Applicant No: A.11-09-XXX
Exhibit No:
Witness: Charles Benson

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| In the Matter of the Application of | ) | |
| Southern California Gas Company (U 904 G) | ) | Application 11-09-XXX |
| For Approval to Retain Its Current Rule 30 | ) | (Filed September 2, 2011) |
| Gas Delivery Specifications. | ) | |
| | ) | |

**DIRECT TESTIMONY OF**

**CHARLES BENSON**

**FOR**

**SOUTHERN CALIFORNIA GAS COMPANY**

**BEFORE THE PUBLIC UTILITIES COMMISSION**
**OF THE STATE OF CALIFORNIA**

**September 2, 2011**

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## I. INTRODUCTION

My name is Charles Benson. I am a Managing Partner of etaPartners LLC and work in their office located at 8 Hollis Street, Groton, Massachusetts 01450.

My educational background is in mechanical engineering. I received a Bachelor of Science degree in mechanical engineering from Bucknell University and a Master of Engineering degree in mechanical engineering from the University of Florida. My career has focused on the development and application of combustion-based energy technologies for the residential, commercial, and industrial sectors. Prior to founding etaPartners, I was a Principal of ENVIRON International Corporation, a Managing Director of the Energy and Transportation Technology Sector at TIAX, LLC and a Vice President of Arthur D. Little, Inc. Prior to those positions, I was employed by Exxon Research and Engineering Company, where I managed combustion research and development activities and consulted in combustion technology for Exxon's worldwide operations. I also worked as an engineer for Pratt and Whitney designing gas turbine engines.

Over the last 20 years. I have worked with natural gas producers, pipeline companies, and local distribution companies to address interchangeability issues associated with the distribution of imported liquefied natural gas, coal bed methane, shale gas, propane-air peak shaving gas, and bio-derived gases. I have directed projects that established guidelines for compositions of imported LNGs that can be distributed through the Everett, Cove Point, and Elba Island import terminals as well as several proposed North American import terminals. In many of these projects, workshops were held with key stakeholders to identify and address

LNG interchangeability issues. Then, to establish guidelines, gas interchangeability analyses were performed; residential appliances were tested; and key industrial, transportation and power generation applications that utilize natural gas were evaluated.

As part of the interchangeability projects described above, I directed the testing in laboratories of about eighty residential appliances, including space heating, water heating and cooking equipment. This work focused on determining the impact of changes in natural gas composition on appliance performance. I have also directed the testing of about 7500 appliances in homes to characterize the performance of entire populations of appliances.

I have not previously testified before the California Public Utilities Commission.

## II. PURPOSE

I will provide an overview of natural gas interchangeability requirements and demonstrate that SoCalGas' current Rule 30 interchangeability limits are appropriate and are consistent with natural gas industry guidelines. I will explain why the distribution of non-interchangeable gases will increase safety risks for SoCalGas' customers. Then I will discuss the critical importance of frequent monitoring and continuous control of gas composition. Finally, I will review the technical work SoCalGas has performed to identify and manage gas interchangeability issues associated with Historical California Production.[1]

[1] Historical California Production is exempt from SoCalGas Rule 30 gas delivery specifications. *See* SoCalGas Rule 30, Section I.5.

## III. COMBUSTION AND INTERCHANGEABILITY

### A. Southern California Gas' Rule 30 Interchangeability Limits are Consistent with Natural Gas Industry Guidelines.

The term interchangeability, as defined by the Natural Gas Council Plus (NGC+) Work Group on Interchangeability[2], is "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." The Wobbe number has been broadly accepted as one of the key indices of natural gas interchangeability. It is representative of the fuel energy input rate (e.g., Btu/hr) to combustion equipment when the gas supply pressure is held constant (as is typical of residential appliances). Any two gas mixtures having identical Wobbe numbers will deliver about the same energy input rate. The Wobbe number is calculated by dividing the gas' Higher Heating Value (HHV) by the square root of its specific gravity.

$$\text{Wobbe Number} = \frac{\text{Heating Value}}{\sqrt{\text{Specific Gravity}}}$$

Natural gas distributed in the United States has an average Wobbe number of about 1336.

As the Wobbe number of a gas supply increases, the rate at which fuel energy flows through a typical metering orifice to an appliance increases. Therefore, key combustion characteristics can be related to the Wobbe number. SoCalGas included upper and lower

[2] White Paper on Natural Gas Interchangeability and Non-Combustion End Use ("NGC+ White Paper"), NGC+ Interchangeability Work Group, 2005, at p. 2.

limitations on the Wobbe number in Rule 30. The range of 1279 to 1385 is consistent with guidelines published by the Interchangeability Work Group.

The NGC+ White Paper notes 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".[3] To provide additional measures of interchangeability for appliances, two multiple index systems were developed from combustion theory and extensive testing: the American Gas Association (AGA) Multiple Index Method[4] and the Weaver Multiple Index Method[5]. These methods are commonly used in the United States and include indices that characterize the impact of gas composition changes on the following combustion phenomena:

- ***AGA multiple index method:*** characterization of lifting, flashback, and yellow-tipping.
- ***Weaver multiple index method:*** characterization of lifting, flashback, yellow-tipping, heat rate, and incomplete combustion.

These phenomena are concisely described below.

- ***Lifting:*** movement of the flame front downstream and away from burner ports as a result of decreases in flame speed relative to flow velocity.

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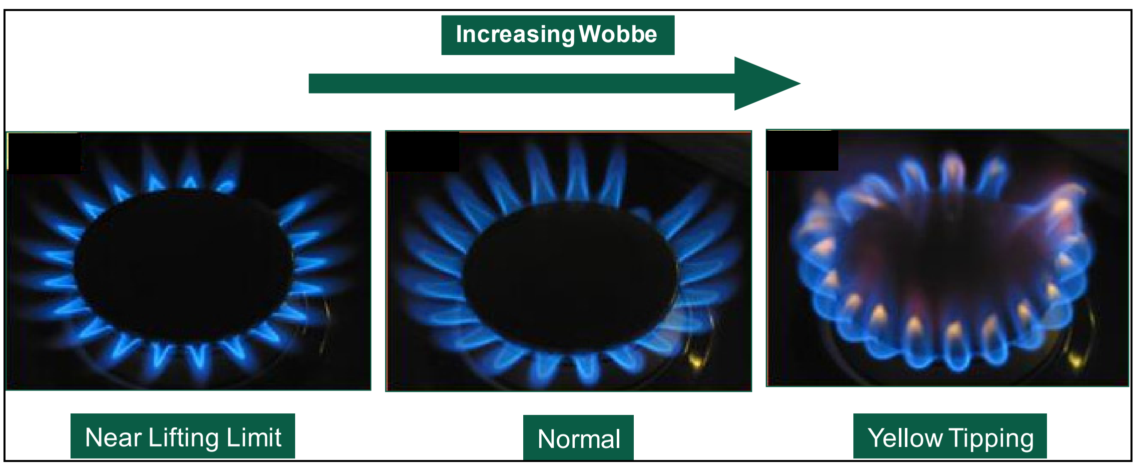
[3] NGC+ White Paper, at p. 7.
[4] Interchangeability of Other Fuel Gases with Natural Gas, American Gas Association Research Bulletin No. 36, 1946.
[5] Formulas and Graphs for Representing the Interchangeability of Fuel Gases, Weaver, E., Journal of Research of the National Bureau of Standards, Vol. 46, No. 3, March, 1951.

- ***Flashback:*** movement of the flame front upstream through the burner ports as a result of flame speed increasing relative to flow velocity.
- ***Yellow tipping:*** generation of soot particles within a flame that radiate incandescently, exhibiting a yellow color.
- ***Incomplete combustion:*** presence of carbon monoxide in the exhaust because carbon in the fuel gas was not fully oxidized to carbon dioxide.
- ***Heat rate:*** change in energy input rate (firing rate). This index is the ratio of the Wobbe numbers for the two gases.

As indicated in Figure 1, increases to the gas Wobbe number tend to drive certain appliance burners towards yellow tipping, while decreases drive them towards flame lifting.

**Figure 1: Flame Characteristics**




Interchangeability index calculations require the specification of two gas compositions. The first, called the adjustment gas, is the fuel for which combustion equipment adjustments (e.g., orifice size, air-shutter setting, and gas pressure) have been made to achieve the desired combustion characteristics. The second, referred to as the substitute gas, is the fuel for which relative combustion equipment performance is estimated.

SoCalGas selected the AGA Multiple Indices for inclusion in Rule 30. The use of these indices, in conjunction with the Wobbe number, is appropriate since the Wobbe number alone cannot accurately predict flame lifting, yellow tipping, incomplete combustion, and flashback. Limiting values are specified in Rule 30 for the AGA lifting, flashback and yellow tipping indices. The full set of interchangeability indices incorporated into Rule 30 are provided in Table 1. All limit values are consistent with industry practice.

**Table 1: Rule 30 Interchangeability Indices**

| Parameter | Current Specifications | Purpose |
|---|---|---|
| **Wobbe Number** | 1279-1385* | • Proper end-use operation<br>• Control yellow tipping<br>• Control CO emissions<br>• Control flame lifting and blow-out |
| **AGA Lifting Index** | ≤ 1.06 | • Control flame lifting |
| **AGA Flashback Index** | ≤ 1.2 | • Control flashback |
| **AGA Yellow Tipping Index** | ≤ 1.2 | • Control yellow tipping |

* For grandfathered producers, the Wobbe index limit is ± 10%, or 1199-1465(assuming 1332 is the adjustment gas).

The NGC+ White Paper states that “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".[6] Furthermore, it concludes that "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".[7] Since Southern California's $NO_x$ emission regulations are among the most stringent in the world, many customers utilize sensitive, low-emissions combustion technology. Consequently, additional interchangeability parameters may be required.

Because service areas may differ with respect to historical gas supplies, maintenance practices, as well as types and ages of end use combustion equipment, testing is often required to verify the acceptability of new or changing gas supplies. Indeed the NGC+ White Paper concludes that "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".[8]

Some classes of end use equipment may not perform acceptably with elevated concentrations of certain natural gas species. SoCalGas included in Rule 30 limits on the concentrations of carbon dioxide and total inerts. Testing conducted by SoCalGas to evaluate the impact of inert species on appliance performance is discussed in Section IV. The Rule 30 limit on total inerts (4 vol. %) is identical to that specified in the NGC+ White Paper.

The Interchangeability Work Group concluded that "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

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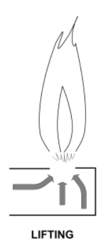
[6] NGC+ White Paper, at p. 7.
[7] NGC+ White Paper, at p. 20.
[8] NGC+ White Paper, at p. 8.

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."[9] Based on the results of combustion equipment testing, SoCalGas included in Rule 30 an upper limit on Higher Heating Value of 1150 Btu/scf.

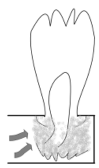
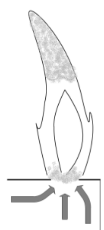
**B. Varying Natural Gas Compositions Beyond Acceptable Limits Can Adversely Impact the Performance of End-Use Equipment**

Gas composition changes affect the performance and safety of residential appliances, commercial appliances, manufacturing equipment, and power generation systems. For example, when gas compositions are outside of acceptable interchangeability limits, appliances can experience flame lifting, flashback, yellow tipping, or elevated levels of carbon monoxide. These impacts are summarized in Table 2.

**Table 2 - Gas-Fired Appliance Combustion Issues**

| Issue | Cause | Harm |
|---|---|---|
| **Flame Lifting**  | Reduced flame speed and increased velocity through the burner ports cause lifting. | Lifting can cause delayed or failed ignition of an appliance burner. With delayed ignition, flames can temporarily flash outside of the appliance enclosure and ignite nearby flammable materials. When flames lift off of burner ports, fuel can bypass the flame front and be partially oxidized downstream. Thus, lifting can produce elevated carbon monoxide emissions(see incomplete combustion) |

[9] NGC+ White Paper, at pp. 12-13.

| Issue | Cause | Harm |
|---|---|---|
| **Flashback**<br><br>FLASHBACK | Increased flame speed and reduced velocity through the burner ports cause flashback. | Flashback can result in combustion upstream of the burner head and unsafe appliance operation. If a flame is establish within burner's gas-air mixing tube, the burner can be destroyed. |
| **Yellow Tipping**<br><br>YELLOW TIPPING | Yellow tipping is the result of soot formation in the flame. Radiation from hot soot particles produces the yellow color. Soot formation can increase when combustion air is reduced or when natural gas contains elevated concentrations of higher molecular weight hydrocarbons (e.g., propane. Butane) | If severe, this condition can result in soot deposition on downstream surfaces and can ultimately cause gas passages to be restricted or blocked. Then flue gases containing CO can be redirected into the living space. Excessive soot deposition can causes problems that range from fires to reduced equipment efficiency (soot acts as an insulator, reducing heat transfer rates). |
| **Incomplete Combustion** | Incomplete combustion results when the carbon in fuel molecules is not fully oxidized to carbon dioxide. Instead, elevated levels of carbon monoxide are produced. Incomplete combustion can be caused by the lack of sufficient combustion air or by flame quenching. | If flue gases are vented into the living space, either by design or through a flue failure, excessive carbon monoxide levels may adversely affect the health of occupants. Carbon monoxide is a colorless, odorless gas that interferes with the delivery of oxygen throughout the body. At elevated concentrations, CO causes symptoms such as headaches, dizziness, weakness, nausea, and disorientation. |

**C. The Compositions of Gases Historically Distributed and the Performance Characteristics of Appliance Populations Must be Considered When Defining Interchangeability Limits.**

Natural gas appliances, when properly tuned and maintained, are typically tolerant of moderate variations in natural gas composition. Within any service region, appliances have been installed, adjusted, and serviced utilizing the natural gas delivered at the time of the procedure. Thus, it is important to consider the range of natural gas compositions historically distributed. Furthermore, a subset of the appliance population in a typical service area is less tolerant due to burner design characteristics, improper adjustment, or lack of maintenance. The sensitivity of these appliances must also be considered.

The Interchangeability Work Group 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… 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.[10]

Historical California Production gases supplied to SoCalGas are not currently subject to the Wobbe number limits of Rule 30. Rather, gases having Wobbe numbers as high as 1465 and as low as 1199 can be introduced into the SoCalGas system. Consequently, a portion of the equipment population in the affected area has been adjusted to operate with high Wobbe number supplies. Subsequently operating these units on lower Wobbe number gases having high concentrations of inert species (carbon dioxide and nitrogen) can cause significant performance problems. Specific issues include flame lifting, increased carbon monoxide emissions, delayed or failed ignition, flame rollout during ignition, unstable pilots, and noisy flames. Conversely, certain appliances adjusted for operation at the lower portion

[10] NGC+ White Paper, at p. 9.

of this Wobbe range can experience yellow tipping and increased carbon monoxide emissions when supplied with gases at the upper end of the Wobbe range.

**D. Distribution of Non-interchangeable Gases will Increase Safety Risks for Southern California Gas' Residential Customers.**

The introduction of a non-interchangeable gas would create significant performance and safety issues for SoCalGas' customers. Certain appliances, when tuned for operation on high Wobbe number gases, will experience flame lifting and emit significantly higher levels of carbon monoxide when low Wobbe number gases are distributed. Conversely, certain appliances tuned for operation on low Wobbe gases will experience yellow tipping and elevated carbon monoxide when operated on high Wobbe gases. Appliances with elevated CO emissions represent a significant safety risk. If an appliance is unvented or if a vented appliance experiences a flue failure or cracked heat exchanger, higher levels of CO can be introduced into the living space. This, in turn, can lead to CO poisoning of the occupants.

**E. Frequent Monitoring and Continuous Control of Gas Composition are Necessary.**

At any moment, the performance of an appliance is affected by the composition of the gas being delivered to its burner. Indeed, combustion equipment responds quite rapidly to the changes in gas composition. Consequently, gas quality should not be controlled through the monitoring of properties or compositions averaged over extended time periods, such as the 24-hour period promoted by the California producers. For example, a brief excursion to elevated levels of inerts can cause the operational problems (flame lifting, burner extinction, pilot instability, flame roll-out) described above. Furthermore, elevated CO emissions due to flame lifting will be experienced for the entire duration of the excursion. So, while the averaged properties being monitored may appear to indicate that gas quality is acceptable, SoCalGas' customers are being exposed to unacceptable safety risks.

## IV. APPLIANCE PERFORMANCE TESTS

### A. SoCalGas' Appliance Tests Confirm Performance Issues Associated with Non-interchangeable Gases.

SoCalGas has tested a wide range of residential, commercial, and industrial combustion equipment to evaluate the performance impacts of natural gas compositions that could be provided by its gas suppliers. From this large body of work, several relevant examples that identify issues associated with variations in gas composition are provided below.

#### 1. Objectives

Consistent with the NGC+ White Paper recommendation, SoCalGas conducted further end-user equipment testing to investigate the appropriateness of SoCalGas' existing Rule 30 gas delivery specifications. The testing was designed to assess the response of residential and small commercial end-use equipment to changes in gas quality and thereby to determine if "SoCalGas' Rule 30 should be changed and whether the current non-hydrogen sulfide limits are too restrictive or redundant in light of the current Rule 30 Wobbe specification and Lifting Index."[11] This research testing considered the variances in gas compositions supplied to the system and the wide range of burner designs found in end-use equipment.

#### 2. Testing Parameters

SoCalGas tested a wide range of commonly used residential, commercial, and industrial combustion equipment to evaluate the performance impacts of varying natural gas

[11] *See* D.10-09-001, at Ordering Paragraph 4.

compositions. These gas compositions reflected gas deliveries that might flow and/or have flowed through SoCalGas' pipeline system.

**Table 3 - Tested Equipment**

| Description | Service Category | Burner Type | Rated Input as tested (BTU/hr) |
|---|---|---|---|
| Burner | Commercial | Range-Top | 33,000 (per burner) |
| Burner | Commercial | Radiant | 40,000 |
| Broiler | Commercial | Char-broiler | 15,000 (per burner) |
| Furnace | Industrial | Heat Treating | 400,000 (per burner) |

SoCalGas' Engineering Analysis Center conducted these tests using industry-standard protocol and calibrated, laboratory-quality instrumentation. Testing assessed Rule 30 and Historical California Production carbon dioxide, total inerts, heating value, and Wobbe Index limits impacts on equipment performance. SoCalGas monitored for flame lifting, flashback, yellow tipping, excessive carbon monoxide emissions, soot build-up, unacceptable operations, and overall safety concerns.

**3. Summary of SoCalGas Test Results**

From this body of work, SoCalGas documented numerous examples of potential end-user safety or operational issues associated with varying test gas' carbon dioxide content, inert content, heating values and/or Wobbe numbers to reflect gas deliveries that might flow and/or have flowed through SoCalGas' pipeline.

1. When using gas that neither complied with the Rule 30 non-hydrogen sulfide limits, nor the Rule 30 Wobbe specifications of 1279-1385, but was within the California producer Wobbe range of 1199-1465, SoCalGas documented the following combustion phenomena: flame lifting, yellow tipping, excessive carbon monoxide emissions, or flashback potential.

2. Hamburger patties were cooked using same procedures and cooking time with high and low Wobbe gas that would have exceeded Rule 30 limits, but was within the

Historical California Production range. The test showed food temperatures decreased as much as 10 degrees and visibly undercooked with low Wobbe gas as compared to patties cooked with high Wobbe gas.

3. When using gas that did not comply with the Rule 30 Wobbe specification limits of 1279-1385, but was within the California producer Wobbe range of 1199-1465, SoCalGas documented increased carbon monoxide emissions.

**a) Commercial Range-Top Burner**

The commercial range-top burner (Exhibit 1) demonstrated significant yellow tipping when operated using gas with: 1) a heating value (of 1201 Btu/cf) that exceeded the Rule 30 maximum limit of 1150 Btu/cf; and 2) a Wobbe number (of 1440) that exceeded the Rule 30 Wobbe maximum limit of 1385, but was within the California producer Wobbe range of 1199-1465.

The commercial range-top burner exhibited flame lifting on several burner ports, when operated using gas with: 1) carbon dioxide levels (of 7%) that exceeded the Rule 30 limit of ≤ 3%; 2) a heating value (of 950 Btu/cf) that fell below the Rule 30 minimum limit of 990 Btu; and 3) a Wobbe number (of 1195) that fell below the Rule 30 Wobbe minimum limit of 1279, but was within the California producer range of 1199-1465.

The commercial range-top burner exhibited excessive carbon monoxide emissions of 1219 ppm, when operated using gas with: 1) a heating value (of 1207 Btu/cf) that exceeded the Rule 30 maximum limit of 1150 Btu/cf; and 2) a Wobbe number (of 1442) that exceeded the Rule 30 Wobbe maximum limit of 1385, but was within the California producer Wobbe range of 1199-1465. In addition, there was considerable soot deposition on the pan and burner grill as a result of operation with this high Wobbe number gas.

**Table 4 - Commercial Range-Top Burner Test Results**

| **Gas Type** | **Added Gas** *Mol %* | **HHV** *Btu/cf* | **Wobbe** *Btu/cf* | **Input Rate** *Btu/hr* | **Supply Pres** *in. WC.* | **CO** *ppm* | **$No_x$** *ppm* | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 100% Pipeline | 0% | 1013 | 1332 | 30,728 | 8.1 | 26 | 100 | • Burner and pilot operated properly without any yellow-tipping or flame lifting. |
| 92.5% Pipeline | 7.5% $N_2$ | 935 | 1203 | 29,355 | 8.1 | 13 | 102 | • Two ports in the bottom back of burner had continuous **flame lifting** and one part had intermittent **flame lifting**. |
| 92.9% Pipeline | 7.1% $CO_2$ | 950 | 1195 | 29,422 | 8.1 | 15 | 90 | • Two ports in the bottom back of the burner had continuous **flame lifting** and one port had intermittent **flame lifting**. |
| 88.3% Pipeline | 11.7% propane | 1201 | 1440 | 35,813 | 8.1 | 34 | 99 | • The pilot exhibited extreme **yellow tipping**.<br>• Some soot was found on cooking top grill. |
| **Burner set at ¾ High** | | | | | | | | |
| 92.2% Pipeline | 7.8% $N_2$ | 936 | 1202 | 24,625 | 8.0 | 13 | 98 | • Yellowing tipping on pilot and burner was reduced due to the introduction of nitrogen. |
| 93.2% Pipeline | 6.8% $CO_2$ | 954 | 1202 | 23,859 | 8.0 | 13 | 97 | • Yellowing tipping on pilot and burner was reduced due to the introduction of nitrogen. |
| 87.9% Pipeline | 12.1% propane | 1205 | 1442 | 26 565 | 8.0 | 15 | 105 | • Pilot and burner exhibited severe **yellow tipping**. |
| 87.9% Pipeline (quenched) | 12.1% propane | 1207 | 1442 | 26,177 | 8.0 | 1219 | 90 | • When flame was quenched with a frying pan filled with 5 lbs of ice, **carbon monoxide** levels severely increased.<br>• Considerable amount of soot found on cook top grill & pan. |

**b) Commercial Radiant Burner**

The commercial radiant burner (Exhibit 2) operated acceptably with natural gases having Wobbe numbers in the range of 1335 to 1386 and with pure methane, which has a Wobbe number of 1361. However, the commercial radiant burner exhibited flame lifting, when operated using gas with: 1) total inert levels (of 5% nitrogen) that exceeded the Rule 30 limit of ≤ 4%; 2) a heating value (of 962 Btu/cf) that fell below the Rule 30 maximum limit of 990 Btu/cf; and 3) a Wobbe number (of 1267) that fell below the Rule 30 Wobbe minimum limit of 1279, but was within the California producer Wobbe range of 1199-1465. For this gas, flame lifting was experienced even though the Rule 30 AGA Lifting Index limit (≤ 1.06) was satisfied.

The commercial radiant burner exhibited potential flashback issues, when operated using gas with: 1) a heating value (of 1201 Btu/cf) that exceeded the Rule 30 maximum limit of 1150 Btu/cf; and 2) a Wobbe number (of 1439) that exceeded the Rule 30 Wobbe maximum limit of 1385, but was within the California producer Wobbe range of 1199-1465.

The commercial radiant burner exhibited flame lifting and excessive carbon monoxide emissions of 1533 ppm, when operated using gas with: 1) carbon dioxide levels (of 10%) that exceeded the Rule 30 limit of ≤ 3%; 2) a heating value (of 912 Btu/cf) that fell below the Rule 30 maximum limit of 990 Btu/cf; and 3) a Wobbe number (of 1128) that fell below the Rule 30 Wobbe minimum limit of 1279, and was not within the California producer Wobbe range of 1199-1465.

1 **Table 5 - Commercial Radiant Burner Testing Results**

| **Gas Type** | **Added Gas** *Mol %* | **HHV** *Btu/cf* | **Wobbe** *Btu/cf* | **Input Rate** *Btu/hr* | **Supply Pres** *in. WC.* | **CO** *ppm* | **NOx** *ppm* | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 100% Pipeline | 0% | 1015 | 1335 | 36,271 | 8.0 | 82 | 6 | • Burner operated properly without any yellow-tipping or flame lifting.<br>• Bottom of the burner was always less radiant than the upper part of the burner. |
| 100% Methane | 0% | 1014 | 1361 | 36,289 | 8.0 | 81 | 6 | • Burner operated properly without any yellowing tipping or lifting.<br>• Bottom part of the burner was always less radiant than the upper part of the burner. |
| 94.8% Methane | 5.2% N2 | 960 | 1266 | 35,465 | 8.0 | 210 | 6 | • The upper part of the burner became less radiant when N2 was injected into the gas mixture.<br>• The burner started showing flame lifting on the bottom. |
| 94.8% Methane | 2.6% N2 + 2.6% CO2 | 961 | 1252 | 33,396 | 8.0 | 237 | 6 | • The upper part of the burner became less radiant when N2 and CO2 were injected to the gas mixture.<br>• The burner started showing flame lifting on the bottom. |
| 95% Methane | 5% CO2 | 961 | 1237 | 33,616 | 8.0 | 232 | 6 | • The upper part of the burnerbecame less radiant when CO2 was introduced to the gas mixture.<br>• The burner started showing flame lifting on the bottom. |
| 89.8% Methane | 10.2% N2 | 909 | 1177 | 31,401 | 8.0 | 966 | 5 | • Bottom part of burner had considerable flame lifting<br>• CO increased noticeably. |
| 89.9% Methane | 5.1% N2 + 5.0% CO2 | 910 | 1153 | 31,869 | 8.0 | 1348 | 5 | • Bottom part of burner had considerable flame lifting<br>• CO increased significantly. |
| 89.9% Methane | 10.1% CO2 | 910 | 1127 | 31,186 | 8.0 | 1533 | 5 | • Bottom part of burner had considerable flame lifting<br>• CO increased greatly. |

| **Gas Type** | **Added Gas** *Mol %* | **HHV** *Btu/cf* | **Wobbe** *Btu/cf* | **Input Rate** *Btu/hr* | **Supply Pres** *in. WC.* | **CO** *ppm* | **NOx** *ppm* | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 92.5% Pipeline | 7.5% N2 | 934 | 1203 | 34,191 | 7.9 | 650 | 4 | • Bottom part of burner exhibited considerable flame lifting. |
| 93.2% Pipeline | 6.8% CO2 | 952 | 1202 | 35,774 | 7.9 | 782 | 4 | • Bottom part of the burner exhibited more flame lifting than with N2. |
| 88.3% Methane | 11.7% propane | 1201 | 1439 | 39,574 | 7.9 | 86 | 8 | • Burner radiated too much on the upper part of the burner. Under this condition, flashback might occur if operated for an extended period of time. |

**c) Commercial Char Broiler**

In the first testing of the commercial char broiler (Exhibit 3), SoCalGas again cooked frozen hamburgers. The testing procedure was as follows:

- Range knobs were adjusted to medium heat.
- Beef patties were kept in a freezer and then cooked for a total of 12 ½ minutes with 3 minutes in between each test.
- The beef patties were cooked for 8 minutes on one side, then 4 minutes on the other side, and then 30 seconds on the first side.
- Inside temperature of the patties was measured immediately after being taken off the grill.
- The test setup, conditions, and procedures for each unit tested were the same and the only thing that changed was the test gases that were introduced.

The commercial char broiler cooked hamburgers adequately when operated on natural gas having elevated propane content of 11.1% and an unacceptable Wobbe number of 1441. However, the hamburgers were undercooked when the identical cooking procedures were followed, but the gas supplied contained an acceptable Wobbe number of 1210, but a carbon dioxide content of 6.7%, which exceeded Rule 30's ≤ 3% limit.

**Table 6 - Commercial Char Broiler Testing Results # 1**

| **Gas Type** | **Spike Added Gas** *Mol %* | **HHV** *Btu/cf* | **Wobbe #** *Btu/cf* | **Input Rate** *Btu/hr* | **Cook Time** *min* | **Freezer Temp** *°F* | **Patty Temp** *°F* | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 93.3% Pipeline | 6.7% $CO_2$ | 963 | 1210 | 14,402 | 12½ | -1.2 | 142.3 | **Hamburger patties were visibly undercooked.** |
| 88.9% Pipeline | 11.1% propane | 1193 | 1441 | 16,050 | 12½ | -2.5 | 153.4 | Hamburger Patties were visibly cooked. |

In the second testing of the commercial char broiler (Exhibit 4), SoCalGas cooked frozen hamburgers. The testing procedure was as follows:

- Range knobs were adjusted to medium heat.
- Beef patties were kept in a freezer and then cooked for a total of 9 ½ minutes with 3 minutes in between each test.
- The beef patties were cooked for 4 ½ minutes on one side, then 4 ½ minutes on the other side, and then 30 seconds on the first side.
- Inside temperature of the patties was measured immediately after being taken off the grill.
- The test setup, conditions, and procedures for each unit tested were the same and the only thing that changed was the test gases that were introduced.

The commercial char broiler cooked hamburgers adequately when operated on natural gas having elevated propane content of 11.3% and an unacceptable Wobbe number of 1435. However, the hamburgers were undercooked when the identical cooking procedures were followed, but the gas supplied contained an acceptable Wobbe number of 1203, but a carbon dioxide content of 7%, which exceeded Rule 30's ≤ 3% limit two times over.

**Table 7 - Commercial Char Broiler Testing Results # 2**

| **Gas Type** | **Added Gas** *Mol %* | **HHV** *Btu/cf* | **Wobbe#** *Btu/cf* | **Input Rate** Btu/hr | **Cook Time** *min* | **Freezer Temp** *°F* | **Patty Temp** *°F* | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 93% Pipeline | 7.0% $CO_2$ | 960 | 1203 | 28,744 | 9 ½ | 0.2 | 159.3 | **Hamburger Patties visibly undercooked** |
| 88.7% Pipeline | 11.3% propane | 1190 | 1435 | 34,037 | 9 ½ | 0.9 | 170.5 | Hamburger patties were visibly cooked. |

SoCalGas determined that the hamburgers were undercooked because: 1) the internal temperature was, on average, 10°F lower than the internal temperature of the hamburgers cooked with gas having elevated propane content and an elevated Wobbe number; 2) the center was pink; and 3) blood was evident in the hamburger. Food safety may be an issue for commercial cooking appliances that are overloaded or not temperature controlled. The problem can occur when the cooking times are set while operating on a high Wobbe number gas and then cooking for the same amount of time on a low Wobbe number gas. Examples of commercial cooking equipment that can be overloaded include deep fat fryers, grills, and ovens. Examples of commercial cooking equipment that are not temperature controlled include char broilers, salamanders and broilers.

**d) Industrial heat treating furnace**

The industrial heat treating furnace (Exhibit 5) was tuned to perform suitably at design firing rates when operating on pipeline gas having a Wobbe number of 1320. Under these conditions, carbon monoxide emissions were below 10 ppm. However, the industrial heat treating furnace exhibited excessive carbon monoxide emissions, when operated using gas with a Wobbe number (of 1435) that exceeded the Rule 30 maximum limit of 1385, but was within the California producer Wobbe range of 1199-1465.

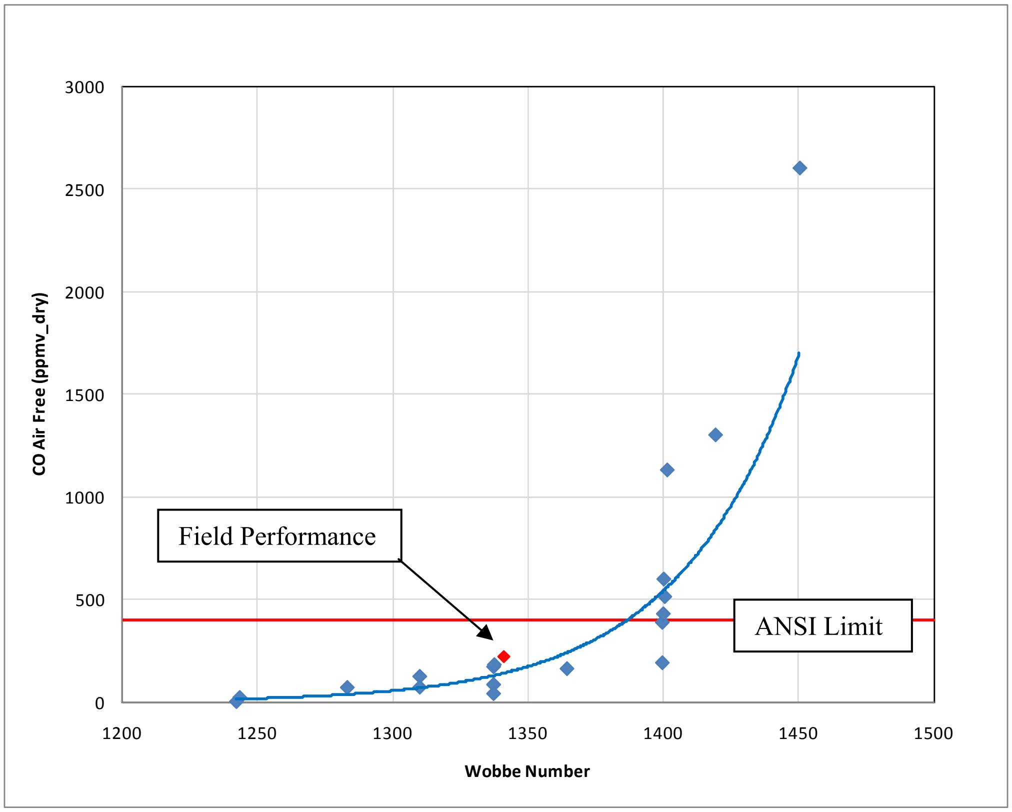
**Table 8 - Industrial Heat Treating Furnace Testing Results**

| **Gas Type** | **HHV** *Btu/cf* | **Wobbe** *Btu/cf* | **Input Rate** *MBTU/hr* | **Supply Pres** *psig.* | **CO** *ppm* | **$No_x$** *ppm* | **Comments** |
|---|---|---|---|---|---|---|---|
| Pipeline | 1010 | 1322 | 4,000 | 5.0 | 16 | 49 | • Very low CO emissions |
| High Wobbe | 1107 | 1412 | 4,000 | 5.0 | Out of Range | 34 | • **CO levels increased dramatically.** |

### 4. Independent Testing

Independent testing conducted by etaPartners LLC has demonstrated that certain residential appliances can experience performance problems when the gas Wobbe number increases. In Figure 2, CO emissions from a residential water heater retrieved from a home are plotted as a function of the gas Wobbe number. Each data point on this graph represents a separate laboratory test in which the water heater was operated on a specific gas composition having the Wobbe number indicated by the x-axis value. The carbon monoxide emissions from this unit increase with increasing Wobbe number. This trend is due primarily to reductions in the level of excess air supplied to the burner. For Wobbe numbers below 1385, CO emissions are relatively low. However, above 1400, the emissions exceed the ANSI certification limit of 400 ppm (air-free).

**Figure 2 – Water Heater Performance**




This finding is consistent with a study conducted by the Lawrence Berkeley National Laboratory for the California Energy Commissions' Public Interest Energy Research Program ("Program").[12] The Program's testing of several residential appliances showed that a high increase in carbon monoxide emissions when natural gas with a Wobbe number of approximately 1330 was replaced with a gas with a Wobbe number of 1419 (which is outside Rule 30, but within the Historical California Production range). For example, the carbon

[12] *See* "Natural Gas Variability in California: Environmental Impacts And Device Performance: Experimental Evaluation Of Pollutant Emissions From Residential Appliances," Appendix J. Summary Reports For Tankless Water Heaters, California Energy Commission Public Interest Energy Research Program (Lawrence Berkeley National Laboratory: June 2010).

monoxide emissions of a residential oven increased from 570 ppm to 860 ppm,[13] and the carbon monoxide emissions of a tankless water heater increased from 6100 to 16000 ppm.[14] The tankless water heater was new but had a bad regulator; this could be a typical scenario of malfunctioning equipment that is in operation in the field.

Collectively, these test result demonstrate that the California production gases should not be allowed to enter SoCalGas' system with high levels of inert species or with high Wobbe numbers. Otherwise, SoCalGas' customers will be exposed to safety-related risks due to elevated CO emissions and undercooked food. Furthermore, the range-top burner exhibited significant performance problems when operating on both the upper and lower Wobbe number gases. Thus, the range of gases that the California producers are now permitted to supply is too wide.

**B. Elevated Concentrations of Inert Species Cause Appliance Flames to Lift and Reduce Appliance Heating Rate.**

As demonstrated in the SoCalGas appliance tests, Rule 30's carbon dioxide limit addresses the risk to customers due to flame lifting. SoCalGas testing of the commercial range-top burner, using carbon dioxide content of 7% resulted in flame lifting. Only 5 vol. % nitrogen caused the commercial radiant burner to exhibit flame lifting. This response is especially critical for appliances that have been adjusted for operation on higher Wobbe number natural gases. For these units, flame lifting can occur at even lower concentrations of

[13] Natural Gas Variability in California: Environmental Impacts And Device Performance: Experimental Evaluation of Pollutant Emissions from Residential Appliances," Appendix E. Summary Reports For Ovens, California Energy Commission Public Interest Energy Research Program (Lawrence Berkeley National Laboratory: June 2010), at p. 62.

[14] Natural Gas Variability in California: Environmental Impacts And Device Performance: Experimental Evaluation of Pollutant Emissions from Residential Appliances," Appendix J. Summary Reports For Tankless Water Heaters, California Energy Commission Public Interest Energy Research Program (Lawrence Berkeley National Laboratory: June 2010), at p. 59.

nitrogen and carbon dioxide. As mentioned, this condition can cause delayed or failed ignition of an appliance burner. With delayed ignition, flames can temporarily flash outside of the appliance enclosure and ignite nearby flammable materials. When flames lift off of burner ports, fuel can bypass the flame front and be partially oxidized downstream. Thus, lifting can produce elevated carbon monoxide emissions.

SoCalGas testing of the commercial char broiler revealed a health risk associated with food safety. SoCalGas found that hamburgers cooked satisfactorily on the commercial char broiler when operated on natural gas having elevated propane content of 11.1% and a Wobbe number of 1441.[15] However, when cooking hamburgers using natural gas with carbon dioxide content of 6.7% and a Wobbe number of 1210, SoCalGas found that the hamburgers were undercooked. This test result demonstrates that gas with carbon dioxide constituent levels that exceed the Rule 30 limits could pose a safety risk to end-use customers because increased carbon dioxide levels reduce the Wobbe number and cooking performance.

## V. RULE 30 NATURAL GAS CONSTITUENT LIMITS

### A. Limits on Carbon Dioxide and Total Inerts Protect Customers from Performance and Safety Issues.

Application of the full set of Rule 30 interchangeability limits, including the limits on carbon dioxide and total inerts content, would ensure that the gases distributed by SoCalGas are interchangeable and, thereby, protect SoCalGas' customers from safety issues such as lifting-induced CO emissions. Monitoring of the concentrations of carbon dioxide, total

[15] The elevated propane content did not lower the Wobbe number, but in fact raised the Wobbe number.

inerts and gas Wobbe number can be utilized to prevent the introduction of gases that could cause flame lifting problems.

SoCalGas' Rule 30 limit on total inerts (4 vol. %) is consistent with industry standards. It is identical to that specified in the NGC+ White Paper. Rule 30's total inerts limitation is also consistent with a study conducted by the Gas Processing Association, which found that a total inerts limit of 3% - 4% is representative of U.S. pipeline tariffs.[16] This finding supports SoCalGas' sampling of pipeline total inerts limitations. Table 9 below demonstrates that a 4% limit on total inerts is equal to or more generous than limits specified by most pipelines.

**Table 9 - Snapshot of Pipeline Total Inerts Limits**

| **Total Inerts** | |
|---|---|
| **Pipeline name** | **Total** |
| SoCalGas | 4% |
| Questar Southern Trails Pipeline Co. | 3% |
| Destin Pipeline Co. | 3% |
| Discovery Gas Transmission | 3% |
| Garden Banks | 3% |
| Transwestern Pipeline Co. | 3% |
| Dominion Transmission | 5% |
| Texas Eastern Transmission | 4% |
| Ruby Pipeline | N/A |
| Kern River Gas Transmission Gas Co. | 4% |

Appliance testing and industry standards and practices directly contradict California producers' arguments that all appliances can operate safely on natural gas having up to 10% total inerts. The sole basis for the California producers claim that all appliances can operate safely on natural gas having up to 10 vol. % total inerts is the testing conducted by GTI of

[16] "The Gas Processing Industry: Its Function and Role in Energy Supplies," Gas Processors Association.

eleven appliances operating on imported LNG gases blended with nitrogen. However, even for this limited fuel set, the GTI report[17] states that "the project was not intended to define a specific set of compositions and operating parameters that are always acceptable". Perhaps most concerning regarding the applicability of the GTI results is the condition and tuning of the appliances. The GTI report states that "all appliances were brand new and properly adjusted in terms of air/fuel ratio for a typical pipeline domestic natural gas". The adjustment gases utilized had Wobbe numbers in the range of 1324 to 1349. The combustion system condition and tuning for these test appliances are not representative of the full range of appliances in SoCalGas' distribution area. Within the SoCalGas service area, the age distribution of appliances is broad. Furthermore, a subset of the appliances may have been tuned for operation on gases having Wobbe numbers greater than 1400. Indeed, a large number of SoCalGas' customers have appliances operating in their homes that are significantly more sensitive to elevated concentrations of inert species than were the appliances tested by GTI. Additional sensitivity may result from Southern California's stringent regulation of oxides of nitrogen. Many customers utilize sensitive, low emission combustion equipment.

**B. SoCalGas' Heating Value Limits are Consistent with Industry Standards**

Rule 30's heating values are consistent with a study conducted by the Gas Processing Association, which found that heating value limits of 950-1150 are representative of U.S. pipeline tariffs.[18] This finding also supports a sampling of pipeline heating value limits.

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[17] Report GRI-03/0159

[18] "The Gas Processing Industry: Its Function and Role in Energy Supplies," Gas Processors Association.

Table 10 -Snapshot of Pipeline Heating Value Limits

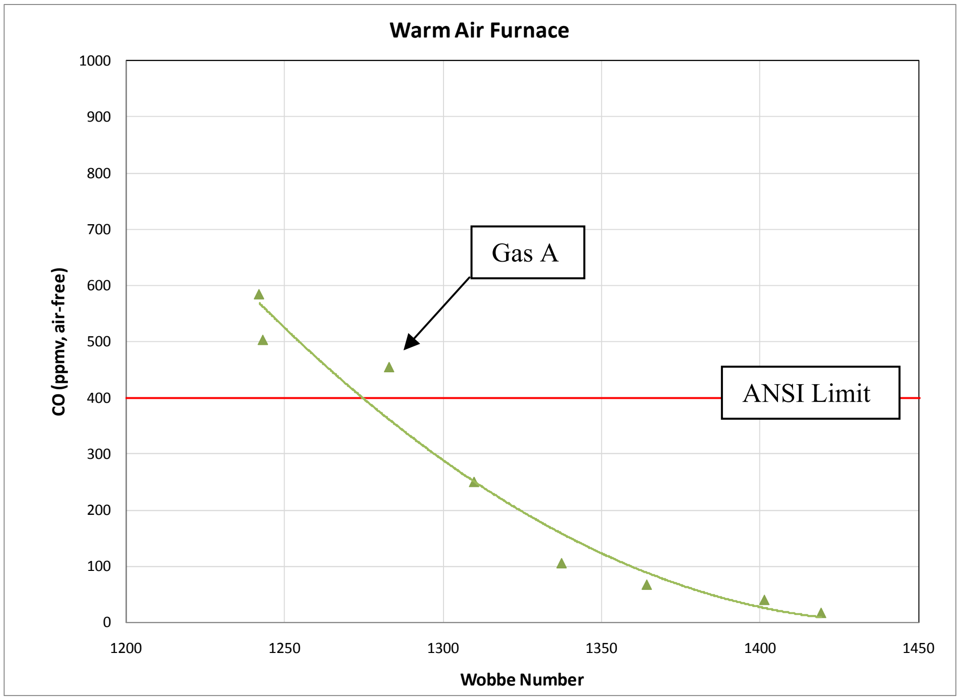
| Heating Value | | |
|---|---|---|
| **Pipeline name** | **Min** | **Max** |
| SoCalGas | 990 | 1150 |
| Kern | 970 | N/A |
| Pine Prairie | 967 | 1069 |
| Carolina Gas Transmission | 950 | 1075 |
| Central New York Oil & Gas | 967 | 1100 |
| Questar Southern Trails Pipeline | 980 | 1150 |
| Ruby Pipeline | N/A | 1100 |
| Energy West Development | 900 | 1100 |
| Enridge Pipelines (Midla) LLC | 950 | 1150 |
| Kinder Morgan Interstate Gas Trans. | 950 | 1100 |

### C. SoCalGas' Current Non-Hydrogen Sulfide Limits Are Not Too Restrictive or Redundant in Light of the Current Rule 30 Wobbe Specification and Lifting Index.

While the Rule 30 Wobbe number and AGA Index limits are generally effective in maintaining interchangeable natural gas supplies, an extra measure of safety is attained by limiting the concentrations of inert species. The NGC+ Working Group "recognize[d] that compositional limits for specific gas constituents may be needed".[19] Independent appliance tests conducted by etaPartners LLC illustrate this benefit. For example, Figure 3 presents the results of tests conducted on a residential warm air furnace. Carbon monoxide emissions from this unit are plotted as a function of the gas Wobbe number. Each data point on this graph represents a separate test in which the furnace was operated on a specific gas composition having the Wobbe number indicated by the x-axis value. The carbon monoxide emissions increase with decreasing Wobbe number, due primarily to flame lifting, as illustrated in Figure 4.

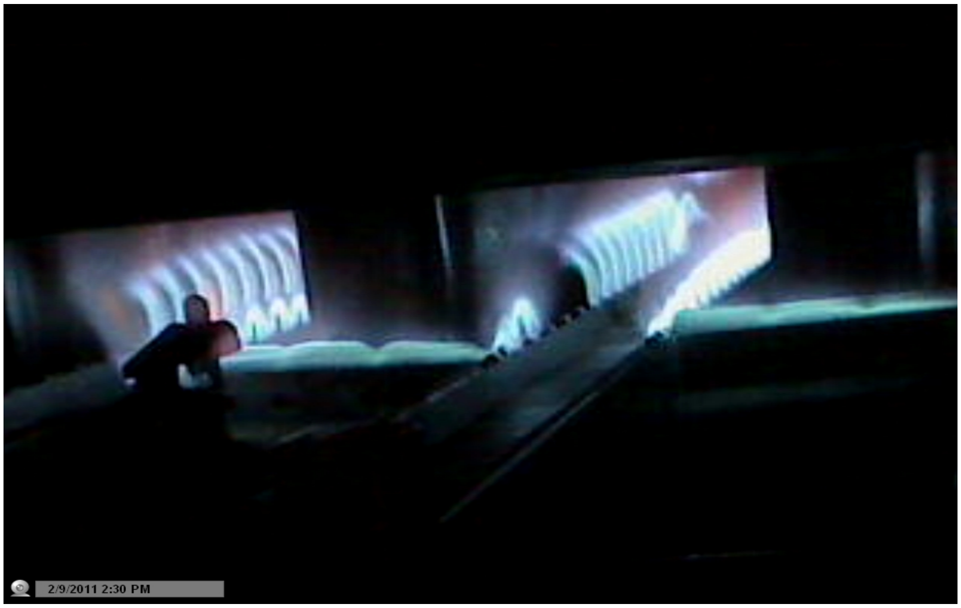
[19] NGC+ White Paper, at p. 23.

**Figure 3 – Furnace Performance**




For Wobbe numbers above about 1300, CO emissions are relatively low. However, below 1300, the emissions rise to levels that exceed the ANSI certification limit of 400 ppm (air-free). Of particular interest is the test result for the gas labeled "A". This gas has a Wobbe number of 1284 and a carbon dioxide concentration of 3.15 vol%. It lies within the Rule 30 Wobbe number range and satisfies the AGA Lifting index limit when a typical 1332 Wobbe SoCalGas system gas is set as the adjustment gas. Yet the performance of the furnace when operating on Gas A is unacceptable. The furnace's flames lift and ANSI CO limit is exceeded. Only the carbon dioxide limit in Rule 30 would exclude this gas from distribution.

**Figure 4 – Furnace Flame Lifting**



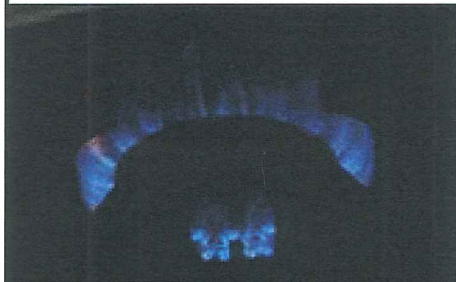
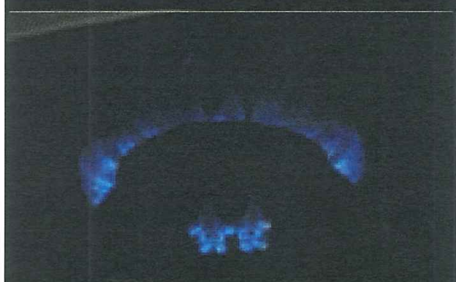

## VI. CONCLUSION

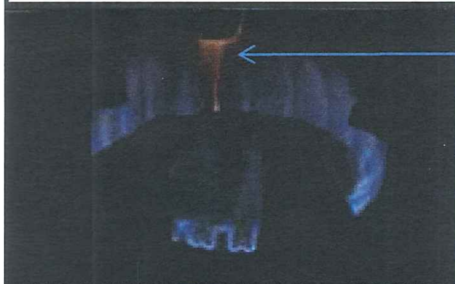
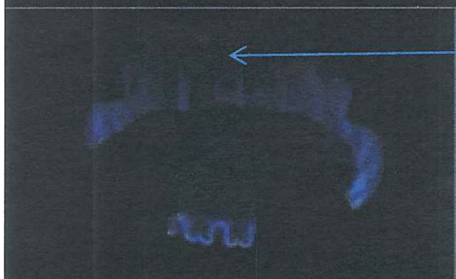
The gas quality specifications in Rule 30 are consistent with interchangeability guidelines established by the natural gas industry. Sound experimental evidence exists to state unequivocally that, the distribution of production gases having a range of Wobbe numbers from 1199 to 1465 will expose SoCalGas' customers to unacceptable safety risks. Furthermore, this range is significantly larger than the guidelines specified by the NGC+ Interchangeability Work Group. Requiring the California producers to comply with the Rule 30 interchangeability standards, including limitations on the concentrations of carbon dioxide, heating value and total inerts, will ensure that all gases distributed by SoCalGas are interchangeable.

This concludes my testimony.

# EXHIBIT 1

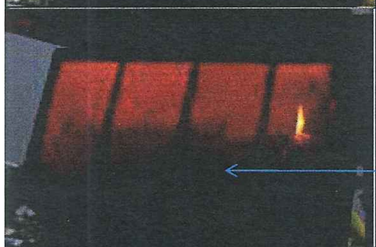
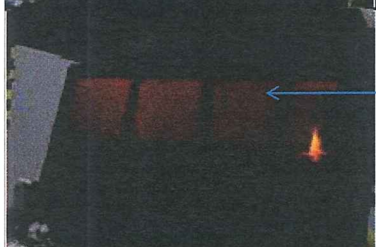
# COMMERCIAL RANGE TOP BURNER

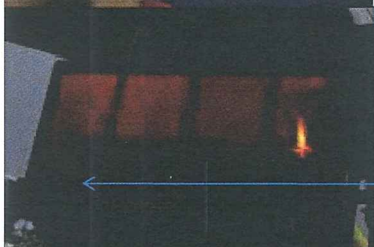
| Illustration of Flame Characteristic | Gas Type | Spike Gas Mol% | HHV BTU /cf | Wobbe # BTU/h | Input Rate BTU/hr | Supply Pres in W.C. | Co ppm* | Nox ppm* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Front Middle Burner on High, Input Rate of 33,000 BTU/hr** | | | | | | | | | |
|  | **Pipeline Gas** | None | 1013 | 1332 | 30649 | 8.1 | 26 | 100 | Burner and pilot operated properly without any yellow tipping or lifting. |
|  | **Pipeline Gas +N2** | 7.5% N2 | 935 | 1203 | 29282 | 8.1 | 13 | 102 | Two ports in the bottom back of the burner had continuous **lifting** and one port had intermittently **lifting.** |
|  | **Pipeline Gas + CO2** | 7.1% CO2 | 950 | 1195 | 29348 | 8.1 | 15 | 90 | Two ports in the bottom back of the burner had continuous **lifting** and one port had intermittently **lifting.** |
|  | **Pipeline Gas + Propane** | 11.7 % Propane | 1201 | 1440 | 35720 | 8.1 | 34 | 99 | The pilot had extreme **yellow tipping**. |

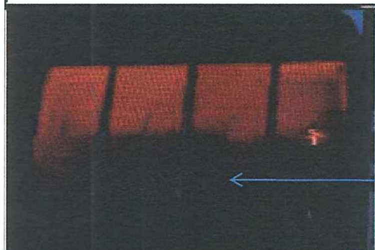
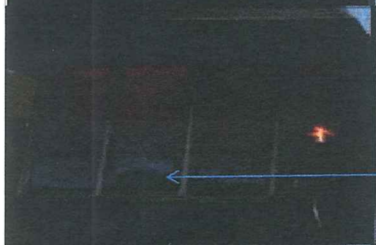
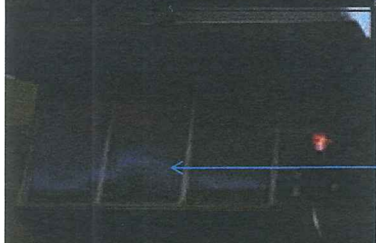
| Illustration of Flame Characteristic | Gas Type | Spike Gas Mol% | HHV BTU /cf | Wobbe # BTU/h | Input Rate BTU/hr | Supply Pres in W.C. | Co ppm* | Nox ppm* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Front Middle Burner on High, Input Rate of 33,000 BTU/hr | | | | | | | | | |
|  | **Pipeline Gas + N2** | 7.8% N2 | 936 | 1202 | 24542 | 8.0 | 13 | 98 | **Yellow tipping** on the pilot and burner was reduced when nitrogen was introduced. |
|  | **Pipeline Gas + CO2** | 6.8 CO2 | 954 | 1202 | 23771 | 8.0 | 13 | 97 | **Yellow tipping** on the pilot and burner was reduced when CO2 was introduced. |
|  | **Pipeline Gas + Propane** | 12.1% Propane | 1205 | 1442 | 26446 | 8.0 | 15 | 105 | Pilot and burner had severe **yellow tipping.** |
|  | **Pipeline Gas + Propane** | 12.1% Propane | 1207 | 1442 | 26058 | 8.0 | 1219 | 90 | When flame was quenched with a frying pan filled with 5lbs of ice the CO emissions increased severely |

# EXHIBIT 2

# COMMERCIAL RADIANT BURNER

| Illustration of Flame Characteristic | Gas Type | Spike Gas Mol% | HHV BTU/cf | Wobbe # BTU/hr | Input Rate BTU/hr | Supply Pres in W.C. | Co ppm* | Nox ppm* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Front Middle Burner on High, Input Rate of 33,000 BTU/hr** | | | | | | | | | |
|  | **100% Pipeline Gas** | None | 1015 | 1335 | 36192 | 8 | 82 | 6 | Burner Operated properly without any yellow tipping or lifting. Bottom part of the burner was always less radiant than the upper burner. |
|  | **100% Methane** | None | 1014 | 1361 | 36210 | 8 | 81 | 6 | Burner Operated properly without any yellow tipping or lifting. Bottom part of the burner was always less radiant than the upper burner. |
|  | **95% Methane** | 5% N2 | 962 | 1267 | 35458 | 8 | 210 | 6 | The upper part of the burner became less radiant when N2 and CO2 were injected to the gas mixture. The burner started showing flame lifting on the bottom. |
|  | **95% Methane** | 2.5% N2+ 2.5% CO2 | 963 | 1253 | 33389 | 8 | 237 | 6 | The upper part of the burner became less radiant when N2 and CO2 were injected to the gas mixture. The burner started showing flame lifting on the bottom. |

| Illustration of Flame Characteristic | Gas Type | Spike Gas Mol% | HHV BTU/cf | Wobbe # BTU/hr | Input Rate BTU/hr | Supply Pres in W.C. | Co ppm* | Nox ppm* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Front Middle Burner on High, Input Rate of 33,000 BTU/hr | | | | | | | | | |
|  | 95% Methane | Zoom-in image of the 95% methane + 2.5% CO2 gas mixture to illustrate the lifting behavior on the lower left and right corners on the ceramic tiles of the Radiant Burner. | | | | | | | |
|  | **95% Methane** | 5% CO2 | 963 | 1239 | 33613 | 8 | 232 | 6 | The upper part of the burner became less radiant when CO2 was introduced to the gas mixture. The burner started showing flame lifting on the bottom. |
|  | **90% methane** | 10% N2 | 911 | 1178 | 31386 | 8 | 966 | 5 | Bottom part of the burner had considerable flame lifting. CO increased considerably. |
|  | **90% Methane** | 5% N2 + 5% CO2 | 912 | 1155 | 31862 | 8 | 1348 | 5 | Bottom part of the burner had considerable flame lifting. CO increased considerably. |
|  | **90% Methane** | 10% CO2 | 912 | 1128 | 31186 | 8 | 1533 | 5 | Bottom part of the burner had considerable flame lifting. CO increased considerably. |

| Illustration of Flame Characteristic | Gas Type | Spike Gas Mol% | HHV BTU/cf | Wobbe # BTU/hr | Input Rate BTU/hr | Supply Pres in W.C. | Co ppm* | Nox ppm* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Front Middle Burner on High, Input Rate of 33,000 BTU/hr | | | | | | | | | |
|  | **100% Pipeline Gas** | None | 1009 | 1332 | 37334 | 7.9 | 107 | 5 | Burner and pilot operated properly without any yellow tipping or lifting. Bottom part of the burner was always less radiant than the upper burner. |
|  | **Pipeline Gas + N2** | 7.5% N2 | 934 | 1203 | 34120 | 7.9 | 650 | 4 | Bottom part of the burner had considerable flame lifting. |
|  | **Pipeline Gas + CO2** | 6.8% CO2 | 952 | 1202 | 35700 | 7.89 | 782 | 4 | Bottom part of the burner had more flame lifting than with N2 |
|  | **Pipeline Gas + Propane** | 11.7% propane | 1201 | 1439 | 39484 | 7.9 | 86 | 8 | Burner radiated to much on the upper part of the burner. Under this condition flashback may occur after operating for an extended period of time. |

# EXHIBIT 3

# COMMERCIAL CHAR BROILER - TEST 1

Food safety may be an issue for commercial cooking appliances that are overloaded or not temperature controlled. The problem can occur when the cooking times are set while operating on a high Wobbe gas and then cooking for the same amount of time, on a low Wobbe gas. Examples of commercial cooking equipment that can be overloaded are deep fat fryers, grills, and ovens. Examples of commercial cooking equipment that are not temperature controlled are char broilers, salamanders and broilers. Below are some preliminary test results from a char broiler.

Testing Procedure- Range knobs were adjusted to medium heat. Beef patties were kept in a freezer and then cooked for a total of 12½ minutes. They were cooked for eight minutes on one side; four minutes on the other side, and then thirty seconds one the first side. Inside temperature of the patties was measured immediately after being taken off the grill.

| **Illustration of Meat Color** | **Gas Type** | **Spike Gas** *Mol %* | **HHV** *BTU/cf* | **Wobbe #** *BTU/cf* | **Input Rate** BTU/hr | **Cook Time** *min* | **Freezer Temp** *°F* | **Patty Temp** *°F* | **Comments** |
|---|---|---|---|---|---|---|---|---|---|
|  | **Pipeline and $CO_2$** | 6.7% | 963 | 1210 | 14,402 | 12½ | -1.2 | 142.3 | Hamburger patty had pink areas inside after it was cut and some red blood dripping from meat. |
|  | **Pipeline Gas and Propane** | 11.1% | 1193 | 1441 | 16,050 | 12½ | -2.5 | 153.4 | Hamburger patty had no pink areas after it was cut and there was no red blood dripping from the meat |

* Averages from three test runs done for each gas mixture.

# EXHIBIT 4

# COMMERCIAL CHAR BROILER - TEST 2

Food safety may be an issue for commercial cooking appliances that are overloaded or not temperature controlled. The problem can occur when the cooking times are set while operating on a high Wobbe gas and then cooking for the same amount of time, on a low Wobbe gas. Examples of commercial cooking equipment that can be overloaded are deep fat fryers, grills, and ovens. Examples of commercial cooking equipment that are not temperature controlled are char broilers, salamanders and broilers. Below are some preliminary test results from a char broiler.

Testing Procedure- Range knobs were adjusted to medium heat. Beef patties were kept in a freezer and then cooked for a total of 9 ½ minutes with 3 minutes in between each test. They were cooked for 4 ½ minutes on one side; 4 ½ minutes on the other side; and then 30 seconds one the first side. Inside temperature of the patties was measured immediately after being taken off the grill. The test setup, conditions, and procedures for each unit tested were the same and the only thing that changed was the test gases that were introduced

| Sample Image of Test | Gas Type | Spike Gas *Mol %* | HHV *BTU/cf* | Wobbe # *BTU/cf* | SCFH | Input Rate BTU/hr | Cook Time *min* | Freezer Temp *°F* | Patty Temp *°F* | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
|  | **Pipeline and $CO_2$** | 7.0% | 960 | 1203 | 30 | 28,744 | 9 ½ | 0.2 | 159.3 | Patties were pink in the center with some blood on the surface. |
|  | **Pipeline Gas and Propane** | 11.3% | 1190 | 1435 | 28 | 34,037 | 9 ½ | 0.9 | 170.5 | Patties were well done with some showing some pink in the center. |

* Averages from twelve test runs done for each gas mixture.

# EXHIBIT 5

# INDUSTRIAL HEAT TREATING FURNACE

## Results Summary

When the total input of the four burners was set at or above 1,390,000 Btu/hr using our base gas - PLG 1013 (HHV: 1013 Btu/cf, Wobbe: 1322 Btu/cf), the introduction of LNG 1107 (HHV: 1107 Btu/cf, Wobbe: 1412 Btu/cf) or PLG 1132 (HHV: 1132 Btu/cf, Wobbe: 1379 Btu/cf) created CO emissions that were higher than what the CO emissions analyzer could measure (20,000 ppm). When the total input of the four burners was lowered to or below 1,390,000 Btu/cf using our base gas PLG 1013, the introduction of LNG 1107 did not create any considerable changes in the emissions.

## Equipment Selection Criteria

This type of industrial furnace was tested because: a) most are custom built and the final product is not tested or certified by an independent facility, b) they can generate high emissions levels if the low $NO_x$ burners are not working properly, and c) it is complex for the low $NO_x$ burners to achieve the high operating temperatures (~1,800 °F) while not exceeding the $NO_x$ requirements. The $NO_x$ requirements from the SCAQMD are 50 ppm @ 3% $O_2$ for any metal heating furnaces which includes metal aging, annealing, forging, heat treating and homogenizing.

## Equipment Specifications

**Description:** Heat treating industrial furnace

**Application:** Preheating titanium billets

**Burner description:** Nozzle-mix, low $NO_x$, and modulating with a turndown of 50:1

**Input rate:** 400,000 (Btu/cf) per burner (four burners)

**Type of fuel:** Natural Gas

**Required gas supply pressure:** 5.0 psig.

## Installation

The furnace was installed and tested at the manufacturer's facility before it was delivered to the customer. Thermocouples were installed at the flue vents, furnace doors and skid to measure exhaust, chamber and gas temperatures. A gas meter was installed to measure gas flow and emissions probes were installed in all four-flue vents.