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

NGC+ Interchangeability Work Group

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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 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] Executive Summary, Page 64

3.1.2 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.

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]. This objective applies to domestic supply as well as imported LNG.

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 Natural gas interchangeability has been an issue since 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 for this effort has taken on a more general definition that includes the ability to substitute one gas for another without materially impacting historical utilization (including gas utilized in the industrial sector as "feedstock").

3.1.2 Interchangeability has remained an issue, but mostly on a regional basis as new domestic supplies came on line. 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

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

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 more 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 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 oxygen and natural gas[3]. As a result, properly installed and maintained equipment from that period is tolerant of normal fluctuations in the underlying gas quality caused by 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.

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 is 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 occur and is likely to

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

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 less than traditional domestic production.

3.3.2 Direct receipt of small amounts of unprocessed gas by transmission pipelines has contributed historically 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 forecasts are for the future imports to be 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 have a larger percentage of non-methane hydrocarbons such as ethane, propane and butanes. Non-methane hydrocarbons have a higher energy density; that is to say that they contain more Btu per unit volume. Higher energy density results in a more efficient production, storage and transportation of LNG, increasing the overall capacity of the LNG supply chain. In addition, 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 systems in some equipment such as gas turbines have been undergoing a substantial shift 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 used to generate electric power. The technology is often referred to as “lean premix combustion”. Other low emission technologies are being applied 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 this becomes a discernable 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 reciprocating engines, it can result in engine knock, negatively effect engine performance and decreased parts life.

b. In combustion turbines, it can result in an increase in emissions, reduced reliability/availability, and decreased parts life.

c. 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.

d. 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.

3.4.3 Varying gas compositions beyond acceptable limits can be problematic in non-combustion-related applications such as 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 for, 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 and the interstate pipeline companies managed quality of that blended gas. The quality specifications were incorporated into the gas purchase and sale contracts. 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 methods have been developed to define the interchangeability of fuel gases 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 treatment of these and other 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 Values[5] is specified in many pipeline tariffs, however, it alone is not a good 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 is related to the thermal input to a burner. It should be noted that while Wobbe is an effective, easy to use screening tool for interchangeability, historically, the industry recognizes that the Wobbe Number alone is not sufficient to completely predict gas interchangeability as 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 among others. The Multiple Index techniques have a history of widespread and satisfactory use in the industry; however, being empirical models the multiple index methods also tend to have some limitations since they are based on the burner systems tested. In

[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).

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.

4.0.5 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 present day efficiency and emission requirements. Access to some of this 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 restrictive in application to 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

- 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
- Blowout
- Incomplete combustion (carbon monoxide production)

- Lifting, and
- Yellow tipping

The major emission characteristics considered were:

- Nitrogen oxides (NOx),
- 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 there are in general, 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 region or in a 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 may help ensure 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 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 A 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 octane in

[6] TIAX – Cove Point Summary & Commonwealth Studies

gasoline. In addition to the anti-knock quality, how an engine operates on a low methane number fuel may be important. The low methane number is usually a result of the presence of high hydrocarbons in the fuel. High hydrocarbons in natural gas change the energy density (energy content per volume) of the fuel, the hydrogen to carbon (H/C) ratio of the fuel, and the burn rates in the engine. This energy density change needs to be accounted for in the fueling system. If it is not accounted for, the change in energy density may increase both the power and equivalence ratio resulting in poor operation 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 LDC supply infrastructure. While there are not as many, there are a limited number of peak shaving plants operated by transmission pipeline companies. Shifts in feedstock composition resulting from unprocessed domestic supplies include increases in heavy hydrocarbon concentrations (C6+) that freeze out and plug heat exchangers which significantly impacts the efficiency and reliability of the liquefaction process. In addition, feedstock containing significant quantities of C2/C3 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 in the liquefaction process. Excess nitrogen concentrations pose additional problems with LNG storage systems as tank boil-off may increase substantially depending on the liquefaction process. In summary, changes in feedstock composition beyond which the plant was designed may require many facilities to retrofit cold box components (heat exchangers and flash vessels) as well as tank storage system components (cold blowers) in order 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 imparted by varying feedstock compositions beyond design as discussed above could significantly compromise the pipeline or LDC’s ability to meet peak day / peak hour demands.

5.0.9 Additional LDC peak shaving concerns include the impact higher hydrocarbon gases impart on propane-air peak shaving operations. Similar to 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 be required to accommodate variations in pipeline supply compositions.

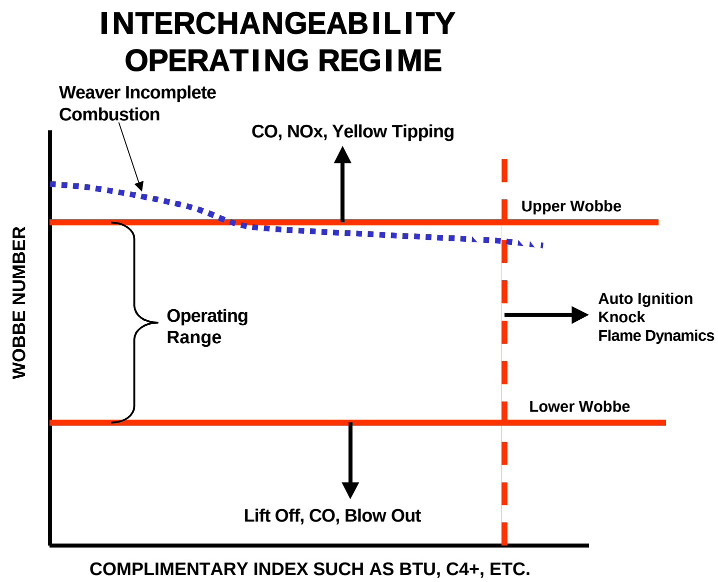
5.0.10 The rate of change in gas composition appears to be an important parameter. Fluctuations in composition beyond the limits equipment is tuned to receive, particularly if it occurs over a short period of time, is likely to reduce the ability of some equipment to perform as intended by the manufacturer.

6.0 Application of Interchangeability Parameters

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

6.0.2 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 and lifting among 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 AGA and Weaver have indices to specifically address lifting phenomena.

6.0.3 A purely scientific approach might lead one to applying many of the Weaver and AGA Bulletin 36 indices. 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 with over-specifying and sought to define a more practical approach. The group built upon the idea of developing an operating regime.



6.0.4 The basis for constructing the operating regime was to propose a parameter and identify which of the end use effects were addressed by the parameter; either in specifying a minimum or a maximum. The Wobbe Number was considered first as it was recognized as the most robust parameter. In general, establishing a maximum Wobbe Number can be used to address certain combustion phenomena such as yellow tipping, incomplete combustion and potential for emissions of NOx 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 relatively Heating Values generally in excess of 1,100 BTU's; however, this can be overcome by selecting a more conservative maximum Wobbe Number coupled with an additional parameter such as Heating Value.

6.0.5 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 categories of options for managing interchangeability. The categories are:

- Management at the production source
- Management prior to introduction into the transmission pipeline system, and
- 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 nearby 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. Treated/processed gas compositions may have distinct characteristics depending on the extent of treatment/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 butanes plus (C4+) level of the NGLs. This means LNG generally does not contain the heavier hydrocarbons but does contain appreciable concentrations of ethane and propane with some butane(s). LNG suppliers could add additional equipment to remove additional NGLs from their gas stream but have historically elected to produce a higher Btu content LNG more compatible with world markets other than the North America. It is important to note that Japan, Korea and Taiwan import over 50% of globally traded LNG, and their gas specification of relatively Heating Value has served as the basis of many current and future LNG supplies. 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, or "dekatherm" basis. Reducing the NGL content reduces the energy value of the LNG and reduces the economic value of each cargo.

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 economics of this option are dependent upon the economics of ethane and propane extraction and the proximity of local markets and/or available infrastructure. Given these facts, this is not an economically attractive option except in the Gulf (Texas and Louisiana) or in coastal locations where there is sufficient demand for ethane and propane. The economics in the Gulf are not what they once were as the domestic petrochemical market has shrunk in recent years. There are no NGL extraction plants associated with the three existing terminals along the East Coast. There is a small slipstream NGL extraction facility operated by a third party in the Gulf.

7.2.2 Conceivably, LNG terminal operators have the option of using an extracted NGL product stream as a source of energy to generate power for example; however, this is generally not a viable option as the volumes produced are likely to far exceed the energy consumed in a local region.

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 density 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] 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 reduced.

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%. Such high oxygen levels may not be acceptable because of current tariff restrictions, concerns on pipeline integrity impact on feedstock plants and other end uses, such as peak-shaving, and underground gas storage.

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.

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 an option of consequence 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 nomination of volumes and specification of receipt and delivery points as specified daily, and sometimes within a day, by shippers. Consequently, the pipeline blending that occurs is coincidental and historically has not been planned to achieve a specific end point or specification. Even where currently occurring, it cannot be relied upon on a prospective basis.

7.2.10 Management of interchangeability of domestic gas is described in Section 7.1, through processing prior to introducing it into the pipeline transmission system and/or inert blending (Section 7.2.5).

7.2.11 It is important to note that following implementation of FERC Order 636, significant numbers of independent producers emerged and over time have entered into contracts with pipelines to transport their gas without prior processing. This occurred as the production grew up nearby the existing pipeline infrastructure and producers determined that it was either infeasible or not economically attractive to process. The volumes 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 gas that was interchangeable.

7.2.12 In summary, when considering all of the options described above, inert injection is the most widely explored option to date. NGL separation may be a viable option in particular situations. Both of these solutions increase the cost of the natural gas supply due to the processing costs of the LNG stream. These costs equate to 3 to 5 cents per MMBtu.

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 exhibit 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 when considering 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 gas appliances and where necessary adjust out-of-spec equipment for changing gas quality. To be 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 to implement. Though difficult when large numbers of customers are involved, this approach has worked 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 known composition will be the fuel source on a continual basis. As described above, the nature of the domestic natural gas has evolved over time. Also, 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 national consensus standards developing organizations could develop standards for installing and placing equipment into service that ensures that the equipment is set up and being installed consistent with the design basis. 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 the gas is at the time the testing in undertaken. National consensus standards developing organization 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 these options are of value for equipment that will be manufactured, installed and placed into operation in the future. Applying these 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 parameter to supplement with other specifications in describing interchangeability[8].

[8] The Work Group agreed to standardize on a set of terms to use in defining interchangeability. "Indices" are described 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.

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 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:

    a. In reciprocating engines, it can result in engine knock, negatively effect engine performance and decreased parts life.

    b. In combustion turbines, it can result in an increase in emissions, reduced reliability/availability, and decreased parts life.

    c. 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.

    d. 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.

11. Varying gas compositions beyond acceptable limits can be problematic in non-combustion-related applications such as 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 for, 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.

12. Gas interchangeability guidelines must consider the full range of requirements for end use equipment.

13. 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.

14. Presently, there are limited publicly and readily available data for the full range of end use equipment and gas supplies.

15. Historical interchangeability indices have been widely used for conventional combustion appliances and are recognized default specifications when actual operating data are unavailable.

16. 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.

17. The European experience in gas interchangeability highlights important issues for establishing U. S. interchangeability guidelines and demonstrates significant differences from the U. S. situation.

18. 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.

19. 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.

20. Placing too broad limits on the interchangeability specifications may result in reduced reliability, increased emissions, and decreased safety on end use equipment, and consequently higher costs to consumers. Placing undue restrictions on the interchangeability indices due to lack of data may result in both limited supply options and higher costs to the consumers.

21. 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
22. 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 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 that work started by this group to gather and analyze historical data to better characterize the change in natural gas supply on a region-by-region, and market-by-market basis, be continued and completed. This data gathering process needs to be standardized so that on-going data collection can be used to develop a better understanding of historical compositional shifts.

2. The Work Group recommends that work started by this group regarding the effects of changing supply on particular end use equipment be continued and completed.

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.

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 is just as important for domestic supply as it is for 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:

    a. Historical gas supply characteristics to accommodate current end users and equipment requirements,

    b. End user 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. The purpose of the transition period is to work to maximize supply while gaining additional experience and knowledge.

10. 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, long-term guidelines will be developed within a timeframe to be defined.

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. 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 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-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.

The interim guidelines focus on consistency with historical gases since, locally, historical gases represent the basis for field installation and adjustment of appliances. Field installation and adjustment represent a set of initial conditions under which interchangeability must be considered. Implementation of the guidelines begins with consideration of local historical gases. National historical gases augment the guidelines by providing boundaries 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. The

Work Group is using the 1992 GRI report, “Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States,”[9] as the historical baseline for gases nationally and regionally.

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 Heating Values higher than 1,110 Btu/scf. Furthermore, it must be recognized that those market areas with demonstrated experience with gas supplies in excess of the interim guideline limits are not precluded from continuing their current operations. 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.[10] 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, and in the 1992 report. It is important to note that these 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.

[9] “Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States,” Gas Research Institute, March 1992, GRI-92/0123.
[10] Details of these calculations are given in Appendix G.

Interim Guidelines Recommendation

Interim Gas Interchangeability Guidelines
for Gases Delivered to End Users[11]

Maximum Wobbe Number Range over Local Historical Average: +/-4%,

subject to:

Wobbe Number Limits:	1,200 to 1,400
Heating Value Limits:[12]	950 to 1,110 Btu/scf
Maximum Butanes+ Limit:	1.5 mole percent.

Outstanding Issues

The following is a list of outstanding issues of stakeholders with regard to the recommended interim guidelines:

Suppliers: The term "local" used in characterizing historical gases under the interim guidelines needs to be defined so that a consistent basis is used.

AGA: The interim guidelines should not preempt local gas interchangeability requirements, existing agreements on gas supply, or new project agreements addressing gas interchangeability. The gas industry has developed gas interchangeability requirements over many years based on sound technical data and analysis. More recently, these technical processes have been applied to new projects including LNG import facilities and their send out. Overruling the resulting technical requirements for gases, including their use in tariffs, would not be technically justified regardless of consistency or inconsistency with the interim guidelines.

[11] These interim guidelines must be considered together with stakeholder issues identified in the following section, "Outstanding Issues." The guidelines do not consider technical requirements for applications that use gas as a feedstock such as LNG peak shaving and petrochemicals production.
[12] Based on high or gross heating value under standard conditions, $60^{o}F$, and 14.7 psia, dry.

AGA: The interim guidelines should not disqualify or bring into question use of gases outside the guidelines that have been demonstrated over time to be safe and reliable in end use systems locally. The Work Group has received information from LDCs that gases outside the interim guidelines has been delivered to end users without developing safety or equipment reliability problems. In these cases, experience suggests that these gases, together with local equipment installation and adjustment practices and other factors, are suitable for the local market.

AGA: The interim guidelines are not suitable for use a draft or *de facto* standards for gas interchangeability. Use of guidelines requires a process for considering local interchangeability beginning with an assessment of local historical gases. As a result, the numbers presented in the interim guidelines are not, themselves, gas interchangeability requirements. More importantly, the lack of data and analysis for end uses beyond traditional gas appliances suggests that consideration of standards based on the guidelines would overreach the technical support available. An LDC non-combustion application, LNG peak shaving, is not covered by the guidelines because it is considered an issue that must be addressed locally.

Gas Turbine User: A 1400 Wobbe Number limit is too considered high based on current manufacturers' specifications. The most conservative manufacturers specification limits Wobbe Number to 1,391. A maximum Wobbe Number range of +/- also exceeds certain turbine manufacturer specifications.

Gas Turbine User: The interim guidelines recommendation does not include limits on individual gas constituents of ethane, propane, butane, and heavier hydrocarbons, which are required in turbine manufacturer specifications.

Gas Turbine User: Wobbe Number rate-of-change limits are not delineated in the interim guidelines recommendation. Rate-of-change limits are required in turbine manufacturer specifications.

GAMA: Implementation of the guidelines should recommend education programs promoting appliance adjustment during a period of transition to new gas supplies.

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

Appendices

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 Wiilams, 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 – Bob Wilson, Keyspan and Rosemarie Halchuck, Xcel Energy

H. Recommended Process for Developing Local Interchangeability Requirements, Ted Williams AGA

Gas Interchangeability Technical Gap Analysis Summary

1. Overview

The NGC+ Technical Team has identified several "information gaps" that must be addressed to better assess the impacts of gas interchangeability issues in North America. Data to eliminate these gaps must be generated to assure the maximum level of supply flexibility. The gap filling process must consider a range of probable gas compositions for current and expected future global LNG imports as well as for evolving domestic supplies. Furthermore, consensus among major stakeholders in the gas supply, transportation and end use value chain requires filling these gaps in a timely fashion. Agreement on interim guidelines relies upon establishing a process and reasonable timeframe for filling the technical gaps with sound scientific analysis and testing.

In summary, interchangeability end use categories could be broken down into five broad areas:

- Appliances
- Industrial & Commercial Burners
- Turbines, Micro-turbines & Power Boilers
- Stationary & Vehicle Engines
- Non-Combustion & Feedstock Applications

. Within each category, there exist older combustion technologies, current technologies and newer combustion technologies. As a result, interchangeability concerns and available information differ within these categories The NGC+ Interchangeability Gap Analysis Sub-Group has identified critical gaps in the available data, and these are summarized below:

1. ***Appliances*** **–** Although more work has been conducted on appliances, both historically and currently, than any other gas utilization equipment, significant gaps remain. Conventional interchangeability parameters, in general, adequately describe combustion phenomena and overall gas interchangeability for the types of burners for which they were developed. However, with the influx of new high efficiency pre-mix burner designs, the current appliance population includes a mix of burner designs that may not be adequately described with historic parameter limits. In addition, consistent data are not available to assess, from a statistical risk perspective, the impacts of varying fuel composition on aged, preexisting maladjusted appliances. This assessment is vital because of the number of appliances in operation, safety issues for customers and the high costs associated with testing by individual companies.

2. ***Industrial & Commercial Burners*** **–** The combustion process is more tightly controlled with industrial and commercial burners than traditional appliance applications. These units also consume much greater volumes of gas per burner. The application of conventional interchangeability prediction parameters (such as the work of Weaver or AGA Bulletin 36) may not apply because these parameters were not originally developed for industrial and commercial applications. In addition, burner designs have evolved to improve efficiency and emissions issues; however these changes increase the sensitivity to fuel composition variations. Industrial and commercial burners represent the largest end use segment of the market but have the least information on the consequences of fuel composition changes in performance.

3. ***Turbines, Micro-turbines & Power Boilers*** **–** Significant data gaps and conflicting information exist from the OEM's regarding the impact of fuel composition. Impacts on performance and emissions appear to be the dominant concern, although other concerns may surface as the industry gains more experience. Of most concern are the newer, premixed combustion gas turbine systems introduced in the last fifteen years; legacy (non-premixed) gas turbine technology is only likely to be impacted by emissions that will change with Wobbe Index shifts. Little information is available on the impact of fuel quality on key operating parameters due to the relatively consistent historic North American supply compositions. Considering the critical nature of fuel composition to gas turbines coupled with the broad reach of the newest technology designs, it is imperative to better understand the potential impact of proposed fuel gas composition changes will have on the end user especially operational reliability during shifts in gas composition.

4. ***Stationary & Vehicle Engines*** - The newer technology associated with this end use is more robust and is assumed to be able to operate over a wider range of fuel compositions. Legacy engines may not be able to operate over a wide range of fuel composition. Methane number has been identified as the best performance measure. However, standardized testing is required to determine the effects of anticipated changes in fuel composition on combustion characteristics, efficiency and emissions.

5. ***Non-Combustion & Feedstock Applications*** - Uses for natural gas in various chemical and manufacturing processes is widespread in North America and includes production of ammonia and fertilizers, reforming, peak shaving liquefaction, and fuel cell applications. These processes must be assessed, with studies completed and results cataloged for the impacts of varying gas composition that accompany overall supply transitions. In addition, the effect of the time rate of composition changes must be evaluated.

2. Proposed Research Components

Table 1 present the highlights of a proposed framework for the research needed to fill gaps the NGC+ Technical Team has identified. It should be noted that this "high level" view of filling the gaps is not all inclusive, and additional work, including possible "retrofit" solutions, may become necessary after completion of the tasks identified below. The matrix includes "common requirements" as well as additional requirements for specific combustion related end use categories. Table 2 identifies general requirements for non-combustion and feedstock end use applications.

3. Conclusions & Implementation Strategy

It has become apparent through the work of the NGC+ Interchangeability Technical Team that significant data gaps exist, and this lack of data inhibits 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 that can be used to maximize supplies into the marketplace. The organizations who should participate in this effort include DOE, equipment manufacturers, gas suppliers, pipelines, LDC's and other industry trade groups. In order to implement the recommendations of the NPC Report**,** the abovementioned research should be accomplished within a two year time frame beginning in 2005. This aggressive schedule is necessary to minimize risks associated with any interim guidelines adopted pending the availability of sufficient data that will allow maximum penetration of LNG imports and additional domestic supplies into the North American market.

The research should capitalize on existing national and international expertise in specific subject areas and should be monitored and managed by a central organization. It is proposed that the program be conducted with the guidance of a Research Oversight Subgroup (ROS) of the NGC+ Interchangeability Technical Team. This group would encompass various stakeholders including OEMs, end users, pipelines and gas suppliers. It is important to recognize that specific organizations, industry groups, OEMs and academic expertise have made significant historical contributions to the subject of interchangeability. These organizations include the work of DOE, GTI, SWRI, CSE and TIAX among others. In order to maximize the efficiency of the gap filling process, these groups should be included in this combined effort. Stated simply, it does not make sense to "reinvent the wheel" since these organizations can bring substantial experience and expertise to the table that will expedite the completion of these tasks in the most efficient, cost effective manner.

Ultimately, this research program should identify scenarios that may be required, such as equipment retrofit, to maximize utilization of evolving gas supplies in the North American marketplace. These scenarios should include possible solutions based on effectiveness and economic efficiencies. Depending on the outcome of these scenarios, additional work may be required to help design and implement workable solutions which would in turn establish the cost / benefits of different options.

Table 1 Combustion Applications				
COMMON REQUIREMENTS	**ADDITIONAL REQUIREMENTS/NOTES**			
END-USE EQUIPMENT	**Turbines & Micro-turbines & Power Boilers**	**Industrial & Commercial Burners**	**Appliances**	**Stationary & Vehicle Engines**
A. Review and Classification of Equipment • Types of equipment, burners. • List of manufacturers. • Rank by sensitivity to fuel composition. • Emissions issues and mitigation strategies.	• All major types and manufacturers can be identified.	• Classify burners and combustion systems by types. • Must consider legacy, operating burners and new types under development.	• Review existing interchangeability project results. • Work with GAMA and others to identify new appliance types.	• Survey of manufacturers and equipment models. • Review operations and emissions measurements and requirements.
B. Collection of Available Data • Previous US and international studies (GTI, TIAX, SoCalGas, etc). • Manufacturers' data on – Emissions, – Efficiency, – Service life, – Combustion changes, – Mitigation alternatives and costs. • Impacts of slow and rapid fuel gas changes. • Determination of major data gaps.	• Most data is proprietary and in the hands of manufacturers. • Collect published data and performance data from users.	• Data may not currently be available. • Performance data from different manufacturers is not on a consistent basis.	• Standardizing results of previous interchange-ability studies. • Identify common conclusions • Previous data for interchangeability parameters (Wobbe, Weaver, AGA Bulletin #36, etc), CO production.	• Collect as much manufacturer data as possible. • Collect data from publications and users.
C. Determination of Testing Needs and Standardized Testing Protocols • Documentation of test methods. • Repeatability of testing. • Selection and measurement of all pertinent parameters. • Develop test gas strategies: – Define acceptability criteria (Btu, Wobbe, Methane Number, other), – Define range of acceptability, – Testing at limits of acceptability range, – Compositional issues (C_1, C_2, C_3, C_4, etc). • Specification of clocking and tuning strategies. • Fundamental combustion properties of natural gas mixtures	• Testing and resulting data may be proprietary • Measurement methods must be established • Method development may be required. • ·C_4+ issues • Significance of Methane Number. • Fundamental property evaluation, combustion stability etc.	• Method development may be necessary. • Selected testing methods to be based on combustion practice and made public.	• Evaluation of current standards for appliance testing and emissions limits. • Long-term testing of sensitive appliances. • Statistical analysis may replace some testing.	• (Items to be developed for final draf
D. Equipment Testing • Possible field and/or laboratory testing. • Examine interchangeability parameters under controlled conditions. • Fill data gaps.	• Test stand studies preferred whenever possible. • Testing with working power turbines, only if necessary.	• 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.	• Statistically relevant group of appliances with a range of types and ages. • Statistical evaluation of appliance “mal-adjustment” over time.	• Test engines in lab setting. • Test existing and older engines in place.
E. Data Analysis and Expected Results • 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.	• Recommended equipment. • Retrofits and additional long-term testing if required.	• Recommended equipment • Retrofits and additional long-term testing is required. • New types of indices may be developed.	• Determine if limit gas testing is recommended to enhance equipment flexibility with varying fuel supply compositions.	• Recommended controls and equipment retrofits. • Additional long term testing if required.

Table 2 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.

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
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Mike Milliet, ChevronTexaco
Les Bamburg, Sempra
Ben Ho, BP
Mark Bentley, ExxonMobil
Pat Outtrim, Cheniere
Ed Lehotsky, Cheniere
Phil Redding, BGNorth America
Hubert Loussouarn, Total
Frank Katulak, Tractebel
John Hritcko, Shell
Randy Mills, ChevronTexaco
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Reji George, El Paso
Ian Morris, Cross Country Energy
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Larry Sasadeusz, Southern California Gas Company
Rosemarie Halchuck, Xcel Energy

Peter Collette, Public Service Electric and Gas
John Erickson, American Public Gas Association
Kevin Shea, Southern California Gas Company
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Joe Bonner, Pacific Gas and Electric
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Colin Wilkes, General Electric Power Generation
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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

Richard Cripps, Association of Home Appliance Manufacturers
Goldman, Hearth, Patio and Barbecue Association

Research
David Rue, GasTechnology Institute

State Official
Ed 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