Southern California Gas Company
A Sempra Energy utility

Final Report

Gas Quality

and

Liquefied Natural Gas Research Study

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Southern California Gas Company

PO Box 513249 SC723B

Los Angeles, CA 90051

DISCLAIMER

Testing protocols used in this study were derived from industry standards and regulatory test procedures. Note, however, that based on the needs of this program and the operating and design characteristics of equipment tested, adherence to the industry and regulatory testing standards was not literal. The reader is cautioned that no inference can nor should be drawn as regards certification of these devices to the industry standards or regulatory requirements as a result of this program.

Southern California Gas Company (SCG)

Larry Sasadeusz
Rod Schwedler
Kevin Shea
Jorge Gutierrez

Bourns College of Engineering – Center for Environmental Research and Technology - University of California, Riverside (CE-CERT)

Wayne Miller
William Welch

Consultants
William Raleigh
William Dennison
A. L. Wilson, Wilson Environmental Associates
Daryl Hosler, Wilson Environmental Associates
Howard Levinsky, Gasunie Research

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[1] See Appendix E for Committee Members

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EXECUTIVE SUMMARY

This research study was designed to assess how residential and small commercial end-use equipment responded to changes in gas quality and to determine if Southern California Gas Company (SCG) needs to modify its current Gas Quality Standards (Rule 30). Furthermore, this assessment is important in light of changing natural gas supplies, both domestic and LNG, newer advanced combustion technologies and certification/testing procedures based on historic gas quality. While the potential exists for gas-fired equipment to exhibit varied performance characteristics when supplied natural gas fuel that varies in composition, this study focused on safety and performance of selected commercial and residential natural gas-fired appliances. The major objectives of the study were as follows:

1. Evaluate each selected unit to determine whether any issues exist relating to equipment safety and performance. Equipment safety includes changes in Carbon Monoxide (CO) levels, combustion stability and Lifting, Flashback, and Yellow Tipping.

2. Compare measured and observed results against the major natural gas Interchangeability Indices, including Wobbe Number, Lifting, Flashback, Yellow Tipping and Incomplete Combustion.

3. Collect NOx emission data during testing.

Thirteen different gas-fired appliances were tested in a formal test program that assessed the response of the devices to a range of natural gas compositions and characteristics. The gas compositions represented heating value and Wobbe Number boundaries of the current SCG Gas Quality Standards (Rule 30).

This study concludes and recommends that SCG needs to incorporate results of this study, national efforts on gas quality and other resources to develop an “Interim Range of Acceptability” encompassing on quality/composition for various end-use category. Other recommendations and findings are:

- Update Gas Quality Standards and Rule 30.
- Include interim Wobbe Number range from 1290 minimum to 1400 maximum.
- The test results were less clear on the need to adjust the 1150 Btu/scf High Heating Value (HHV) maximum limit.
- Neither HHV nor Wobbe Number is an absolute predictor of equipment performance.

- The Range of Acceptability concept may need to replace the current approach which utilizes AGA Interchangeability Indices: Lifting Index, Flashback Index, and Yellow Tip Index. These indices have performed well for appliances and equipment designed and installed up to the 1990's but may not be accurate for newer, more efficient, and less polluting equipment.
- Additional metrics need to be added for better predictions, such as Methane Number which is currently utilized by engine manufacturers for Internal Combustion (I.C.) Engine performance. Turbines or feedstock applications may also require metrics or compositional limits other than the AGA Interchangeability Indices.
- Establish longer term goals for a wide "Range of Acceptability" based on national standards.

Long term, SCG will work with industry, manufacturers and government on the development and implementation of national gas quality standards that allow for the broadest range of gas compositions without significant impact on utilization equipment. Further recommendations include:

- Develop a target "Range of Acceptability", provide a transition period and encourage equipment manufacturers to produce equipment that operates safely over the entire range.
- Simplify testing standards and protocols. Single standard testing/protocols should be adopted for certification, performance, safety and emission testing.
- Continue to work to promote testing of large equipment by manufacturers, possibly with DOE sponsorship.
- Continue to work with manufacturers and agencies on development of testing protocols and test gas specifications.
- Determine if adjustment gas or gases could be used during equipment set-up to allow for the widest range of acceptable gas composition. This determination should be based on sound statistical methodologies.

INTRODUCTION

During this study, laboratory tests on a variety of Natural Gas-fired residential and commercial equipment were conducted to evaluate safety and performance and to gather emissions data. The evaluation focused on how equipment operating characteristics changed as a function of changes in natural gas composition.

Different gas compositions, which represented a range of potential gas compositions that could enter the Southern California Gas Company (SCG) distribution system from Liquefied Natural Gas (LNG) supplies, California-produced gas, traditional out-of-state gas supplies or supplies from non-traditional sources, were used in the study. Specific study objectives were to assess SCG's current Gas Quality Standards (Rule 30) to ensure they will continue to provide customer safety and equipment performance as it relates to:

1) Higher heat content and higher Wobbe Number natural gas supplies that may enter SCG's system;

2) Transient and steady state equipment performance changes through the range of gas compositions;

3) New and emerging end-use combustion technologies; and

4) The relationship between changing gas compositions and combustion performance.

SCG and the gas industry have identified a need to examine the effects of changing Natural Gas composition for each type of end use equipment and combustion technology in the residential, commercial and industrial service categories. End use equipment that needs to be assessed includes residential appliances, small and large Commercial/Industrial equipment, reciprocating engines, turbines and non-combustion applications. Within each end use equipment category there are older combustion technologies, current technologies still being installed and newer emerging combustion technologies. This study focused on end use equipment representing residential appliances and small commercial equipment.

Equipment tests were conducted at Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT), located at the University of California, Riverside, at the SCG's Engineering Analysis Center, located in Pico

Rivera, California, and at several manufacturer locations.

An Air Emissions Advisory Committee (AEAC) was established by SCG to review, advise and provide oversight in the air emissions element of the study. The AEAC was composed of technical representatives from interested regulatory agencies and LNG terminal proponents. (See Appendix E)

BACKGROUND

SCG and San Diego Gas & Electric Company (SDG&E) provide gas distribution services to approximately six million customers in southern California. The largest portion of this area's current gas supply that reaches our customers originates from the Rocky Mountains, the Permian Basin, and the San Juan Basin. A smaller portion is produced within California.

While supplies have traditionally been adequate to meet demand, a nationwide natural gas supply imbalance is developing, as new gas reserves are not being discovered and developed at a rate matching the overall increase in demand. The rapid growth in natural gas demand and a slowdown in developing new North American gas supplies have led to increased gas commodity prices. At current and projected natural gas prices, importation of natural gas, shipped as LNG, has become an economically viable option. The US Department of Energy's (DOE) "Energy Outlook 2003" projects a ten-fold increase in LNG imports from 2001 to 2025. Five west coast LNG supply projects are in various stages of development. At this time, we cannot predict which projects will initiate operation. However, we believe that LNG will provide a substantial portion of future California natural gas supplies and will access end users through new receipt points close to load centers.

Supplies of LNG for the SCG system would originate primarily from Pacific Rim countries, such as Indonesia, Russia, and Australia. The respective chemical compositions and heating values of LNG supplies from these sources differ from natural gas supplied to southern California from out-of-state domestic sources as some ethane, propane and butanes have been removed from out-of-state domestic natural gas prior to shipment via interstate pipelines. Furthermore, gas components such as CO_2, N_2, and O_2 and heavier hydrocarbon components ($>C_4$), which are common in domestic natural gas supplies, are virtually nonexistent in LNG. California-produced gas can exhibit concentrations of higher ethane and propane similar to LNG.

Completion of just one proposed LNG terminal on the West Coast could deliver from 500MMscf to a 1Bscf of natural gas into the SCG and SDG&E gas distribution systems each day, replacing gas from sources currently supplying this region. Multiple terminals could deliver much more. Thus, significant numbers of SCG and SDG&E customers' utilization equipment could experience a change in gas composition from out-of-state domestic natural gas to gas supplies from LNG. Furthermore, given the operating characteristics of the SCG/SDG&E transmission and distribution systems and customer usage patterns, many customers may be subject to "swings" in gas composition from traditional interstate supplies to new supplies or vice versa in relatively short timeframes.

SCG has actively tested appliances and small industrial/commercial equipment to monitor equipment performance over broad ranges of gas composition. Extensive testing in the laboratory and field in the mid 90's led to the establishment of an upper Btu limit for SCG's Gas Quality Standards (Rule 30). During those tests, it was noted that for a few tested appliances test results were not consistent with the interchangeability indices calculations. Subsequent testing over the next several years confirmed that some newer end-use combustion technologies, such as premix/powered combustion, yielded results that were not predictable within the conventional interchangeability indices calculations. These combustion systems, although resulting in better efficiencies and lower NOx, seem to be more sensitive to changes in gas quality and rate of change in gas quality.

SCOPE

This research study was designed to assess current Gas Quality Standards (Rule 30) and the potential need to modify these standards based on safety and performance of selected, representative commercial and residential natural gas-fired appliances.

The major objectives of the study were as follows:

1. Evaluate each selected unit to determine any issues relating to equipment safety and performance. Equipment safety includes changes in Carbon Monoxide (CO) levels, combustion stability, lifting, flashback, and yellow tipping.
2. Compare measured and observed results against the major natural gas interchangeability indices, including Wobbe Number, Lifting, Flashback, Yellow Tipping and incomplete combustion.
3. Collect NOx emission data during testing.

Based upon earlier studies, a list of potentially sensitive equipment was drafted as a starting point. This list and a detailed questionnaire were provided to industry experts for review and comments. Manufacturer associations and more than 40 companies representing residential equipment manufacturers, burner manufacturers, boiler manufacturers and food service equipment manufacturers were contacted. Several industry consultants were retained to provide advice and SCG received valuable advice from these various external sources on the list of candidate equipment types to be tested. Further input and guidance was provided through internal SCG surveys, meetings and discussions with SCG industrial service technicians, research managers and highly experienced industrial/customer service training instructors.

Combustion systems and equipment were categorized as residential, commercial or industrial equipment. In order to maximize the number of different combustion systems and equipment types to be tested, equipment represented in more than one equipment type category would only be tested in one of the categories.

Once the list of equipment to be tested was finalized (Table 1), significant assistance was provided by SCG field service personnel, the AEAC and industry participants by providing access to test equipment on a loan basis. SCG also purchased equipment either new from retailed outlets, or salvaged from homes. Brand name and model number anonymity have been maintained to encourage full participation of all.

The study approach was to test the selected natural gas-fired equipment at gas composition boundary conditions within the existing Gas Quality Standards (Rule 30) limits. Equipment selection and prioritization was based on surveys of SCG employees (Field Service and Applied Technology), input from equipment manufacturers, analysis of other technical studies and input from industry experts and the Air Emissions Advisory Committee. Equipment selection was reviewed against and guided by specific criteria:

1. Critical time-controlled processes with limited or no temperature control
2. Narrow air/fuel ratio operating band
3. Performance/safety possibly dependent on flame characteristics
4. Safety concerns related to flue gases
5. Existence of sophisticated heat exchanger/combustion system
6. Historical combustion system related safety concerns
7. High population density in southern California
8. Recommendations from credible industry experts
9. Information from background and industry research
10. Technology entering southern California marketplace

Table 1 below shows the equipment selected and tested during this study. In addition to the Service Type Categories, Burner Type, and Size, it also shows the selection criteria that were identified for each device.

Table 1 – List of Equipment Tested

Unit	Description	Service Categories	Burner Type	Rated Input (BTU/hr)	Selection Criteria[2]
1	Horizontal Condensing Forced Air Furnace	Residential	Low NOX, induced combustion system with in shot burners firing into a tube-type heat exchanger	105,000	3,4,5,8,9,10
2	Flammable Vapor Ignition Resistant Water Heater	Residential	Atmospheric (with limited air)	36,000	3,4,8,9,10
3	Instantaneous Water Heater	Residential	Low NOX	117,000	2,3,4,5,8,10
4	Legacy Water Heater	Residential	Atmospheric	32,000	3,4,7
5	Legacy Floor Furnace	Residential	Atmospheric	32,000	3,4,6,7,8
6	Gravity Built-in Wall Furnace	Residential	Atmospheric	35,000	3,4,6,7,8
7	Pool Heater	Residential	Low NOX	250,000	2,3,5,10
8	Condensing Hot Water Boiler	Commercial	Low NOX	199,000	3,4,5,8,10
9	Hot Water Boiler	Commercial/ Industrial	Low NOX	500,000	3,4,5,7,8
10	Steam Boiler	Commercial/ Industrial	Low NOX	300,000	3,4,5,7,8
11	Steam Boiler	Commercial/ Industrial	Ultra Low NOX	660,000	3,4,5,7,8,10
12	Deep Fat Fryer	Commercial	Powered, surface-type	86,000	3,4,5,7,8
13	Chain-Driven Char Broiler	Commercial	Radiant tile operating in blue-flame mode	96,000/ 75,000	1,3,5,7,8

[2] The selection criteria were updated on the basis of the final equipment selected and additional information from manufacturers or industry experts.

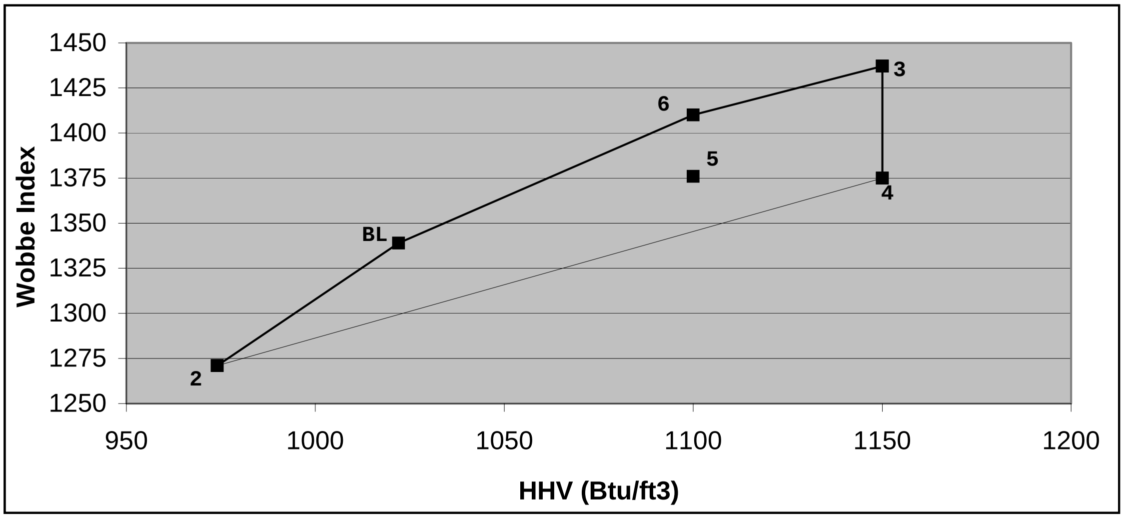
For the purposes of this study, operational safety is defined primarily by CO concentration in the flue gas. Other parameters, such as lifting, flashback, yellow tipping, etc., are taken into account in the overall safety evaluation, but the main parameter is CO. The CO concentration used as this safety indicator is 400 ppmv air-free, although we recognize that some appliances have different levels of acceptable safety performance related to CO and combustion stability. Also, certification/acceptance is with a specific test gas composition at STP (Standard Temperature and Pressure) which may not be applicable to other natural gas compositions. However, as noted, this study used 400 ppmv air-free as the basis for safety performance with all test gases as a reference to "safe" performance.

Test gas compositions selected for this study were based on current SCG Gas Quality Standards (Rule 30) and the potential HHV and Wobbe Number of acceptable future natural gas supplies. The approach used in selecting these "test gases" was to develop compositions that reflected HHV and Wobbe at boundary conditions within the current SCG Gas Quality Standard utilizing minimum and maximum components within the current standard. Intermediate gas compositions were utilized to further test equipment that exhibited sensitivities at the boundary condition in order to determine upper operating ranges for safety and performance and to provide input on HHV and Wobbe Number impacts. In some cases the selected compositions reflect actual gas compositions that may be present currently in the SCG system. However, they were not specific to compositions in either existing supplies or known LNG gas supplies. The test gas matrix was developed in a multi-tier system: primary and secondary. Primary gas blends are:

- Baseline gas (BL) corresponding to the average gas quality in the SCG system. 1020 Btu HHV and 1330 Wobbe Number.
- Low Btu/Low Wobbe Number (Gas 2) – The lowest combination of higher heating value and Wobbe Number within current Gas Quality Standards (Rule 30). 970 Btu HHV and 1271 Wobbe Number.
- High Btu/High Wobbe (Gas 3) – The highest possible combination of HHV and Wobbe Number that complies with current Gas Quality Standards (Rule 30). 1150 Btu HHV and 1437 Wobbe Number.
- High Btu/Low Wobbe Number (Gas 4) – This is the lowest Wobbe Number for the highest heating value in the Gas Quality Standards (Rule 30). 1150 Btu HHV and 1375 Wobbe Number.

Secondary blends were selected to test any sensitivity observed while testing the Primary gas blends. These were blended by holding the Wobbe Number constant at 1375 (Gas 4) and lowering the HHV to 1100 Btu HHV (Gas 5). The other secondary gas blend held the 1100 Btu HHV and raised the Wobbe Number to 1400 (Gas 6).

FIGURE 1 - GAS COMPOSITION MATRIX



In order to ensure commonality between all tests, gas compositions were either blended with a mass-flow mixing system or supplied from pre-mixed bottled gases. Then, for each equipment test the respective test gases were supplied in a specified order. The units were first run on Baseline gas and then Gas 2 and Gas 3 in succession. If any sensitivities were observed, the remaining Gases 4 – 6 were tested, as necessary. Not only were changes in gas components noted for the various test gases, but the rate of change from one to the other was also observed. Gases 4a and 5a were subsets used to see if there was any influence resulting from the number of hydrocarbons used to prepare the mixtures (e.g., mixture of high heating value and Wobbe that contained a mixture of only three hydrocarbons -methane, ethane, and propane or five hydrocarbons – methane, ethane, propane, butanes, C5+).

Note that there were limitations in the mass-flow gas blending system used in this study, which precluded the use of Gases 6a, 7a and 7b. These gases had been identified in the original test design and were listed in the "White Paper" (Appendix D).

The specific test gas compositions used in this study are presented in Table 2. Table 3 presents the Gas Indices for each of the test gases.

Table 2 – Gas Composition[3]

Primary	METHANE	ETHANE	PROPANE	iso-BUTANE	n-BUTANE	iso-PENTANE	n-PENTANE	C6 plus	CARBON DIOXIDE	NITROGEN	MN	Wobbe#	HHV
1 Baseline, Line Gas	96.08	1.78	0.37	0.06	0.06	0.01		0.03	1.18	0.44	100	1338.9	1022
2 970 Btu Gas	96.00								3.00	1.00	108	1271	974
or 1000 Btu Gas	97.00	0.75	0.10						2.00	0.15	106	1315	1000
3 1150 Btu Gas, Hi Wobbe	87.03	9.23	2.76	0.99					0.00	0.00	75	1437	1150
4 1150 Btu Gas, Lo Wobbe	84.92	4.79	2.40	1.20	1.20	0.60	0.60	0.30	3.00	1.00	68	1375	1150
(w/Nitrogen)	84.92	4.79	2.40	1.20	1.20	0.60	0.60	0.30	0.00	4.00	68	1392	1150
4a or 4 component mix	84.45		11.55						3.00	1.00	68	1375	1150
Secondary													
If fails test gas 4													
5 1100 Btu Gas, Avg. Wobbe	88.88	5.28	2.61	0.34	0.50	0.11	0.06	0.06	1.40	0.75	79	1376	1100
5a or 4 component mix	90.85		7.00						1.40	0.75	79	1376	1099
6	91.83	5.81	1.74	0.31	0.31						84	1410	1100

[3] The study allowed for a +/- 1% in both heating value and Wobbe and individual components were targets not absolutes to reach the Btu / Wobbe numbers. Actual Btu and Wobbe Numbers are identified in individual reports.

Table 3 – Test Gas Indices

Test Gas	Base	2	3	4	5	6	Limits
Heating Value (Btu/cf)	1020	970	1150	1150	1100	1100	970 to 1150
Wobbe Number	1332	1270	1437	1375	1376	1400	5%
AGA Indexes							
Lifting	1	1.06	0.92	0.98	0.97	0.935	<= 1.06
Flashback	1.01	1.01	1.03	1.03	1.02	1.018	<= 1.2
Yellow Tipping	1	1.10	0.81	0.80	0.88	0.857	>= 0.8
Weaver Indexes							
Flashback	0	0.044	-0.065	-0.022	-0.024	-0.055	<= 0.26
Yellow tipping	0	-0.076	0.209	0.207	0.128	0.141	<= 0.3
Incomplete Combustion	0	-0.053	0.099	0.060	0.049	0.074	<= 0.05
Lifting	1	0.933	1.124	1.050	1.052	1.091	>= 0.64
Heat Rate	1	0.953	1.077	1.029	1.031	1.060	0.95 to 1.05
Primary Air Ratio	1	0.953	1.077	1.030	1.031	1.060	0.80 to 1.20

Historical Gas Interchangeability Indices, identified in Table 3, were developed for atmospheric type burners from data gathered from testing residential appliances and a specially developed AGA test burner[4]. The indices indicated that several of the test gases were not interchangeable with the Baseline gas as indicated by the highlighted numbers. Some equipment tested in this study would have been expected to demonstrate performance problems or sensitivity with Gases 3, 4 and 6. However, test results showed sensitivity only with Gas 3.

These indices do not apply to the engines, turbines, and feedstock equipment categories. Other indices or gas composition requirements are utilized for safety and performance, such as Methane Number for engines.

[4] AGA Bulletin 36

STANDARDS AND PROTOCOLS

Testing protocols used in this study were derived from industry standards and regulatory test procedures. However, based on the needs of this program and the operating and design characteristics of equipment tested, it should be noted that adherence to the industry and regulatory testing standards was not literal. The reader is cautioned that no inference can nor should be drawn with regard to certification of these devices to the industry or regulatory requirements as a result of this program.

Prior to testing each piece of equipment, a detailed test protocol was developed by SCG, CE-CERT and industry experts/consultants, who were either members of the AEAC or separately contacted to provide input and guidance. The approach used in developing the test protocols for each appliance type was largely to combine and simplify testing standards.

Deviations from the standards were included when specific sections were believed to be superfluous or inappropriate to specific appliances or operating/installation realities. While standard industry or regulatory certification test standards provide consistent test methodologies and a basis for comparing test results, they are not always valid for observing the operation of natural gas-fired equipment installed at an end user's location. For instance, many of the standards define that a specific ambient temperature range be maintained at the test site. While this is appropriate for ensuring comparable results between test units, it does not address equipment performance at ambient conditions encountered in the field. Thus, professional experience and engineering judgment were required to develop the appropriate tests for each unit tested.

As a final quality assurance control measure, all protocols were thoroughly reviewed by SCG, CE-CERT and industry experts prior to testing.

Various standards from the following organizations were used as inputs or as the basis for the test protocols used in this study:

- ANSI – American National Standards Institute.
- AOAC – Association of Official Analytical Chemists.
- ASHRAE – American Society of Heating, Refrigeration and Air Conditioning Engineers.
- ASTM – American Society of Testing and Materials.

- **SCAQMD** - South Coast Air Quality Management District.
- **UL** – Underwriters Laboratories.
- **Manufacturer Test Guidelines**

GENERAL TEST PROCEDURE

The testing of each natural gas-fired appliance was conducted according to the individual equipment-specific individual test protocols. Test objectives were to determine safety and performance, and to gather emissions data as a function of fuel composition. These objectives were met through a series of tests conducted at steady state and transient (sudden gas changing) conditions.

The general protocol incorporated in each equipment-specific test protocol is described below. Detailed test protocols for each piece of equipment can be found in the individual reports in Appendices A, B and C.

1. The end-user equipment was installed and set-up according to the appropriate test standard(s) and/or manufacturers' specifications.

2. Appliance testing at "as received" conditions was performed with Baseline Gas and/or Baseline and Primary Gases. Data were monitored and collected for each gas tested. These data included CO, CO_2, O_2 and NO_x emissions, flame lifting, flashback, yellow tipping, temperature fluctuations, smooth ignition and production output and quality.

3. After testing at "as received" conditions, the gas input rate was adjusted to "rated input" conditions, if necessary. Then, appliances were tested at "rated input" conditions with Baseline Gas. High speed switching was used as test gases were changed. Data were monitored and collected for each gas tested. These data included CO, CO_2, O_2 and NO_x emissions, flame lifting, flashback, yellow tipping, temperature fluctuations, smooth ignition and production output and quality.

4. After testing at "rated input" conditions, additional tests, as required by the equipment-specific test protocol, were performed (i.e., over -fire and under-fire testing with Baseline Gas and/or Baseline and Primary Gases). Data were monitored and collected for each gas tested. These data included CO, CO_2, O_2 and NO_x emissions, flame lifting, flashback, yellow tipping, temperature fluctuations, smooth ignition and production output and quality.

5. Hot and/or cold ignition tests with Baseline and Secondary Gases at rated input, under fired or over-fired conditions were performed. During this time, visual observation of the flame, ignition delays and other observed phenomena were documented.

SUMMARY OF FINDINGS

The research study was designed to assess current Gas Quality Standards (Rule 30) and the potential need to modify these standards due to changing gas supplies and newer advanced combustion technologies. The following findings were identified relative to the stated objectives identified in the Scope section of this document. The numbering scheme is for reference only and does not indicate level of importance.

Objective 1 – Safety and Performance

1. There were no performance issues observed in the equipment tested that might have resulted from rapid changes in gas composition through the range of test gases.

2. All equipment tested operated safely within the context of this study and performed satisfactorily when set up to Baseline gas (BL) and operated with 970 HHV/ 1270 Wobbe Number (Gas 2), 1150 HHV / 1375 Wobbe Number (Gas 4), 1100 HHV / 1375 Wobbe Number (Gas 5) and 1100 HHV / 1400 Wobbe Number (Gas 6).

3. Most of the equipment operated satisfactorily on the 1150 HHV/ 1437 Wobbe Number (Gas 3), however, safety problems were encountered on some equipment.

    - The gravity built-in wall furnace showed significant CO emission level sensitivity to the High HHV / High Wobbe Number. However, the other legacy (used) residential indoor appliances tested were quite forgiving with respect to gas composition changes.

    - The deep fat fryer produced elevated CO levels when operating with the highest HHV and Wobbe Number gas. However, it maintained consistent food quality over all test conditions.

4. The CO levels for two other units, condensing boiler and pool heater, neared the Critical Point with 1150 HHV / 1437 Wobbe Number (Gas 3). (For purposes of this study the Critical Point is assessed as a change in CO concentration of 75 ppmv between baseline gas and other gas mixtures.) (See Figure 2).

5. The temperature changes for all units, except the deep fat fryer, increased when burning gases with higher HHV and higher Wobbe Number than baseline gas. This exception is believed to be the result of incomplete combustion due to limited air supply. (The actual combustion or flame temperatures could not be measured on all of the test units. For these units, either the stack temperature or heat exchanger temperature was used as the temperature change.) (See Figure 3).

6. The chain driven charbroiler (time-based cooking) exhibited several product quality problems. When the equipment was tuned to the high HHV/high Wobbe Gas (Gas 3) and switched to baseline gas, the meat sometimes came out undercooked. When tuned to baseline gas and switched to high HHV/high Wobbe Number gas, meat patties were sometimes overcooked.

7. Overall, neither HHV value nor Wobbe Number of the gas consistently correlated with equipment performance.

<u>Objective 2– Interchangeability Indices</u>

1. Interchangeability Indices in Table 3 indicated a potential for problems with three of the gas blends. However, with the exception of the 1150 HHV/ 1437 Wobbe Gas (Gas 3), when combusted in the gravity built-in wall furnace and the deep fat fryer the historic gas interchangeability analysis techniques did not always provide a means for predicting the acceptability of a fuel composition for the equipment tested.

<u>Objective 3 – Emissions Data</u>

1. HHV and Wobbe Number generally showed positive correlation with NOx emissions with Wobbe Number having the higher correlation.

2. All Low-NOx units showed higher NOx emission levels with the higher HHV / higher Wobbe Number gases, except for the horizontal condensing forced air unit. (See Figure 4).

3. Several of the units tested exhibited more NOx sensitivities with a greater number of hydrocarbon species in a given HHV / Wobbe Number gas.

4. Of the boilers tested in this study, one, the ultra Low-NOx boiler (the

newest technology and meeting one of the tightest emissions standards) showed little NOx emissions sensitivity over the range of gases. This unit also showed the least CO sensitivity.

5. Indoor residential appliances tested did not exhibit significant NOx sensitivities to gas composition changes. Some appliances showed small increases and others showed small decreases in NOx emissions concentration between study gas blends.

6. Low NOx pool heater showed NOx emissions sensitivity to changes in gas composition.

Other Key Findings

1. During this study, it was apparent from contacts with manufacturers and industry experts that there is a general lack of awareness regarding the wide range of gas compositions and characteristics distributed within SCG's territory and throughout the nation.

2. The "as-received" fuel input rates for several of the new, residential units tested in this study were at less than 90% of the nameplate rating values.

3. Initial testing of the instantaneous hot water heater indicated elevated CO levels when supplied with all study gases. During subsequent testing, it was discovered that the burner was extremely sensitive to slight gas supply pressure pulsations caused by an upstream regulator. The unit was retested with a different regulator and this test sequence did not indicate elevated CO levels.

Note: The individual equipment test reports are contained in Appendices A, B and C. The test reports contain detailed test results for each equipment unit tested at CE-CERT laboratory in Riverside, California and at the SCG Engineering Analysis Center in Pico Rivera, California.

Figure 2 - Changes in CO Emissions Relative to Baseline Gas

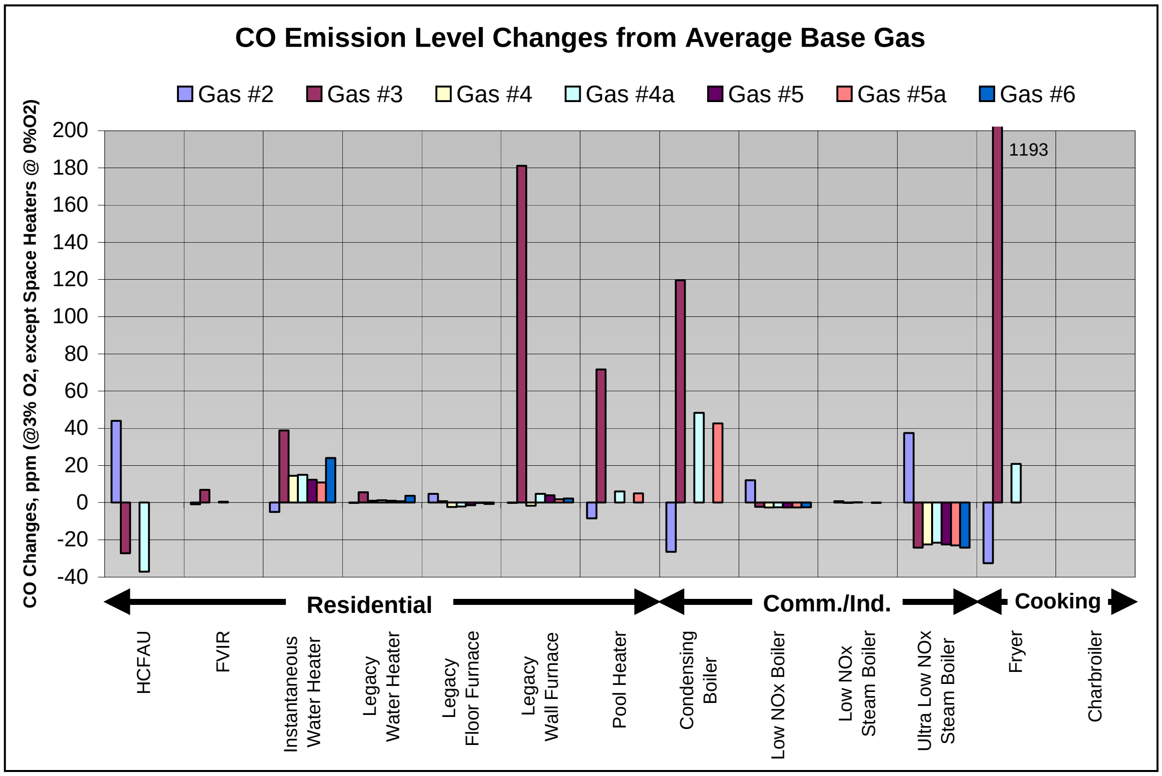


Figure 3 – Changes in Indicative Temperatures Relative to Baseline Gas

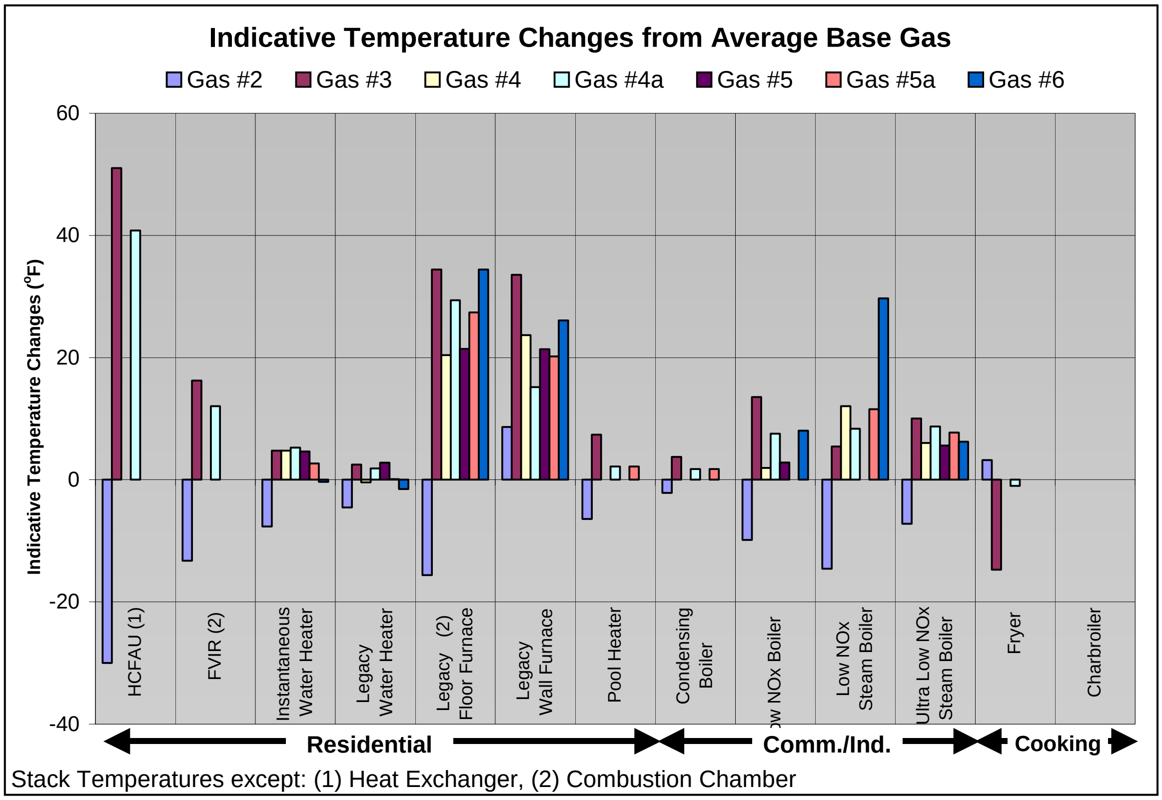
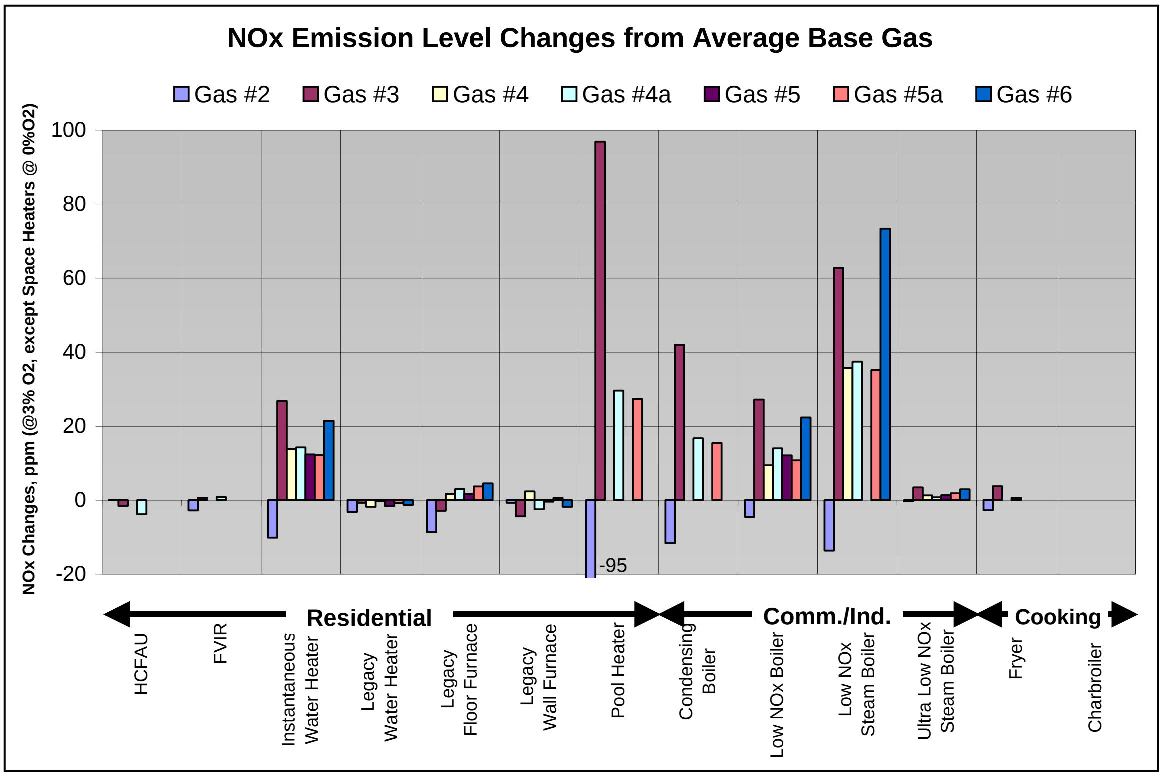


Figure 4 - Changes in NOx Emissions Relative to Baseline Gas



CONCLUSIONS

The following conclusions are based on data gathered during tests of the individual pieces of equipment. Global generalizations should not be extrapolated without more statistically based results, since other end-use equipment may have different parameters.

1. SCG Gas Quality Standard has an allowable range of 970 - 1150 HVV and allows for the Wobbe Number to be within +/- 10% of the typical composition of gas within the system. Theoretically, within the current Standard the Wobbe Number Limit could reach 1437 +. Based on the results of this study, SCG needs to modify the Gas Quality Standard to include a maximum and minimum numeric Wobbe Number limit. All units tested performed satisfactorily over a wide range of gas compositions and characteristics up to the 1150 HHV and 1400 Wobbe Number study limits.
2. The test results were less clear on the need to adjust the 1150 Btu HHV maximum limit. All units tested performed satisfactorily on an 1150 Btu HHV / 1375 Wobbe Gas (Gas 4) composition while some experienced problems with the 1150 Btu HHV / 1437 Wobbe Number Gas (Gas 3).
3. Other aspects of the SCG Gas Quality Standard need to be reviewed and updated:
   - Additional metrics need to be added for better predictions. Neither HHV nor Wobbe Number is an absolute predictor of equipment performance.
   - A "Range of Acceptability" concept may need to replace current approach utilizing AGA Interchangeability Indices: Lifting Index, Flashback Index, and Yellow Tip Index. These indices generally have performed well for appliances and equipment designed and installed up to the 1990's but may not be good predictors for newer, more efficient, less polluting equipment.
   - Engine manufacturers currently utilize Methane Number as an I.C. Engine performance indicator. Gas turbines or feedstock applications require metrics or compositional limits other than AGA Interchangeability Indices
4. Standard safety and NOx emission testing procedures/protocols that use specific test gas compositions may not be applicable nor are they a true indicator of performance in actual end use installations. Testing or certifying over a range of gas compositions may be more appropriate. Differences in building codes, and safety and environmental regulations in different geographic locations may also necessitate changes to acceptance protocols in different geographical locations.

RECOMMENDATIONS

1. SCG needs to incorporate results of this study, national efforts on gas quality and other inputs to develop an "Interim Range of Acceptability" based on quality/composition for each end-use category.
   - Update Gas Quality Standards and Rule 30.
   - Include interim Wobbe Number range from 1290 minimum to 1400 maximum.
   - Establish longer term goals for wide "Range of Acceptability" based on national standards.

2. SCG will work with industry, manufacturers and government to develop and implement new, nationally applicable gas quality standards that allow for the broadest range of gas compositions that may reasonably be encountered.
   - Develop a target "Range of Acceptability", provide a transition period and require equipment manufacturers to produce equipment that operates safely over the entire range.
   - Simplify the testing standards and protocols. Single standard testing/protocols should be adopted for certification, performance, safety and emission testing.
   - Continue to promote testing of large equipment by manufacturers, possibly with DOE sponsorship.
   - Work with manufacturers and agencies to develop testing protocols and standardize a range of test gases.
   - Determine, based on sound statistical methodologies, if an adjustment gas or gases could be used for equipment set-up to allow for the widest range of acceptable gas compositions.