangeability for a number of types of natural gas and other fuel gases.

3.3 Changes in Natural Gas Supply

3.3.1 There are limited historical data on the precise composition of natural gas during the period of rapid growth described above, but contaminants (water, inerts, etc) were clearly being controlled while the variability in hydrocarbon composition was not as well documented. Up until the late 1990's, the presence of a growing NGL market and relatively low cost supply had created a consistent incentive to maximize the removal of higher hydrocarbons from the domestic gas supply, particularly in the Gulf Coast and Mid-continent supply areas. Domestic gas supplies appeared to be bountiful, and the only stimulus needed to increase production were high pricing levels that resulted in more drilling. The 2001-2004 steep run-up in gas prices has indeed increased drilling, but the production from these new wells has not offset declines in the historic supply basins. Discovery and development of new supply basins is barely keeping pace with the decline of older existing supply basins. As regions like the Appalachian Basin, Rocky Mountains, and Canada began producing more substantial quantities of gas with their own specific gas composition, distinct variability in gas compositions between regions began to develop, and this situation is likely to persist and further evolve as supply continues to change. Most notable has been the increase in coal-seam production in the Rocky Mountains and Appalachian basin. This gas is composed almost entirely of methane and inerts (nitrogen and CO₂) that yields a heating value significantly lower than traditional domestic production.

3.3.2 Direct receipt of small amounts of unprocessed gas by transmission pipelines has historically contributed to the difference of delivered natural gas in certain areas and continues to be a practice.

3.3.4 Finally, with three of the four existing regasification terminals regaining active status (the fourth remains in service), LNG imports have begun to rise, and future imports are forecasted to account for a more significant percentage of total North American supply. The economics of LNG transportation are such that LNG marketers prefer to have the ability to purchase LNG from a wide range of supply sources, most of which contain almost no inerts (such as CO₂ and N₂) and more non-methane hydrocarbons, such as ethane, propane and butanes, than historical US supplies. Non-methane hydrocarbons have a higher energy density; that is to say, they contain more Btu's per cubic foot. Higher energy density results in a more efficient production, storage and transportation of LNG, thereby increasing

³ The design basis was generally done to provide for an excess of air to ensure for more complete combustion conditions.

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

the overall capacity of the LNG supply chain. In addition, LNG is almost free of inerts (nitrogen and carbon dioxide) as those are removed in the process of boil off during transportation. As a consequence, the worldwide LNG market evolved as a high Btu marketplace, thus potentially placing North America at a competitive disadvantage relative to other existing and growing markets.

3.4 Changes in End Use Equipment

3.4.1 Combustion burner designs vary widely among end uses. In addition, burner system designs in some equipment, such as gas turbines, have been changed substantially since the early 1990s. The shift was initiated by and has been intensified by ever increasing requirements to reduce emissions and increase fuel efficiency. This shift impacts combustion equipment ranging from reciprocating engines and commercial space heating equipment to the newest combustion turbine technology in electric power generation. The new burner technology is often referred to as “lean premix combustion”. Other low emission technologies are also being used in home appliances as states work to meet Clean Air Act requirements. The net effect of these new designs is a greater sensitivity to gas composition characteristics and less tolerance of fluctuations in gas composition after the equipment has been set for a specified quality of natural gas. Equipment using these new designs is becoming widespread and as older equipment is replaced over time, the new designs will become pervasive throughout a broad number of end user segments. If these burners become a common trend in residential and light commercial end user markets, change will occur over a relatively long time period; particularly in the residential segment, since tens of millions of households have one or more gas consuming appliance.

3.4.2 Varying natural gas composition beyond acceptable limits can have the following effects in combustion equipment:

- a. In appliances, it can result in soot formation, elevated levels of carbon monoxide and pollutant emissions, and yellow tipping. It can also shorten heat exchanger life, and cause nuisance shutdowns from extinguished pilots or tripping of safety switches.
- b. In reciprocating engines, it can result in engine knock, negatively affect engine performance and decreased parts life.
- c. In combustion turbines, it can result in an increase in emissions, reduced reliability/availability, and decreased parts life.
- d. In appliances, flame stability issues including lifting are also a concern.
- e. In industrial boilers, furnaces and heaters, it can result in degraded performance, damage to heat transfer equipment and noncompliance with emission requirements.

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

3.4.3 Varying gas compositions beyond acceptable limits can be problematic in non-combustion-related applications in which natural gas is used as a manufacturing feedstock or in peak shaving liquefaction plants, because historical gas compositions were used as the basis for process design and optimization of operating units. More specifically, domestic LNG peak shaving liquefaction plants will most likely require retrofits to continue operations utilizing regasified LNG as feedstock. Propane-air peak shaving operations will also likely require retrofits and/or additional controls to continue operations.

3.5 Changes in Natural Gas Transportation

3.5.1 Before the passage of FERC Order 636 in 1985, wholesale natural gas was purchased by LDCs from interstate natural gas pipelines that purchased and amalgamated the supply from producers. During this period the interstate pipeline companies managed quality of the delivered gas by blending. The quality specifications were incorporated into the gas purchase and sale contracts. In general, these gas quality specifications in purchase contracts were designed to allow the acceptance of a wide variation of gas supply in small increments to a large portfolio of supply gas that was already flowing. As a result, the overall quality level of the delivered gas stream did not reflect the extremes of the receipt purchase specifications.

Order 636 separated the gas transportation and ownership responsibilities, canceling those contracts, which then allowed suppliers, marketers and end users to purchase and ship their own gas on those pipelines. During this restructuring of the business systems, quality specifications for natural gas transported on the pipelines were incorporated in tariffs.

3.5.2 This restructuring of the interstate pipeline industry encouraged the building of competing pipelines into marketplaces and interconnects between pipelines, greatly increasing the probability of delivering natural gas to end use customers from different production basins and processing regimes. Further regulatory restructuring of the pipeline business has increasingly limited the operational capability of interstate pipelines to adjust the flow of the pipeline unless requested by the shippers.

4.0 Overview of Interchangeability Indices

4.0.1 A variety of calculation methods have been developed to define the interchangeability of fuel gases for traditional end use equipment including:

- Single index methods
- Multiple index methods

4.0.2 These methods are generally based on empirical parameters developed to fit the results of interchangeability experiments. The single index methods are based on energy input while the multiple index methods incorporate fundamental combustion phenomena. Science Applications, Inc., (SAI), published a comprehensive review of these and other

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

interchangeability techniques in 1981 under sponsorship of the former Gas Research Institute (GRI), "Catalogue of Existing Interchangeability Prediction Methods."⁴

4.0.3 A range of heating values⁵ is specified in many pipeline tariffs, however, heating value alone is not a sufficient indicator of the interchangeability of gases.

4.0.4 The most common single index parameter is the Wobbe Index sometimes referred to as the *Interchangeability Factor*. The definition of the Wobbe Number is based on the heating value and specific gravity of a gas, and it is related to the thermal input to a burner (Btu per hour). It should be noted that while Wobbe is an effective, easy to use screening tool for interchangeability, the industry historically recognizes that the Wobbe Number alone is also not sufficient to completely predict gas interchangeability because it does not adequately predict all combustion phenomena.

4.0.5 Multiple index methods date back to the late 1940's and include the AGA Bulletin 36 Indices and the Weaver Indices. The multiple index techniques have a history of widespread and satisfactory use in the industry; however, as empirical models, the multiple index methods also have limitations based on the burner designs and fuel gases tested in the development research. In general, the new gas supply, called "substitute gas" is evaluated for behavior of specific combustion phenomena, including flame lifting, flashback, yellow tipping and incomplete combustion, relative to an "adjustment gas" or the gas normally used in the past with properly adjusted equipment.

4.0.6 A great deal of research has been performed to develop and assess interchangeability indices. However this work is continuing as appliances and other end use combustion devices become more sophisticated to meet current efficiency and emission requirements. Access to some of these valuable data has not been possible because the research was performed on a proprietary basis. The most reliable method for assessing the interchangeability of a substitute gas is to examine performance of various combustion devices in the laboratory after initial adjustment to a reference gas. This is obviously time consuming and can be impractical. The alternative to extensive laboratory testing is the use of prediction methods such as those highlighted above. However, it must be recognized that all of these methods are empirical and as such, may be their application may be restricted to the combustion phenomena, fuel gases and burner types for which they were derived.

5.0 Effects of Changing Natural Gas Composition on End Use Equipment

5.0.1 The Work Group recognized the need to examine the effects of changing composition for each type of end use equipment and combustion technology. As described in section 3.4.1, there are older combustion technologies, current technologies and newer combustion technologies within each end use equipment category. The categories of equipment considered were

⁴ Performance Modeling Of Advanced Burner Systems- Catalogue Of Existing Interchangeability Methods, Final Report Phase II, GRI – 80/0021, 1980.

⁵ Higher heating value, also referred to as Gross Heating Value by ISO, traditionally measured in British Thermal Units (BTU).

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

- Appliances,
- Industrial boilers, furnaces and process heaters,
- Reciprocating engines including Natural Gas Vehicles
- Combustion turbines, and
- Non-combustion uses including LNG peak shaving liquefaction and chemical and consumer product manufacturing.

5.0.2 The effects of changing composition in combustion applications can be described by a set of combustion specific phenomena and emission characteristics. The combustion specific phenomena include:

- Auto-ignition (also referred to as “knock” in engine applications)
- Combustion dynamics (pressure fluctuations and vibration)
- Flashback
- Lifting
- Blowout
- Incomplete combustion (carbon monoxide production), and
- Yellow tipping.

The major emission characteristics considered were:

- Nitrogen oxides (NO_x),
- Unburned hydrocarbons, and
- Carbon monoxide, and
- The response of supplemental emission control technology.

5.0.3 The Work Group examined each of these effects and in general found that there is a good theoretical understanding of the onset and management of these effects. However, in general, there are limited documented operational data that can be used to relate these effects consistently and reliably to compositional limits in natural gas covering the range of end use applications considered.

5.0.4 The Work Group also found that historical composition of natural gas plays a key role in assessing and managing interchangeability of gas supplies. This is best exemplified when considering home appliances. These units are initially installed and placed into operation using the natural gas as received, in a given region or market area. Appliance performance degrades when the appliance is operated with gas that is not interchangeable with the gas used to tune the appliance when it was first installed. Although the safety certification of appliances ensures that they perform safely when operated well above and below their design firing rates, much of that margin has historically been used to accommodate fluctuations in air temperature and humidity that also affect appliance performance. Marginal, improperly tuned or maintained equipment, and some newer low emission appliances are not as tolerant to changes in gas composition. Thus, ensuring that

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

gas supplies are interchangeable with historical local supplies used to tune “legacy” equipment is an important consideration in addressing interchangeability.

5.0.5 In addition, it has been documented through field testing that a small but significant fraction of residential appliances are performing marginally or poorly on domestic natural gas due to improper installation or lack of maintenance. These units can be especially sensitive to natural gas composition changes.⁶

5.0.6 One of the major concerns of varying natural gas composition in reciprocating engines is engine knock. The anti-knock property of a natural gas fuel can be expressed as a methane number and is analogous to the octane rating of gasoline. In addition to the anti-knock quality, the operating performance of an engine on a low methane number fuel may be important. Low methane number is usually a result of the presence of high hydrocarbons in the fuel. In addition to the methane number, the Wobbe number is also an important parameter for gas engines as it determines both the power and equivalence ratio and changes that might result in poor operational and environmental performance.

5.0.7 Non-combustion end uses include feedstock applications in various chemical and manufacturing processes such as ammonia fertilizers, reforming, fuel cells and LNG peak shaving liquefaction plants. Varying feedstock gas compositions can also negatively impact the efficiency and even the safety of these processes. In general, specific process design requirements are specified around a relatively tight range of feedstock compositions.

5.0.8 Of particular concern is the impact to LDC peak shaving liquefaction operations as these facilities have evolved into a critical part of the supply infrastructure of some LDCs. There are a smaller number of peak shaving plants operated by transmission pipeline companies. Shifts in feedstock composition resulting from unprocessed domestic supplies include increased concentrations of heavy hydrocarbons (C_6+) that can freeze out and plug heat exchangers, significantly impacting the efficiency and reliability of the liquefaction process. In addition, feedstock containing high concentrations of C_2/C_3 fractions as well as nitrogen from Btu stabilized regasified LNG can also significantly impact the efficiency and reliability of plant operations. LNG peak shaving liquefaction plants in general do not have the internal capacity or an “outlet” for these non-methane components that are traditionally removed from the gas by the liquefaction process. Depending on the liquefaction process, excessive inert concentrations pose additional problems with LNG storage systems because of increased tank boil-off. In summary, changes in feedstock composition beyond the original plant may require many facilities to retrofit cold box components (heat exchangers and flash vessels) as well as tank storage system components (cold blowers), and these retrofits may be necessary to accommodate unprocessed domestic supplies and regasified LNG imports. The inability to effectively and efficiently re-fill peak shaving storage during off-peak periods due to liquefaction system constraints caused by varying feedstock compositions beyond design could significantly compromise the pipeline or LDC’s ability to meet peak day/peak hour demands.

⁶ TIAX – Cove Point Summary & Commonwealth Studies

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

5.0.9 Additional LDC peak shaving concerns include the impact of higher hydrocarbon gases on propane-air peak shaving operations. As with the liquefaction plants, these facilities were designed with specific blending capabilities and limitations based on historical pipeline gas compositions. Existing systems may not have the necessary capacity to adequately blend peak shaving supplies with higher hydrocarbon pipeline supplies while maintaining interchangeability criteria. As a result, retrofit of these facilities may also be required to accommodate variations in pipeline supply compositions.

5.0.10 The rate of change in gas composition appears to be an important parameter for some end uses. Fluctuations in composition beyond the limits that the equipment was tuned to receive, particularly if the changes occur over a short period of time, are likely to reduce the ability of some equipment to perform as designed by the manufacturer.

6.0 Application of Interchangeability Parameters

6.0.1 The Work Group considered the range of effects above and sought to define an approach to apply interchangeability parameters that addressed the full range of effects and that could ultimately achieve the objective, that is, to *“Define acceptable ranges of natural gas that can be consumed by end users while maintaining safety, reliability, and environmental performance.”*

6.0.2 For traditional end use equipment, evaluation of acceptable gas quality variations begins with the actual adjustment gas. The actual adjustment gas is the first gas that is supplied to an appliance, that is, the gas used during the moments of appliance installation to adjust the equipment and set it “on rate.” This concept is, of course, the basis for both single and multiple index calculations methods, which define mathematical indices based on a specified “Adjustment Gas” with known properties such as heating value and specific gravity and/or composition. In practice, development of the adjustment gas composition must be based on the history of gas supplies to the region and on the operations of the utility. Three situations may pertain:

- 1) The actual adjustment gas is identical to a consistent and known historical average gas. In this case, the delivered gas composition has been constant over long periods of time, and all appliances in the region have been installed with the same actual adjustment gas. This situation is experienced by those regions, such as parts of the Northeast and Midwest, which have historically received consistently processed pipeline supplies from producing regions such as the Gulf Coast and Mid-Continent supplies.
- 2) The utility establishes a specified or “target” gas based on the historical gas supplies. In this situation, the company effectively targets a single heating value and possibly other specifications (e.g., Wobbe, gas composition, orifice sizing tables) and provides these values to the installers of gas appliances, municipal building departments, gas suppliers, system operators, etc. The company may develop different target values for different zones or districts within its delivery system, depending on the gas source, the history of the gas supply, and other factors, such as elevation. This specification is currently used by companies that have managed interchangeability issues, such as companies that distribute gas at high altitudes, that have completed appliance readjustment programs within their system, or that use Btu stabilization for

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

interchangeability control. The utility typically monitors and provides necessary information to installers upon request to ensure the adjustment gas at the time of appliance installation is consistent with the stated target gas values.

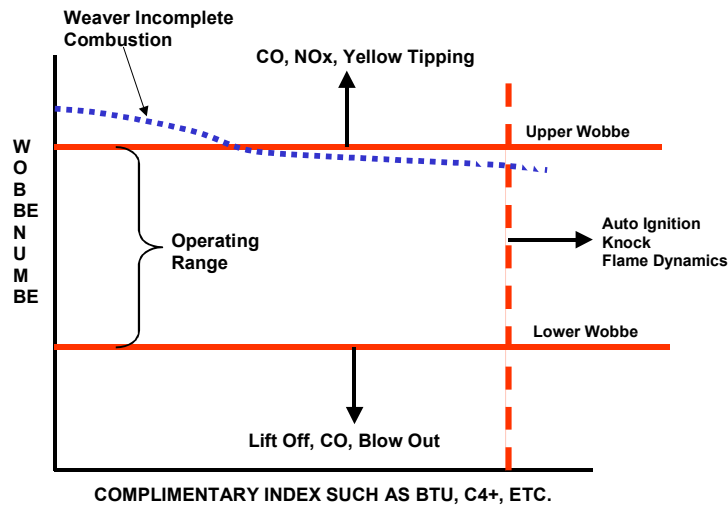
- 3) There is no specified target value, and the composition of the delivered gas has varied over time. In this case, there is no single actual adjustment gas that can be defined for the delivery system, and the appliances within the system may have different and possibly unknown set points, depending on the variability of the gas supply. If evaluation of interchangeability is required, an estimate for the adjustment gas will be necessary. Alternatives may include the average historical composition, the minimum or maximum extremes, or a combination. This situation may exist in producing regions where the degree of gas processing may vary depending upon where the supply is obtained relative to processing facilities and to the extent contractual blending is available.

6.0.3 The Work Group drew upon the European experience and adopted the concept of developing an operating regime to define the acceptable limits. This approach entails selecting parameters that address the end use effects described above, such as auto-ignition, incomplete combustion, yellow tipping, lifting, and others. Indices such as those found in AGA Bulletin 36 and Weaver target specific end use effects while the Wobbe number is a more generic metric. For example, both the AGA Bulletin 36 and Weaver methods define indices to specifically address yellow tipping phenomena.

6.0.4 A purely scientific approach might lead one to applying many of the Weaver and AGA Bulletin 36 indices for every end use application. However, limited testing data on low emission combustion equipment indicate that these indices may not consistently account for the observed combustion related behavior. In addition, the Work Group was concerned about specifying overly restrictive limits and sought to define a more practical approach. The group built upon the idea of developing an operating regime.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

**Figure 1. INTERCHANGEABILITY
OPERATING REGIME**



6.0.5 As shown in Figure 1, the basis for constructing the operating regime was to propose a parameter and identify which end use effects were addressed by that parameter, either in specifying a minimum or a maximum limit. The Wobbe Number was considered first because it was recognized as the most robust single parameter. In general, establishing a maximum Wobbe Number can address certain combustion phenomena such as yellow tipping, incomplete combustion and potential for increased emissions of NO_x and CO. Establishing a minimum Wobbe Number can be used to address lifting, blowout and CO. Laboratory testing and combustion theory has shown that simply selecting a maximum Wobbe is not sufficient to address incomplete combustion over a range of gas compositions (especially for natural gas with heating values in excess of about 1,100 Btu/scf. However, this limitation can be overcome by selecting a more conservative maximum Wobbe Number coupled with an additional parameter such as heating value.

6.0.6 The “art” is in selecting additional parameters to address the remaining end use effects. Experience has shown that specifying a maximum Heating Value can address auto-ignition (or knock), flashback, combustion dynamics, and when coupled with the Wobbe Number, incomplete combustion and sooting. Alternatively, the Work Group found that a maximum value for a specified fraction of hydrocarbons, such as butanes plus can address these same parameters.

7.0 Options for Managing Interchangeability

7.0.1 There are three options for managing interchangeability:

- Management at the production source
- Management prior to introduction into the transmission pipeline system, and

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

- Management at the point of end use

Each of these options is described below and placed in context with the existing infrastructure.

7.1 Management at the Production Source

7.1.1 Natural gas interchangeability can be managed near the source of production. For domestic supply, this generally entails treating and processing gas to reduce concentrations of inerts, contaminants such as corrosive compounds and hydrocarbons other than methane. Gas is treated to reduce inerts and corrosive compounds such as water, hydrogen sulfide, carbon dioxide and nitrogen. Gas is processed through refrigeration, lean oil absorption, or cryogenic extraction to reduce various levels of natural gas liquids (NGLs) such as ethane, propane, butanes, pentanes and hexanes plus. The level of NGL extraction is dependent upon the technology, existing NGL infrastructure, economics and known gas specification requirements. Some existing and future domestic supply sources do not have access to processing plants and may not be sufficient in volume to justify the cost of processing. In this case, pipeline blending (contract) may be the preferred option as to not limit supplies which otherwise cannot be processed. The gas delivered into a pipeline will have distinct composition and characteristics depending on the extent of any treatment or processing as well as the original gas source and composition. The gas quality and interchangeability characteristics of treated/processed “conventional” natural gas and coal-bed methane, for example, can vary significantly, and gases of these two types may not be interchangeable with each other.

7.1.2 Imported LNG is processed at the production source primarily for the removal of NGL components, such as pentanes and hexanes plus, that would freeze during the liquefaction process. This means LNG generally does not contain the heavier hydrocarbons but does contain appreciable concentrations of ethane and propane with some butane(s). Many LNG-importing countries have developed their gas distribution infrastructure based on regasified LNG and have set minimum heating value standards, which are relatively high compared to the North American market. It is important to note that Japan, Korea and Taiwan import over 70% of globally traded LNG, and their gas specification of relatively high heating value has served as the basis of many current and future LNG supplies. LNG suppliers could add equipment to remove additional NGLs from their gas stream but have elected to produce a higher Btu content LNG more compatible with world markets. Also, many LNG supply regions lack infrastructure and markets for extracted ethane and propane products. In addition, economics favor leaving some NGLs in the gas as transportation and sales are executed on an energy (Dekatherm) basis. Reducing the NGL content reduces the energy value of the LNG and reduces the economic value of each cargo for the supplier.

7.2 Management Prior to Introduction Into the Transmission Pipeline System

7.2.1 Imported LNG can be processed to reduce the NGL content at the LNG receiving terminal. LNG terminal operators or shippers contracting with terminal operators or third parties can use NGL separation technology to achieve the desired interchangeability indices. The feasibility of this option is dependent upon the economics of NGL extraction

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

and the proximity of local markets and/or available infrastructure to transport the NGL to market. Given these facts, this option is viable only in the Gulf Coast (Texas and Louisiana) or other coastal locations where there is sufficient NGL demand and infrastructure. NGL extraction economics in the Gulf Coast have weakened in more recent years due to the impact of escalating natural gas prices. There are no NGL extraction plants associated with the three existing LNG terminals along the East Coast. There is a small third party slipstream NGL extraction facility processing a portion of the regasified LNG from the Gulf Coast LNG terminal.

7.2.2 In theory, LNG terminal operators have the option of using an extracted NGL product stream as a fuel source, for example, to generate power; however, this option is generally not viable because the NGL supply would likely exceed the energy consumed and varies in volume and composition with changing LNG supplies.

7.2.3 Injection of an inert gas is an option at the LNG terminal. There are three types of inerts that can be used:

- Nitrogen
- Air, and
- Flue gas

7.2.4 Inert gas injection reduces the heating value, increases the specific gravity of the gas, and as a consequence reduces the Wobbe Number and changes other interchangeability indices. For example, injection of one (1) percent by volume of nitrogen or air reduces the Wobbe Number of natural gas by approximately 1.3 percent.⁷

7.2.5 The costs of air injection are significantly lower than nitrogen injection. Air injection has been historically used for managing interchangeability. It is common in propane/air peak shaving and is also used at city gate stations in some regions of the US where the base natural gas supplies currently contain less inerts than the historical appliance adjustment gases.

7.2.6 There is one drawback with air injection, as it introduces oxygen into the natural gas; for example, injection of 3 percent air by volume results in an oxygen level to approximately 0.6 mol%. These oxygen levels may not be acceptable because of current tariff restrictions, concerns about pipeline integrity, underground gas storage, and impact on feedstock plants and other end uses, such as peak shaving.

7.2.7 Injection of flue gas is an option; however, it requires that a source of flue gas be in immediate proximity of the terminal. None of the domestic terminals use flue gas injection. In addition, the presence of oxygen, other combustion products such as CO₂ and moisture in the flue gas pose a more severe risk to pipeline integrity as these components can all contribute to corrosion of steel. Special care may need to be taken for LNG sources that use this technology and are upstream of underground storage fields or other locations

⁷ The reduction in a parameter such as Wobbe Number will be greater than the simple reduction in heating value alone as the specific gravity is also increased.

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

that may operate as a wet gas system, since corrosion at those locations could occur as a result of the formation of carbonic acid.

7.2.8 Blending within an LNG receiving terminal is conceivably an option. An LNG terminal operator may have the option to blend two LNG sources to achieve an overall specification; however, this may create operational issues and to rely on this option for all but a small portion of the supply would reduce overall terminal capacity. As such, blending is not a viable option for terminal operators.

7.2.9 Blending applied by the pipeline operator is also technically feasible. However, widespread use of blending is out of the direct control of the pipeline operator. The transportation of natural gas is governed by daily and sometimes more frequent nomination of volumes and specification of receipt and delivery points by shippers. Consequently, any pipeline blending that occurs is coincidental and historically has not been planned to achieve a specific end point or specification. Even in pipelines where blending currently occurs, this practice is thus not a consistently reliable method of interchangeability management.

7.2.10 It is important to note that following implementation of FERC Order 636, significant numbers of producers have entered into contracts with pipelines to transport their gas without prior NGL removal. This situation resulted as the production sources developed near the existing pipeline infrastructure and producers determined that it was either infeasible or not economically attractive to extract NGLs. The volume of any one source tended to be small, approximately less than 10 Mmscfd, and pipelines were often able to take advantage of incidental blending to achieve a delivered gas that was acceptable.

7.2.11 In summary, of all the options described above, inert injection is the most widely investigated and implemented option to date for North America LNG imports. NGL separation may be a viable option in particular situations. Both of these solutions increase the cost of the natural gas supply because of the additional costs of conditioning the LNG stream. .

7.3 Management at the Point of End Use

7.3.1 Some gas utilities in the Rocky Mountain Region use air injection at the city gate stations. This inert gas injection serves to condition their mid-continent supply gas from a Wobbe Number of 1330 to 1200; appliances in this region were originally adjusted for high nitrogen (low Wobbe Number) natural gas, and the higher Wobbe Number supplies were shown to result in interchangeability problems. This management process is similar to that described in section 7.2 *Management Prior to Introduction Into the Transmission Pipeline System*. It should be noted that this gas quality management practice in the Rocky Mountain Region is the exception in the current national LDC infrastructure. For some large industrial natural gas customers in France, such as several glass manufacturing factories, air injection equipment has been used to stabilize the quality of their fuel gas.

7.3.2 Another option is to inspect end use equipment such as gas appliances and if necessary, to adjust improperly operating equipment for changing gas quality. To be

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

effective, this option requires a high percentage of installed equipment to be inspected and adjusted by trained personnel. This approach is expensive and requires multiple years for complete implementation. Although difficult when large numbers of customers are involved, this approach has been effective in different parts of the country.

7.3.3 There are also options that can provide greater clarity for equipment manufacturers and aid in development of North American interchangeability standards. The options include

- Addition of specificity to design and installation standards
- Development and implementation of a limit-gas testing regime

Each of these is described in greater detail below.

7.3.4 In general, end use equipment is designed presuming that a gas stream of an unchanging known composition will be the sole and continued fuel source. However, as described above, the composition of the domestic natural gas has evolved over time, and in addition, the composition of natural gas varies from region to region within the country. Manufacturers could adjust the design basis for particular end use applications, especially for low emission equipment. Also manufacturers could adjust combustion equipment at the factory and seal the equipment to ensure that it arrives for installation in a configuration consistent with the design basis.

7.3.5 End use equipment manufacturers do provide instructions for installing and placing equipment into service. Manufacturers and even the organizations that publish national consensus standards could develop installation and adjustment standards that ensure that the equipment is installed and placed into service according to the equipment design. The standards could also provide guidance for installers in the event that factory settings are found to be out of spec.

7.3.6 Much of the end use equipment in place today is placed into service using one test gas, usually whatever gas is delivered at the time the testing is undertaken. National consensus standards developing organizations or manufacturers working together could define a multiple test-gas testing regime. This is the approach that is used in the European Community for appliances. A benefit of this approach is that it defines the working range for end use equipment. The working range can then be factored into broader interchangeability standards.

7.3.7 In summary, the options in 7.3.3 are of value for equipment that will be manufactured, installed and placed into operation in the future. Applying these options for end use applications with large fleets in place, such as appliances will be extremely costly.

8.0 Findings

1. The heating value specification alone, as used in some tariffs today, is not an adequate measure for gas interchangeability. However, it may be an appropriate

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

- parameter to assure interchangeability if used in conjunction with other specifications.⁸
2. Most pipeline tariffs do not contain adequate specifications to define or set interchangeability limits. Most gas distribution company tariffs do not contain them either.
 3. There is a large body of work that has been conducted by the American Gas Association and other research bodies on interchangeability and interchangeability indices. In addition, a number of pipeline and distribution companies have amassed first-hand operating experience in managing interchangeability. Other parts of the world including Europe have also successfully instituted programs to manage interchangeability. However, it is not known to what extent this research and experience applies to low emissions combustion technology.
 4. Gas interchangeability indices represent the best starting point for developing guidelines for natural gas interchangeability.
 5. The Wobbe Number provides the most efficient and robust single index and measure of gas interchangeability. There are limitations to the applicability of the Wobbe Number, and additional specifications are required to address combustion performance, emissions and non-combustion requirements.
 6. Gas interchangeability guidelines must consider historical regional gas compositional variability as well as future gas supply trends. Interchangeability is an issue for both domestic gas supply and LNG imports.
 7. European experience suggests that understanding the historical range of gases distributed in the U.S. is critical in establishing future interchangeability guidelines.
 8. Presently, there are limited data characterizing the changes that have occurred over time in natural gas composition on a regional basis.
 9. Combustion equipment in use today is characterized by two major categories of technology, conventional and low emissions. Low emissions combustion technology, developed primarily in response to Federal and State emissions requirements, is relatively new. Current low emissions combustion technology utilizes various control systems, exhaust treatments, designs to achieve lower emissions and can vary by application. In some applications, the newer technology improves fuel efficiency and reduces cost.
 10. Varying natural gas composition beyond acceptable limits can have the following effects in combustion equipment:

⁸ The Work Group agreed to standardize on a set of terms to use in defining interchangeability. "Indices" are defined in AGA Bulletin 36 and Weaver (e.g. - incomplete combustion index, yellow tipping, etc.). "Parameters" are used to define ranges or limits for components expressed as composition. "Specifications" encompass both indices and parameters.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

- a. In appliances, it can result in soot formation, elevated levels of carbon monoxide and pollutant emissions, and yellow tipping. It can also shorten heat exchanger life, and cause nuisance shutdowns from extinguished pilots or tripping of safety switches.
 - b. In reciprocating engines, it can result in engine knock, negative changes in engine performance, and decreased parts life.
 - c. In combustion turbines, it can result in increased emissions, reduced reliability/availability, and decreased parts life.
 - d. In industrial boilers, furnaces and heaters, it can result in degraded performance, damage to heat transfer equipment and noncompliance with emission requirements.
 - e. In all end use equipment, it can result in flame instability, including lifting and blowout in appliances.
11. For traditional end use equipment, evaluation of interchangeability begins with the concept of adjustment gas. The adjustment gas may be specified as the average of a consistent historical supply or as target values established by the utility. In cases where the historical supply has varied and there is no established target, the adjustment gas concept is more difficult to develop and quantify.
 12. Varying gas composition beyond acceptable limits can be problematic in non-combustion-related applications where natural gas is used as a manufacturing feedstock or in peak shaving liquefaction plants, because historical gas compositions were used as the basis for process design and optimization of operating units. More specifically, domestic LNG peak shaving liquefaction plants will most likely require retrofits to continue operations with regasified LNG as feedstock. Propane-air peak shaving operations will also likely require retrofits and/or additional controls to continue operations.
 13. Gas interchangeability guidelines must consider the full range of requirements for all end use equipment.
 14. Fluctuations in composition beyond the limits equipment is tuned to receive, particularly if it occurs over a short period of time, is likely to reduce the ability of some equipment to perform as intended by the manufacturer.
 15. Combustion turbine operation with fuel gas supplies near or above 1400 Wobbe occurs at world-wide locations; however proper operation, including meeting emission limits, of some existing equipment may require installation of additional equipment and control systems, including fuel pre-heat requirements. Additional constituent limits may be necessary (such as butanes+, propane etc) to address

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

- manufacturer concerns until research/data are available to better understand the impact on operability of this equipment.
16. The time rate of change of fuel composition changes is problematic for some end use applications, including combustion turbines. As a practical matter, in general, the work group found that gas composition variability rate of change should not be a significant issue and should meet existing turbine manufacturers' requirements.
 17. Modern gas internal combustion engines can operate safely and efficiently over a reasonable range of Wobbe and Heating Value numbers with closed loop controls. However, as indicated earlier in the paper, excessive concentrations of higher hydrocarbon constituents such as propane and ethane results in low Methane Numbers and damaging engine knock. Limits on these constituent limits in addition to Wobbe and Heating Value ranges may be necessary to satisfy manufacturer' fuel specifications.
 18. Presently, there are limited publicly and readily available data for the full range of end use equipment and gas supplies.
 19. Historical interchangeability indices have been widely used for conventional combustion appliances and are recognized default specifications when actual operating data are unavailable.
 20. Limited testing and research conducted by distribution companies, equipment manufacturers and researchers indicate that historical indices may not adequately account for the full range of effects with low emissions technology.
 21. The European experience in gas interchangeability highlights important issues for establishing U. S. interchangeability guidelines and demonstrates significant differences from the U. S. situation.
 22. Interchangeability specifications can be used to define an operating regime that addresses end use effects, such as auto-ignition, stability, incomplete combustion and pollutant formation among others. The Work Group found that based on current and projected available gas supply, at least two interchangeability specifications are required to adequately address the end use effects.
 22. Gas system infrastructure impacts must be considered when supply compositions change for extended periods of time. The impacts when shifting to a dry, leaner supply source may include failure of certain gas transmission and distribution piping component seals and gaskets in valves, pipe clamps, joint sealants and other mechanical components. Additional infrastructure issues include impacts to custody transfer gas measurement techniques (thermal vs. volumetric billing) and related gas accounting issues.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

23. In the majority of cases, interchangeability is best managed at two key points along the value chain, at the origin of supply or prior to delivery into the existing pipeline infrastructure.
24. Overly broad limits in the interchangeability specifications may result in reduced reliability, increased emissions, and decreased safety on end use equipment, and consequently higher costs to consumers. On the other hand, unduly conservative restrictions on the interchangeability specifications due to lack of data may result in both limited supply options and higher costs to the consumers.
25. Interstate transmission pipelines transport 80 percent of the natural gas. Approximately, 20 percent of the natural gas consumed is produced and consumed within the same state. The FERC has jurisdiction over interstate transmission pipelines while State agencies have jurisdiction over intrastate transmission.
26. Gas supply compositions within the US vary by region depending on demand, available supply, the degree of processing and pipeline blending. The 1992 GRI survey of gas supplies included gas composition data for over 6,800 samples from 26 cities in the United States. The absolute minimum and maximum Wobbe numbers in the data were 1201 and 1418, respectively. Most of the data showed a narrower range of Wobbe numbers, with tenth and ninetieth percentile levels of 1331 and 1357, respectively. The team found that the historical range of gas compositions reported in the 1992 survey has been successfully utilized; more recent gas composition data is currently being collected. However, it is critical to recognize that not all gases within the absolute range are interchangeable with each other. The range of interchangeability for a given region is considerably tighter than the variation between regions of the country.
27. Complete management of gas interchangeability requires specification of both minimum and maximum limits for Wobbe numbers. The issue of supplies with increasing Wobbe numbers is currently more widespread than the issue of supplies with decreasing Wobbe numbers. Furthermore, a number of utilities with low Wobbe supplies have implemented interchangeability management practices in the past, while many utilities already receiving or anticipating receipts of higher Wobbe number supplies have little to no experience in interchangeability management. The Team's focus was therefore evaluation of maximum Wobbe limits. The Team recognized the equal importance of a minimum Wobbe limit and the need for inclusion in the proposed research program.
28. It has become apparent through the work of the NGC+ Interchangeability Technical Team that significant data gaps exist that inhibit non-traditional supplies from entering the North American market. There is general recognition that a collaborative effort will be necessary to conduct research and obtain essential information necessary to maximize supplies into the marketplace including D.O.E., equipment manufacturers, suppliers, pipelines, LDC's and other industry trade groups. As a result, to meet the recommendations of the NPC Report, it is proposed that the abovementioned research be accomplished within a two-year time frame

White Paper on Natural Gas Interchangeability And Non-Combustion End Use

beginning in 2005. This aggressive schedule is necessary to minimize risks associated with any interim guidelines adopted while awaiting the additional information needed to allow LNG imports and additional domestic supplies maximum penetration into the North American market.

9.0 Recommendations

1. The Work Group recommends the completion of work started by this group to gather and analyze historical composition data that will better characterize the change in natural gas supply on a region-by-region and market-by-market basis. This data gathering process must be standardized so that on-going data collection can be used to develop a better understanding of shifts to the historical compositions.
2. The Work Group recommends the completion of work started by this group on the effects of changing supply on particular end use equipment.
3. The Work Group recommends that appliance manufacturers and equipment certifying organizations for gas burning equipment consider adopting limit gases testing that is representative of current and future supplies. Such testing as part of the design certification process will help ensure that new appliances and equipment can deliver safe and reliable performance under varying and changing gas supply conditions. In addition, an education process is recommended promoting appliance inspections and adjustment during a period of transition to new gas supplies.
4. Additional research must be conducted to define the compositional limits of natural gas to support development of longer-term interchangeability guidelines for low emission and high efficiency combustion designs.
5. The Work Group recognized the value in adopting a national range for key parameters such as the Wobbe Number to provide certainty for producers and suppliers. This specification is equally important for domestic supply and for imported LNG. However, the Work Group also recognized the need for flexibility since certain areas may be able to utilize a wider range of gas compositions than other areas.
6. While adopting a wide national range for key specifications such as the Wobbe Number is important for supply flexibility, acceptable interchangeability ranges for specific regions or market areas may be more restrictive as a consequence of historical compositions and corresponding end use settings.
7. The Work Group supports the use of processes for development of interchangeability specifications based on the Wobbe Number and supplemental parameters that can be applied regionally, locally, and nationally. These processes have been used in a number of local and regional interchangeability studies over the past three decades. Appropriate processes incorporate the following elements:

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

- a. Historical gas supply characteristics to accommodate current end users and equipment requirements,
 - b. End use equipment gas interchangeability requirements based on published end use equipment test data and to the extent required, additional testing over the range of gases representative of current and future supplies,
 - c. Consideration of interchangeability management options and costs, and
 - d. Development of numerical specifications.
8. The NGC+ Interchangeability Work Group has identified several “information gaps” that must be addressed to better understand the overall impacts of gas interchangeability in North America. These gaps must be addressed to provide the maximum level of supply flexibility considering current global LNG import composition profiles as well as evolving domestic supply compositions. More importantly, reaching consensus among major stakeholders in the gas supply, transportation and end use value chain is predicated on filling these gaps in a timely fashion. Consensus on interim guidelines relies upon establishing a process and timeframe for filling the technical gaps based on sound scientific analysis and testing.
 9. The Work Group recommends that a transition plan be adopted given the lack of readily available historical data to characterize both the change in natural gas supply and in end use equipment. The transition plan is based on adoption of recommendations described above and adoption of interim interchangeability guidelines given below. The purpose of the transition period is to maximize supply while gaining additional experience and knowledge.
 10. The work group recognizes that compositional limits for specific gas constituents may be needed (in addition to the proposed Interim Guidelines to address non-combustion feedstock issues including but not limited to domestic LNG peak shaving liquefaction plants. The work group also recognizes that imposing general constituent limits would be inappropriate because the design bases for these facilities vary with the historical supplies delivered at the time of the facilities’ construction. These constituents include:

Non-methane Hydrocarbons

- Ethane
- Propane
- Butane(s)
- Pentane(s)
- Hexanes+

Inerts

- Nitrogen
- Carbon Dioxide

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Furthermore, the work group recommends that each facility/process impacted by changing supply composition be evaluated on an individual basis. Facilities that will receive supplies exceeding design feedstock constituent limits will require retrofit to maintain design capacity and efficiency of operation. Retrofits will likely vary from facility to facility and will incur new and unplanned operating and capital expenditures. Evaluation of these retrofits and associated cost burdens must be considered during the Regulatory approval process.

11. The Work Group recommends that interim interchangeability guidelines be applied during a transition period of no more than three years so that the data gaps can be closed and interchangeability guidelines/standards can be formally developed. Alternative language was suggested as well, and long-term guidelines will be developed within a timeframe to be defined.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Recommendations for Interim Guidelines for Gas Interchangeability

Background

The Work Group recognizes that there is a need to maximize the available supply and at the same time meet the specifications of end use equipment. As stated above, the Work Group found that there are gaps in the data regarding regional characteristics as well as the specific limitations and tolerances for end use equipment. The Work Group recommended the adoption of a transition period to gather and analyze additional data and conduct more testing to provide a basis for establishing more definitive guidelines. Specific gaps that must be addressed during this transition period form an integral part of this recommendation. Ultimately, the desire is to create as much flexibility in supply with which end use equipment can operate, in a manner that does not materially change operational safety, efficiency, performance or materially increase air pollutant emissions.

The Work Group discussed at length development of numerical guidelines for gas interchangeability. At this time, the Work Group recommends interim guidelines for gas interchangeability based on: (1) extensive data and analysis for traditional gas appliances and combustion behavior in appliances, and (2) the lack of data on gas interchangeability for a broad range of other end use applications. The interim period for use of these guidelines depends upon the filling of major data gaps for end uses (see Table 1 and Table 2) and consensus needed for interchangeability requirements of these end uses, which is forecasted to require 2 to 3 years. After that time period, it is envisioned that development of more complete and longer-term guidelines can be pursued.

The interim guidelines are for gases delivered to points in the gas transportation system most closely associated with end users: gases delivered to local distribution companies (LDCs). The guidelines do not necessarily apply directly to points upstream in the transportation system where blending, gas processing, and other factors may suggest that gases outside the ranges of the guidelines will still satisfy the guidelines at LDC city gates. The Work Group is continuing to investigate development of guidelines for points upstream.

Field installation and adjustment represent a set of initial conditions under which interchangeability must be considered. Therefore, the interim guidelines focus on consistency with historical gases (also referred to as “adjustment gases”) since locally, historical gases represent the basis for field installation and adjustment of appliances. The Work Group used the 1992 GRI report on natural gas composition in 26 major US cities⁹ as the historical baseline for gases nationally and regionally. The use of these data is the basis for establishing interim guidelines for the ranges of interchangeability. At this time, it is conservative to limit the boundaries for interchangeability ranges to gases seen historically in the U. S. gas system.

⁹ “Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States,” Gas Research Institute, March 1992, GRI-92/0123.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

The interim guideline limits proposed in this document have been developed for new gas supplies to those market areas without extended experience with gas supplies characterized by Wobbe Numbers higher than 1,400 or gross heating values higher than 1,110 Btu/scf.¹⁰ The limiting values were developed using conventional interchangeability index calculations based on an adjustment gas corresponding to the mean of the annual average composition data in the 1992 GRI composition report.¹¹ The 1992 “average” gas was characterized by a Wobbe Number of 1345 and gross Heating Value of 1035 Btu/scf. This “average” gas is assumed to be a reasonable estimate for an average adjustment gas in the US. It is important to note that the limiting values in the interim guidelines simply serve to establish boundaries for market areas that have received historical gas supplies with gas quality close to the 1992 reported national mean and that have experienced successful end use with these gas supplies. These boundaries should be applicable until additional research and/or experience has clearly demonstrated that supplies above the caps do not negatively impact end users in these market areas.

¹⁰ Based on gross or higher heating value (HHV) at standard conditions of 14.73 psia, 60°F, dry, real basis.

¹¹ Details of these calculations are given in Appendix G.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Interim Guidelines

- A. A range of plus and minus 4% Wobbe Number Variation from Local Historical Average Gas or, alternatively, Established Adjustment or Target Gas for the service territory.¹

Subject to:

Maximum Wobbe Number Limit: 1,400²

Maximum Heating Value Limit: 1,110 Btu/scf²

- B. Additional Composition maximum limits:¹

Maximum Butanes+: 1.5 mole percent

Maximum Total Inerts: 4 mole percent

- C. EXCEPTION: Service territories with demonstrated experience³ with supplies exceeding these Wobbe, Heating Value and/or Composition Limits may continue to use supplies conforming to this experience as long as it does not unduly contribute to safety and utilization problems of end use equipment.

Notes:

¹ Experience has shown that using this plus/minus four percent formula in combination with the compositional limits will result in a local Wobbe range that is above 1,200.

² Based on gross or higher heating value (HHV) at standard conditions of 14.73 psia, 60°F, dry, real basis.

³ Demonstrated experience refers to actual end use experience established by end-use testing and monitoring programs.

Table 1 Data Gaps -Combustion Applications

COMMON REQUIREMENTS		ADDITIONAL REQUIREMENTS/NOTES			
White Paper on Natural Gas Interchangeability And Non-Combustion End Use END-USE EQUIPMENT		Appliances	Turbines & Micro-turbines & Power Boilers	Industrial & Commercial Burners	Stationary & Vehicle Engines
A.	<p>Review and Classification of Equipment</p> <ul style="list-style-type: none"> Types of equipment, burners. List of manufacturers. Rank by sensitivity to fuel composition. Emissions issues and mitigation strategies. 	<ul style="list-style-type: none"> Review existing interchangeability project results. Work with GAMA and others to identify new appliance types. 	<ul style="list-style-type: none"> All major types and manufacturers can be identified. 	<ul style="list-style-type: none"> Classify burners and combustion systems by types. Must consider legacy, operating burners and new types under development. 	<ul style="list-style-type: none"> Survey of manufacturers and equipment models. Review operations and emissions measurements and requirements.
B.	<p>Collection of Available Data</p> <ul style="list-style-type: none"> Previous US and international studies (GTI, TIAX, SoCalGas, etc). Manufacturers' data on <ul style="list-style-type: none"> Emissions, Efficiency, Service life, Combustion changes, Mitigation alternatives and costs. Impacts of slow and rapid fuel gas changes. Determination of major data gaps. 	<ul style="list-style-type: none"> Standardizing results of previous interchange-ability studies. Identify common conclusions Previous data for interchangeability parameters (Wobbe, Weaver, AGA Bulletin #36, etc), CO production. 	<ul style="list-style-type: none"> Most data is proprietary and in the hands of manufacturers. Collect published data and performance data from users. 	<ul style="list-style-type: none"> Data may not currently be available. Performance data from different manufacturers is not on a consistent basis. 	<ul style="list-style-type: none"> Collect as much manufacturer data as possible. Collect data from publications and users.
C.	<p>Determination of Testing Needs and Standardized Testing Protocols</p> <ul style="list-style-type: none"> Documentation of test methods. Repeatability of testing. Selection and measurement of all pertinent parameters. Develop test gas strategies: <ul style="list-style-type: none"> Define acceptability criteria (Btu, Wobbe, Methane Number, other), Define range of acceptability, Testing at limits of acceptability range, Compositional issues (C₁, C₂, C₃, C₄, etc). Specification of clocking and tuning strategies. Fundamental combustion properties of natural gas mixtures 	<ul style="list-style-type: none"> Evaluation of current standards for appliance testing and emissions limits. Long-term testing of sensitive appliances. Statistical analysis may replace some testing. 	<ul style="list-style-type: none"> Testing and resulting data may be proprietary Measurement methods must be established Method development may be required. C₄+ issues Significance of Methane Number. Fundamental property evaluation, combustion stability etc. 	<ul style="list-style-type: none"> Method development may be necessary. Selected testing methods to be based on combustion practice and made public. 	
D.	<p>Equipment Testing</p> <ul style="list-style-type: none"> Possible field and/or laboratory testing. Examine interchangeability parameters under controlled conditions. Fill data gaps. 	<ul style="list-style-type: none"> Statistically relevant group of appliances with a range of types and ages. Statistical evaluation of appliance "mal-adjustment" over time. 	<ul style="list-style-type: none"> Test stand studies preferred whenever possible. Testing with working power turbines, only if necessary. 	<ul style="list-style-type: none"> Representative examples of the most sensitive types of burners and combustion systems to be tested in the laboratory. Most sensitive burners to be field tested. 	<ul style="list-style-type: none"> Test engines in lab setting. Test existing and older engines in place.
E.	<p>Data Analysis and Expected Results</p> <ul style="list-style-type: none"> Identify relationships between performance and fuel composition, if these exist. Establish/confirm applicable interchangeability parameters. Predictive tools for effect of changing fuel composition on performance. 	<ul style="list-style-type: none"> Determine if limit gas testing is recommended to enhance equipment flexibility with varying fuel supply compositions. 	<ul style="list-style-type: none"> Recommended equipment. Retrofits and additional long-term testing if required. 	<ul style="list-style-type: none"> Recommended equipment Retrofits and additional long-term testing is required. New types of indices may be developed. 	<ul style="list-style-type: none"> Recommended controls and equipment retrofits. Additional long term testing if required.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Table 1 Data Gaps -Combustion Applications

COMMON REQUIREMENTS	ADDITIONAL REQUIREMENTS/NOTES			
END-USE EQUIPMENT	Appliances	Turbines & Micro-turbines & Power Boilers	Industrial & Commercial Burners	Stationary & Vehicle Engines
<p>F. Review and Classification of Equipment</p> <ul style="list-style-type: none"> • Types of equipment, burners. • List of manufacturers. • Rank by sensitivity to fuel composition. • Emissions issues and mitigation strategies. 	<ul style="list-style-type: none"> • Review existing interchangeability project results. • Work with GAMA and others to identify new appliance types. 	<ul style="list-style-type: none"> • All major types and manufacturers can be identified. 	<ul style="list-style-type: none"> • Classify burners and combustion systems by types. • Must consider legacy, operating burners and new types under development. 	<ul style="list-style-type: none"> • Survey of manufacturers and equipment models. • Review operations and emissions measurements and requirements.
<p>G. Collection of Available Data</p> <ul style="list-style-type: none"> • Previous US and international studies (GTI, TIAX, SoCalGas, etc). • Manufacturers' data on <ul style="list-style-type: none"> – Emissions, – Efficiency, – Service life, – Combustion changes, – Mitigation alternatives and costs. • Impacts of slow and rapid fuel gas changes. • Determination of major data gaps. 	<ul style="list-style-type: none"> • Standardizing results of previous interchange-ability studies. • Identify common conclusions • Previous data for interchangeability parameters (Wobbe, Weaver, AGA Bulletin #36, etc), • CO production. 	<ul style="list-style-type: none"> • Most data is proprietary and in the hands of manufacturers. • Collect published data and performance data from users. 	<ul style="list-style-type: none"> • Data may not currently be available. • Performance data from different manufacturers is not on a consistent basis. 	<ul style="list-style-type: none"> • Collect as much manufacturer data as possible. • Collect data from publications and users.
<p>H. Determination of Testing Needs and Standardized Testing Protocols</p> <ul style="list-style-type: none"> • Documentation of test methods. • Repeatability of testing. • Selection and measurement of all pertinent parameters. • Develop test gas strategies: <ul style="list-style-type: none"> – Define acceptability criteria (Btu, Wobbe, Methane Number, other), – Define range of acceptability, – Testing at limits of acceptability range, – Compositional issues (C₁, C₂, C₃, C₄, etc). • Specification of clocking and tuning strategies. • Fundamental combustion properties of natural gas mixtures 	<ul style="list-style-type: none"> • Evaluation of current standards for appliance testing and emissions limits. • Long-term testing of sensitive appliances. • Statistical analysis may replace some testing. 	<ul style="list-style-type: none"> • Testing and resulting data may be proprietary • Measurement methods must be established • Method development may be required. • C₄+ issues • Significance of Methane Number. • Fundamental property evaluation, combustion stability etc. 	<ul style="list-style-type: none"> • Method development may be necessary. • Selected testing methods to be based on combustion practice and made public. 	

Table 1 Data Gaps -Combustion Applications

COMMON REQUIREMENTS	ADDITIONAL REQUIREMENTS/NOTES			
END-USE EQUIPMENT	Appliances	Turbines & Micro-turbines & Power Boilers	Industrial & Commercial Burners	Stationary & Vehicle Engines
<p>I. Review and Classification of Equipment</p> <ul style="list-style-type: none"> Types of equipment, burners. List of manufacturers. Rank by sensitivity to fuel composition. Emissions issues and mitigation strategies. 	<ul style="list-style-type: none"> Review existing interchangeability project results. Work with GAMA and others to identify new appliance types. 	<ul style="list-style-type: none"> All major types and manufacturers can be identified. 	<ul style="list-style-type: none"> Classify burners and combustion systems by types. Must consider legacy, operating burners and new types under development. 	<ul style="list-style-type: none"> Survey of manufacturers and equipment models. Review operations and emissions measurements and requirements.
<p>J. Collection of Available Data</p> <ul style="list-style-type: none"> Previous US and international studies (GTI, TIAX, SoCalGas, etc). Manufacturers' data on <ul style="list-style-type: none"> Emissions, Efficiency, Service life, Combustion changes, Mitigation alternatives and costs. Impacts of slow and rapid fuel gas changes. Determination of major data gaps. 	<ul style="list-style-type: none"> Standardizing results of previous interchange-ability studies. Identify common conclusions Previous data for interchangeability parameters (Wobbe, Weaver, AGA Bulletin #36, etc), CO production. 	<ul style="list-style-type: none"> Most data is proprietary and in the hands of manufacturers. Collect published data and performance data from users. 	<ul style="list-style-type: none"> Data may not currently be available. Performance data from different manufacturers is not on a consistent basis. 	<ul style="list-style-type: none"> Collect as much manufacturer data as possible. Collect data from publications and users.
<p>K. Determination of Testing Needs and Standardized Testing Protocols</p> <ul style="list-style-type: none"> Documentation of test methods. Repeatability of testing. Selection and measurement of all pertinent parameters. Develop test gas strategies: <ul style="list-style-type: none"> Define acceptability criteria (Btu, Wobbe, Methane Number, other), Define range of acceptability, Testing at limits of acceptability range, Compositional issues (C₁, C₂, C₃, C₄, etc). Specification of clocking and tuning strategies. Fundamental combustion properties of natural gas mixtures 	<ul style="list-style-type: none"> Evaluation of current standards for appliance testing and emissions limits. Long-term testing of sensitive appliances. Statistical analysis may replace some testing. 	<ul style="list-style-type: none"> Testing and resulting data may be proprietary Measurement methods must be established Method development may be required. C₄+ issues Significance of Methane Number. Fundamental property evaluation, combustion stability etc. 	<ul style="list-style-type: none"> Method development may be necessary. Selected testing methods to be based on combustion practice and made public. 	

Table 1 Data Gaps -Combustion Applications

COMMON REQUIREMENTS	ADDITIONAL REQUIREMENTS/NOTES			
END-USE EQUIPMENT	Appliances	Turbines & Micro-turbines & Power Boilers	Industrial & Commercial Burners	Stationary & Vehicle Engines
<p>L. Review and Classification of Equipment</p> <ul style="list-style-type: none"> • Types of equipment, burners. • List of manufacturers. • Rank by sensitivity to fuel composition. • Emissions issues and mitigation strategies. 	<ul style="list-style-type: none"> • Review existing interchangeability project results. • Work with GAMA and others to identify new appliance types. 	<ul style="list-style-type: none"> • All major types and manufacturers can be identified. 	<ul style="list-style-type: none"> • Classify burners and combustion systems by types. • Must consider legacy, operating burners and new types under development. 	<ul style="list-style-type: none"> • Survey of manufacturers and equipment models. • Review operations and emissions measurements and requirements.
<p>M. Collection of Available Data</p> <ul style="list-style-type: none"> • Previous US and international studies (GTI, TIAX, SoCalGas, etc). • Manufacturers' data on <ul style="list-style-type: none"> – Emissions, – Efficiency, – Service life, – Combustion changes, – Mitigation alternatives and costs. • Impacts of slow and rapid fuel gas changes. • Determination of major data gaps. 	<ul style="list-style-type: none"> • Standardizing results of previous interchange-ability studies. • Identify common conclusions • Previous data for interchangeability parameters (Wobbe, Weaver, AGA Bulletin #36, etc), • CO production. 	<ul style="list-style-type: none"> • Most data is proprietary and in the hands of manufacturers. • Collect published data and performance data from users. 	<ul style="list-style-type: none"> • Data may not currently be available. • Performance data from different manufacturers is not on a consistent basis. 	<ul style="list-style-type: none"> • Collect as much manufacturer data as possible. • Collect data from publications and users.
<p>N. Determination of Testing Needs and Standardized Testing Protocols</p> <ul style="list-style-type: none"> • Documentation of test methods. • Repeatability of testing. • Selection and measurement of all pertinent parameters. • Develop test gas strategies: <ul style="list-style-type: none"> – Define acceptability criteria (Btu, Wobbe, Methane Number, other), – Define range of acceptability, – Testing at limits of acceptability range, – Compositional issues (C₁, C₂, C₃, C₄, etc). • Specification of clocking and tuning strategies. • Fundamental combustion properties of natural gas mixtures 	<ul style="list-style-type: none"> • Evaluation of current standards for appliance testing and emissions limits. • Long-term testing of sensitive appliances. • Statistical analysis may replace some testing. 	<ul style="list-style-type: none"> • Testing and resulting data may be proprietary • Measurement methods must be established • Method development may be required. • C₄+ issues • Significance of Methane Number. • Fundamental property evaluation, combustion stability etc. 	<ul style="list-style-type: none"> • Method development may be necessary. • Selected testing methods to be based on combustion practice and made public. 	

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Table 2

Data Gaps Non-Combustion & Feedstock Applications

- Categories:
 - Chemical feedstock (ammonia, fertilizer, reforming, LNG peak shaving liquefaction, etc)
 - Fuel cells.

- Identify and survey users/developers.
- Determine sensitivity to changes in fuel composition.
- Summaries of ranges of acceptable fuel composition and impact of changes
- Document necessary process retrofits (if any) & estimate cost impacts.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

**White Paper on Natural Gas Interchangeability and
Non-Combustion End Use**

Appendices¹²

- A. Overview of Natural Gas Supply and Historical Characterization Data, Mike Millet, Chevron Texaco, Ali Quarishi, AGA and Mark Hereth, PPIC**
- B. Impact of Changing Supply on Natural Gas Infrastructure, Terry Boss, INGAA**
 - From production to delivery to end use customers
 - Includes LNG Liquefaction for Peak Shaving
- C. Changing Supply Impacts on End-Use (Burner Tip Combustion Issues), Ted Willams, AGA and Bob Wilson, Keyspan**
 - Overview of End Use – Bruce Hedman, EEA
 - Appliances – Mark Kendall, GAMA
 - Power Generation – Mike Klassen, CSE
 - Reciprocating Engines – Bruce Hedman, EEA
 - Industrial Heating – PGC
 - Peak Shaving – Bob Wilson, Keyspan
- D. Monitoring Interchangeability and Combustion Fundamentals, Edgar Kypers, Shell**
- E. Managing Interchangeability, Grant McCracken, Panhandle Energy**
- F. Changing Supply Impacts on End Use (Non-Combustion Issues), To be defined by Process Gas Consumers**
- G. Derivation of Interim Guideline Calculations – Rosemarie Halchuk, Xcel Energy and Bob Wilson, Keyspan**
- H. Research Recommendations**

¹² These appendices will be provided as they are developed by the Working Group.

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

**Natural Gas Council Plus
Work Group on Natural Gas Interchangeability
and Non-Combustion End Use Participation**

Ted Williams, American Gas
Association, Chair
Mark Hereth, P-PIC, Facilitator

LNG Suppliers

Edgar Kuipers, Shell
Mike Milliet, ChevronTexaco
Les Bamburg, Semptra
Ben Ho, BP
Mark Bentley, ExxonMobil
Pat Outtrim, Cheniere
Ed Lehotsky, Cheniere
Phil Redding, BG North America
Hubert Loussouarn, Total
Frank Katulak, Tractebel
John Hritcko, Shell
Randy Mills, ChevronTexaco
Al Fatica, BP
Rudy Adamiak, Tractebel
Greg Bartholomew, Semptra

Pipelines

Terry Boss, Interstate Natural Gas
Association of America
Grant McCracken Panhandle Energy
Todd Dustman, Questar
Hank Poellnitz, El Paso
Dennis Alters, Cross Country Energy
Scott Zersen, El Paso
Reji George, El Paso
Ian Morris, Cross Country Energy
Thanh Phan, Duke Energy
Jeryl Mohn, Panhandle Energy
David Noss, Dominion Energy
Bruce Hedman, Energy and
Environmental Analysis

Utilities (LDCs and in some instances
Power Generation)

Robert Wilson, Keyspan Energy
Larry Sasadeusz, Southern California
Gas Company

Rosemarie Halchuk, Xcel Energy
Peter Collette, Public Service Electric and Gas
John Erickson, American Public Gas
Association
Kevin Shea, Southern California Gas
Company
Lee Stewart, Southern California Gas
Company
Joe Bonner, Pacific Gas and Electric
Mark Satkamp, Louisville Gas and Electric
Robert Trumbower, Peoples Gas
Glen Schwalbach, Wisconsin Public Service
Michael Gerdes, BSH
Michael Farmer, Peoples Gas
Pieter Ouwerkerk, Exelon
Robert Kemper, Southern California Gas
Company
Frank Strauss, Consolidated Edison
Ali Quraishi, American Gas Association
Steven Zavodnick, Baltimore Gas and Electric
Lori Traweek, American Gas Association
Ed Anderson, RJRudden
Regis Klingler, CMS Energy
Jack Zerega, Public Service Electric and Gas
Richard Rudden, RJ Rudden and Associates
Joseph Santaro, Niagara Mohawk

Power Generation

Chuck Linderman, Edison Electric Institute
Jack Cashin, Electric Power Supply
Association
Bruce Rising, Siemens
Craig Chancellor, Calpine
Colin Wilkes, General Electric Power
Generation
Keith Barnett, American Electric Power
Dona Gussow, Florida Power and Light
Mike Klassen, Combustion Science &
Engineering, Inc.
Richard Roby, Combustion Science &
Engineering, Inc.
Nicole Prudencio, Calpine

White Paper on Natural Gas Interchangeability
And Non-Combustion End Use

Jim Downs, Calpine

Feedstock

Tom Carville, The Fertilizer Institute

George Valadez, Alcoa.

Dena Wiggins, Process Gas

Consumers

Dave Schalles, Bloom Engineering

(for Alcoa)

Kirsten Gibbs, Process Gas

Consumers

Appliances

Mark Kendall, Gas Appliance Manufacturers
Association

Frank Stanonik, Gas Appliance Manufacturers
Association

Richard Cripps, Association of Home
Appliance Manufacturers

Jack Goldman, Hearth, Patio and Barbecue
Association

Research

David Rue, GTI

State Official

Eric Orton, State of Utah

Gas Processing

Mark Sutton, Gas Processors Association

Meetings and Conference Calls of the Main Work Group

April 2 -- conference call

May 13-14 - meeting (Houston)

June 6 - conference call

July 1 - conference call

July 22-23 - meeting (Washington)

September 10 - conference call

September 13-14 - meeting (Houston)

October 18-19 - meeting (New Orleans)

October 25 - conference call

October 27 - conference call

October 29 - conference call

December 7-8 - meeting (Washington)

December 14 - conference call

December 16 - conference call

February 2-3 -- meeting (Houston)

February 11 -- conference call

February 14 -- conference call

February 23 -- conference call

February 25 -- conference call

Submission Contents

CL_PL04-3_022805.pdf.....	1-1
HDP_Paper.pdf.....	2-31
InterchangeabilityPaper.pdf.....	32-65