Final LNG Research Study White Paper

Version 2.0

Submitted to the Southern California Gas Company

by

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1. Introduction

Sempra Energy Utilities provide gas distribution services to approximately six million customers in Southern California through Southern California Gas Company (SCG) and San Diego Gas and Electric (SDG&E). Most of this gas originates from the Rocky Mountains, Texas, and the San Juan Basin. A smaller portion originates from within California.

While supplies have traditionally been adequate to meet demand, an imbalance is developing as new findings have been limited. Rapid growth in natural gas demand and a slowdown in new gas supplies in North America have led to increased market costs. With prices at their current and projected levels, importation of natural gas shipped as Liquefied Natural Gas (LNG) and re-gasified has become an economically viable option. The DOE's "Energy Outlook 2003" projects a ten-fold increase in LNG imports from 2001 to 2025. Four major LNG supply projects, currently in development, are projected to provide a substantial portion of California's gas demand in the future.

Supplies of LNG for the projected developments in the SCG system would originate primarily in Pacific Rim countries, Indonesia, Russia, and Australia. The LNG supplies have higher concentrations of higher molecular weight components such as ethane, propane, and butane. The chemical composition of LNG supplies from these sources differs from the out-of-state domestic sources where some ethane, propane and butane have been removed prior to shipment via interstate pipelines. Furthermore, gas components like CO_2, N_2, and O_2 and heavier hydrocarbon components ($>C_4$) that exist in out-of-state domestic supplies are virtually nonexistent in LNG. California-produced gas can exhibit similar concentrations of higher molecular weight components. Thus, introducing the LNG into the distribution system can result in a gas mixture with an increased heating value and higher Wobbe Number (Wobbe) than traditional supplies.

A potential exists for certain gas-fired equipment to exhibit varied performance characteristics when provided with natural gas fuel that varies in composition. Previous studies by SCG and others indicate a potential for improper equipment operation when fuel gas composition changes and air/fuel remain fixed or have limited capacity to adjust. Of primary interest are gases received from new Liquefied Natural Gas (LNG) terminals or other potential new supplies into the SCG system.

This study will consist of an evaluation of the performance, safety, and emissions impacts of a variety of residential, commercial, and industrial processes that use natural gas as a fuel. The evaluation will focus on operating differences as a function of changes in natural gas blends. The different gas blends will represent a range of potential gas compositions resulting from increases in LNG supplies, California production gas or supplies from non-traditional sources. The specific objectives are to assess SCG's current Gas Quality Standards to assure customer safety as they relate to:

1) Higher heat content and Wobbe resulting from the introduction of LNG
2) Transient and steady-state performance changes resulting from on-line changes in composition
3) Relationship to new and emerging combustion technologies in natural gas end-use
4) Relationship of changing gas compositions to combustion emissions

A literature and database review has been conducted by the CE-CERT project team that consists of an electronic search of one or more databases such as COMPENDEX, MELVYL, and industry information. The first objective of the review is to determine the state of knowledge in the performance, safety, and emissions from equipment using natural gas as a function of changing gas compositions. A second objective is to determine the population profile of the equipment categories. Equipment selected for testing will include residential, commercial, and industrial units.

The following is a preliminary assessment from the project team on the potential impacts of different gas compositions on combustion characteristics of burner systems:

A basic combustion diagram for an open atmospheric burner system is presented in Figure 1. The diagram illustrates the relative emissions, flame temperature, and efficiency as a function of air-fuel ratio. For burner systems without feed-forward or feedback control, the introduction of fuel gases with different compositions can alter the air-fuel ratio. As can be seen in Figure 1, changing the air fuel ratio can dramatically affect process-operating parameters.

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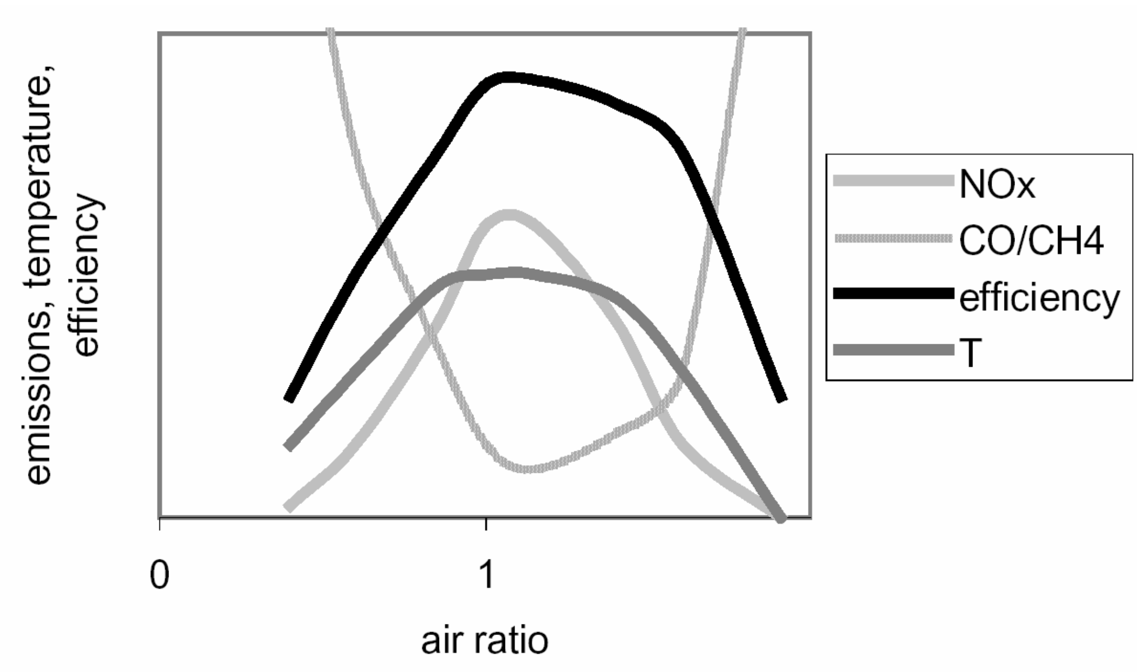
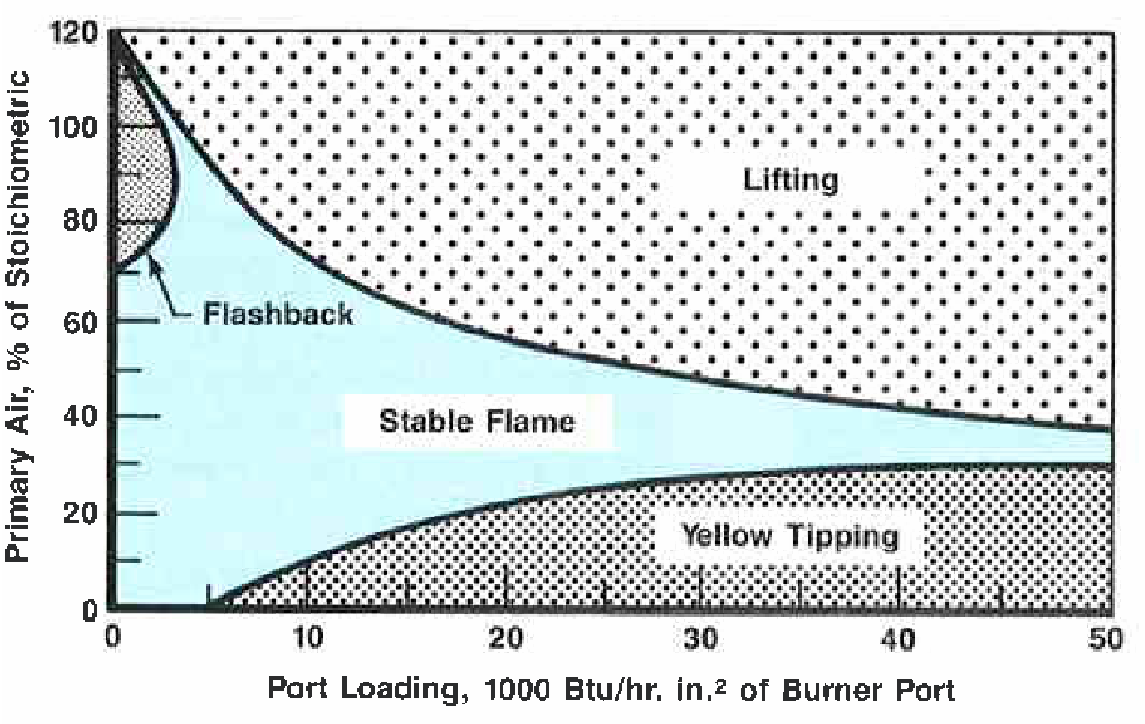


[Source: Pickenacker et al][1]

Figure 1
Natural Gas Fired Process Parameters* as a Function of Air-Fuel Ratio

*** Note – open atmospheric burners only**

Past research demonstrates that for a given burner and gas composition, stable and unstable regions of operation exist.[2] Figure 2, a flame characteristic diagram, shows the unstable regions of flashback, lifting, and yellow tipping. As the gas composition changes, with no adjustment or physical change to the burner, both the operating point on the diagram and the regions of instability shift. It is essential for burners to operate in the stable region for the appliance to perform satisfactorily.



[Source: Steinmetz, G. F.][3]

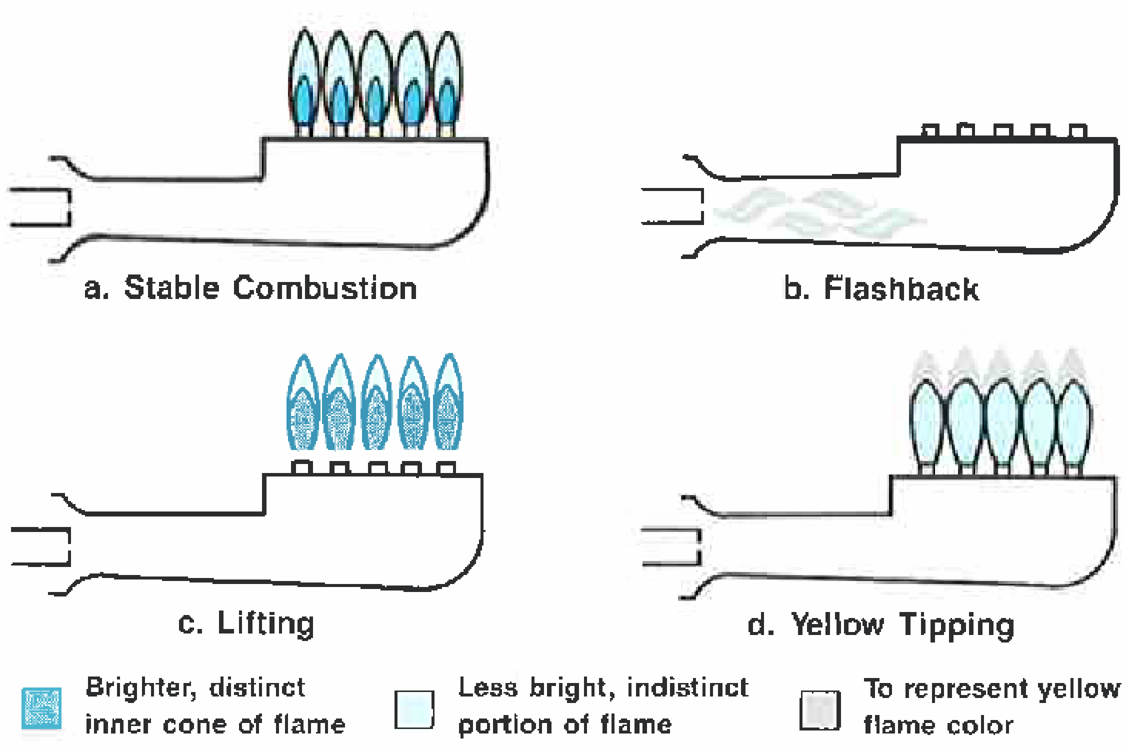
Figure 2
Flame Characteristic Diagram*

*** Note – example only. Exact location of regions is a function of both burner design and gas composition.**

Figure 3 illustrates various stable and unstable operating characteristics of an open atmospheric burner. Flashback and "smooth ignition" (Figure 3b) are evaluated by a number of tests under the equipment safety standards, but like the emission testing requirements, they are broader than necessary for the purposes of the study. One such group of standards is the American National Standards Institute (ANSI) Z21 categories, which are safety standards for various gas appliances and controls (example: ANSI Z21.47 – Gas-Fired Forced Air Furnaces). The recommended protocol would include the basic elements of each applicable standard, but not every detailed element. For equipment covered by the Z21 standards, for example, tests would be with supply pressure at 7.0" WC, at 4.0" WC, and throttled for operation at 1/3 third of rated input. Fuel gases would be those selected for the basic combustion emission tests.

In general, flame lifting (Figure 3c) seems an unlikely result of operation with gases of high Wobbe and it is recommended that the evaluation of it be limited in the interest of devoting the resources to areas of more concern. Observations during the gas changeover sequence should include notice of lifting, especially at the cold start and especially for premix burner systems. Additional cold start observations would be appropriate if any tendency is noted in those basic tests.

Yellow tipping (Figure 3d) is a reasonably likely phenomenon in combustion of gases having heavy components and high Wobbe. Observations during the gas changeover sequence must be diligent with respect to yellow tipping, especially at steady state. If significant yellow tipping is determined to be a result of change to LNG type gases, the protocol should include separate investigation of soot deposition. This can be done by placement of clean surfaces in the path of the combustion products.



[Source: Steinmetz, G. F.][3]

Figure 3
Flame and Burner Characteristics

Pilot operation:

It is recommended that pilot operation be evaluated in two ways. One way would be by simple observation during the gas changeover sequences required. The other would be by repetitive ignition tests, conducted essentially per the applicable safety standards, but tailored to the needs of the study. Under the Z21 standards, this would require repetitive on-off cycling at a number of conditions. For this project, two conditions are of interest – with normal supply pressure (7.0" WC) and with 4.0" WC supply. Fuel gases would be those selected for the basic combustion emission tests.

2. Related Work

There have been a number of studies related to safety, performance, and emissions from equipment and processes as they relate to different gas compositions. While these studies provide a background and context to the proposed work, it should be made clear that the proposed test program will focus on appliances and processes that have been or will be sold in the Southern California area. Additionally, the gas matrix in the proposed test program covers a wider range of heat content and Wobbe (encompassing the limits of SCG gas specifications) than previous work.

SCG has completed internal studies that compared safety, performance, and emissions from a number of equipment and processes using pipeline gas and higher calorific gas.[4] Included in the test matrix were a residential forced air unit, small and large low-NO_x boilers, a residential gas range broiler, a catalytic heater, an industrial furnace, and a natural gas engine. While the results of the report are proprietary, there were differences found in some processes with regard to flame/surface temperatures and emissions of NO_x, CO, and HC when comparing pipeline gas with LNG.

A gas interchangeability study conducted for Washington Gas Light focused on developing index limits to allow a wide range of LNG to be accommodated through nitrogen blending.[5] Tested appliances included cooktops, ovens, broilers, space heaters, furnaces, boilers, and water heaters. The main objective of the study was to determine the amount of nitrogen needed to blend with various LNG gases in order to achieve performance characteristics (flame lifting, yellow tipping, CO emissions) as traditional pipeline gas in the Washington Gas Light service territory. The basic finding was that appliance performance for LNGs blended with prescribed amounts of nitrogen would be essentially similar or better than appliance performance with traditional pipeline gas.

A gas interchangeability study conducted by the Gas Technology Institute investigated the degree to which gas of different composition changes the performance of a variety of residential combustion appliances compared with their performance using typical North American pipeline gas.[6] Initial testing was performed on a precision IT burner (a standard reference burner designed by AGA to interpret flashback, lifting, and yellow-tipping) in order to develop baseline images per the AGA flame code to be used as a standard for comparing flame appearance of appliances, where applicable. The appliance matrix consisted of new units, and included two water heaters, two ovens, to range tops, a furnace, an unvented space heater, a radiant space heater, an unvented fireplace and a clothes dryer. The test gases in the appliance study ranged from 1020 Btu/ft^3 and 1324 Wobbe to 1162 Btu/ft^3 and 1437 Wobbe. The study found that changes in the appliance burner performance were generally small over the entire range of gases tested. A few of the appliances exhibited larger changes than others, particularly appliances with a closed combustion chamber. None of these changes, however, resulted in an appliance operating outside the standards set for operation and safety. The study also found that appliance performance was consistent for fuel gases with a similar Wobbe, regardless of the composition of the gas. Another conclusion was that flashback and flame lifting did not occur on any of the appliances for the entire range of gases tested.

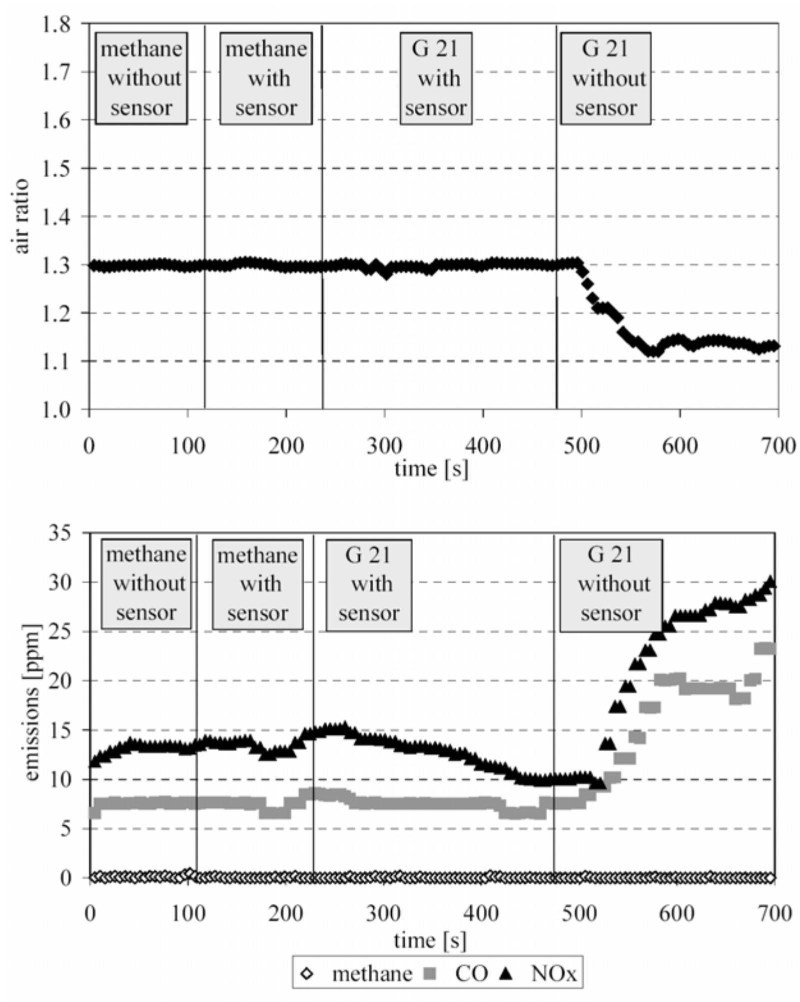
A study conducted for the California Energy Commission Public Interest Energy Research (PIER) program focused on the performance of catalytic combustion systems as a function of variability of natural gas fuel compositions.[7] This study first surveyed the compositions of natural gas produced and delivered in the United States and throughout the world. Then, subscale catalytic combustion modules were tested with controlled additions of higher molecular weight hydrocarbons and inert gases to simulate the range of gas compositions found in the survey. Results showed that the addition of inert gases had practically no effect on the performance of the catalytic combustion modules. Addition of higher molecular weight hydrocarbons fell within the acceptable operating "window" for most domestic United States pipeline sources. The majority of gases had calculated shifts (of combustion temperatures) of less than 20 ^{o}C, which is within the tolerance of catalytic combustors. The study found that gases with combustion temperature shifts greater than 20 ^{o}C (resulting from higher concentrations of higher molecular weight components) could be accommodated in catalytic combustion systems by lowering the catalyst inlet temperature to maintain combustor durability.

A paper published by the United States Department of Energy, National Energy Technology Laboratory reviewed the technical issues associated with using variable-composition gaseous fuels in low-emission energy systems.[8] The paper considered advanced gas turbines, reciprocating engines and fuel cells. For gas turbines, pre-mix combustion has become popular for reducing NOx emissions. Although pre-mix combustion has proven advantages for controlling emissions, flame position and stability may be affected by changes in fuel composition. Particular concerns noted in the study include flame flashback, auto-ignition, dynamic oscillations and lean blowout. For high performance (lean-burn) reciprocating engines, there has traditionally been a trade-off between high efficiency and NO_x emissions. Further reduction in the lean-misfire limit has shown promise in reducing NO_x, but the narrow operational and control range required will be complicated by any changes in fuel properties. For stoichiometric engines, downstream catalysts are available that significantly reduce NO_x, CO, and HC emissions. Compression ratios and engine efficiency, however, are limited by the fuel chemistry. Because higher molecular weight hydrocarbons have a shorter auto-ignition time, they can lead to engine knock. While some work has been done with on-board variable gaseous fuels monitoring and subsequent engine operation adjustments, no practical implementation of this concept is yet available.

A paper presented at the 22nd World Gas Conference in Tokyo discusses issues with gas appliances in the 21st century, including potential impacts of variation in gas quality.[9] The paper discusses existing or expected problems resulting from wide ranges of Wobbe (1015 – 1516) between countries, calorific value, flame velocity/methane number, and sulfur/ammonia content. The potential problems include disruption of service by safety devices, flame instability, low efficiencies, appliance durability issues, corrosion, and engine knocking. Possible solutions are also discussed, including development of a wider range of appliance performance standards, treatment/blending of supply gases, development of self-adapting appliances, and on-board adjustments to prevent engine knock.

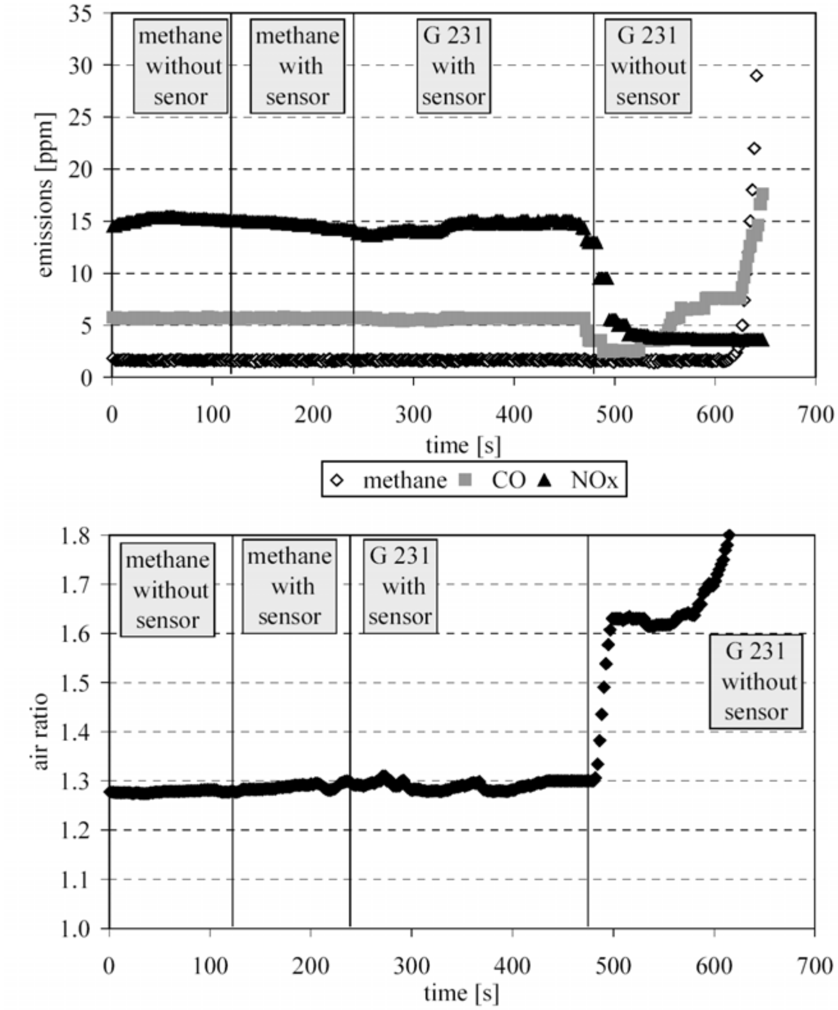
A major study has been undertaken in the UK regarding the potential changes in gas composition and the impact on safety, performance, and emissions of natural gas fired processes.[10] The study was commissioned due to the UK's expected dependence of imported gas to increase rapidly over the next five to fifteen years. The potential imported gases have a higher Wobbe index than traditional supplies, and may have an effect on the safety, performance and emissions of gas-fired processes. The study expects the LNG market to grow significantly and a significantly important source of gas to meet Europe's demand. The conclusion of the Phase 1 report is that a problem related to future gas quality does exist, and that future work should be undertaken to address the problems in the most cost-effective way.

Finally, a European study looked into the performance of a burner control system that adjusts air-fuel ratio based on the composition of the fuel gas.[1] Figures 4a and 4b illustrate the performance of a process with and without the burner control system for two different gas blends and methane only. The figures show the potential of dramatic variations in performance and emissions for burner systems operating without controls.



[Source: Pickenacker][1]

Figure 4a
Burner Performance with Different Fuel Gas Compositions



[Source: Pickenacker] [1]

Figure 4b
Burner Performance with Different Fuel Gas Compositions

3. Test Gas Specifications

The proposed project is a limited scope research study designed to assess current gas quality standards and the potential need to modify these standards in the future. Rather than test all equipment on a wide variety of gas blends, the approach will be to test the equipment at boundary conditions. Processes that exhibit sensitivities at boundary conditions will then be tested with intermediate gas blends in an effort to determine the point at which the sensitivities occur.

The gas blend matrix has been developed in a three-tiered format as follows:

Primary Gas Blends

1) **Baseline (pipe) gas** - Gas at CE-CERT is expected to come from Blythe (approximately 1015 Btu/ft^3, 1330 Wobbe). This gas will be used in setting up equipment (including firing rate) and performing initial tests. Previous experience at CE-CERT indicates that the gas composition of this pipeline gas is constant. If composition does change by more than 1% in HHV or Wobbe (as indicated by the on-line gas analyzer), provisions will be made to blend appropriate components into the pipeline gas to ensure consistent baseline compositions for all units tested.

2) **Low Btu/Low Wobbe –** The lowest possible combination of Higher Heating Value and Wobbe within the current SCG system specifications is 973 Btu/ft^3 and 1271, respectively.

3) **High Btu/High Wobbe –** The highest possible combination of Higher Heating Value and Wobbe that complies with current SCG system specifications is 1150 Btu/ft^3 and 1430, respectively.

4) **High Btu/Low Wobbe –** the Wobbe for this gas will be dropped to a level close to the lowest possible number for the high Btu gas. This results in a gas with a HHV of 1150 Btu/ft^3 and a Wobbe of 1375. This provides a theoretical gas with the highest Btu and

lowest Wobbe achievable with SCG Rule 30 Section H Gas Quality Specifications, and can only be achieved with CO_2 as the inert component.

Secondary Gas Blend

Processes that exhibit any sensitivities to test gas #3 and/or test gas #4 will undergo further testing in an effort to determine a range of acceptable operation.

5) **Intermediate Btu/Low Wobbe –** The HHV will be dropped to 1100 Btu/ft^3 while holding the Wobbe constant at 1375.

Tertiary Gas Blends

Processes that exhibit no sensitivities to test gas #5 will undergo further testing using one of the following blends (depending on results from test gases #3 and #4):

6) **[a] 1125 Btu/ft^3, 1375 Wobbe or [b] 1100 Btu/ft^3, 1400 Wobbe**

Processes that do exhibit sensitivities to test gas #5 will undergo further testing using one of the following blends (depending on results from test gases #3 and #4):

7) **[a] 1075 Btu/ft^3, 1375 Wobbe or [b] 1100 Btu/ft^3, 1350 Wobbe**

A graph of the proposed gas composition matrix is shown in Figure 5. The detailed compositions of test gases are presented in Appendix B.

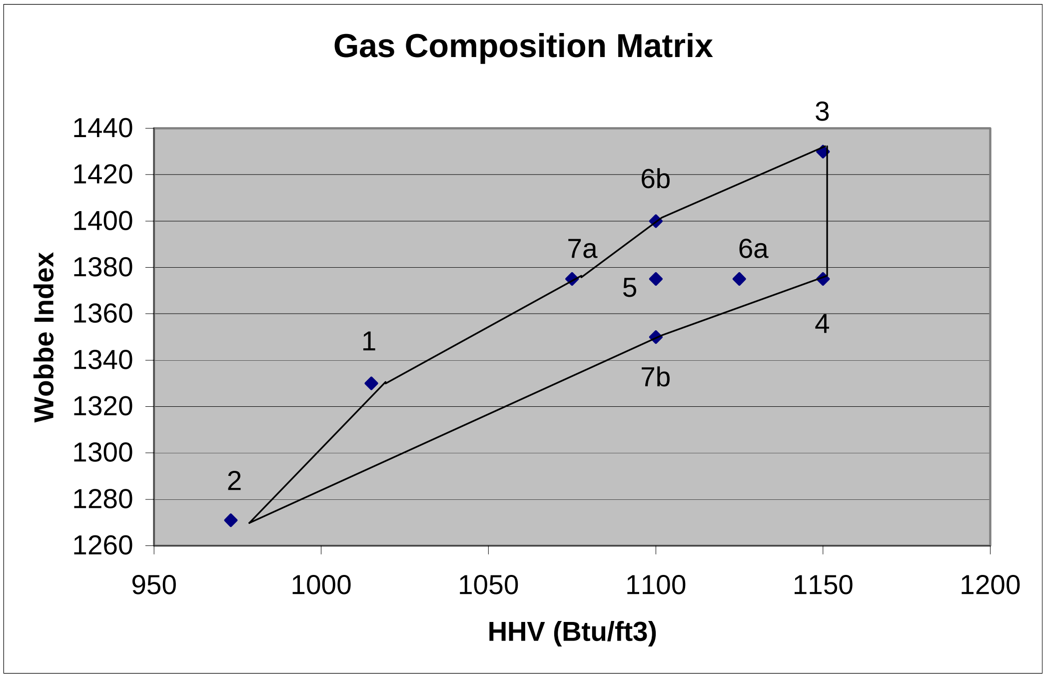


Figure 5
Test Gases

CE-CERT has developed a gas delivery system capable of providing a wide variety of representative gas compositions on a consistent and repeatable basis. The system will use a unique gas blending system consisting of compressed gas standards, heated pressure regulators, a heat exchanger, a controlled gas injection system, pipeline gas, a flow meter, and an on-line gas chromatograph to deliver specified flow rates and compositions of natural gas to the tested process units.

Individual compressed gas cylinders containing methane, ethane, propane, butanes/pentanes, nitrogen, and carbon dioxide will be used to obtain the target concentrations when blended with the pipeline gas. For process units with large input rates, several cylinders will be manifolded together to provide the specified flow rate of each component gas.

4. Equipment Selection

One of the biggest challenges expected in conducting the program is the identification, procurement, and operation of the equipment units selected for testing. We anticipate that significant assistance will be provided by SCG, the AEAC, and industry participants in providing test equipment to CE-CERT on a loan basis for the program. Based on previous test programs, we feel this is an acceptable approach, provided that SCG is willing to share applicable test results with the cooperating entity, and that brand names and model numbers are kept anonymous in any published material. A second assumption is that all equipment can be tested in a representative operating condition at CE-CERT's laboratories. It is expected that some processes cannot be adequately duplicated in a laboratory setting, and may require on-site field testing in order to evaluate properly. Given the complexities of the gas blending and analysis system, we have assumed that any field testing will require a change in the scope of the proposed phase II test program.

The equipment selection and prioritization will be based on surveys of SCG employees and equipment manufacturers, analysis of other technical studies, input from industry experts and input from AEAC members. SCG, working with CE-CERT, will review the input against specific criteria identified below. Each piece of equipment will be given a priority from A to C with A the highest priority. Given time constraints and uncertainties of the testing itself, prioritization provides identification of the most critical pieces of equipment required to meet the project objectives. Our goal is to test up to twenty pieces of equipment including A, B and C priorities.

There are combustion systems and equipment represented in both commercial and residential categories and in the commercial and industrial categories. In order to maximize the number of combustion systems and equipment types tested, equipment that is represented in two categories may be tested in only one of the categories.

Based on the review of literature as well as consultations with SCG and industry representatives, the following selection criteria was developed for identifying and prioritizing test units:

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

Equipment Matrix

Given the time frame of the testing element of the proposed Phase II program, we estimate that between ten (10) and twenty (20) individual equipment/processes can be tested. As an approximation of the test matrix, one or two processes in each of the nine equipment categories listed in the RFI will be tested (Appendix A). Larger equipment covered by air quality site permits will not be a part of the study.

To the extent possible, equipment will be provided with windows, mirrors or similar provisions to enable direct observation of flames. Burner and pilot behavior will be observed and recorded for each gas at the time of gas changeover and at steady state. In addition, pertinent requirements of the standards applicable to the equipment will be applied. For example, the ANSI Z21 standards include requirements such as smooth burner cross-ignition and lack of flashback at 1/3 of the nominal firing rate. A specific protocol will be developed for each family of equipment.

It is our experience that it is typically quite difficult to get good photographs of flame phenomena. However, we plan have digital camera and video capability available. We will attempt to record phenomena of special interest, but will have to describe it subjectively in any case.

5. General Test Description

The test program will be conducted according to individual test protocols developed for each individual process. The main objectives of the test program are to determine the safety, performance, and emissions of the natural gas-fired processes as a function of fuel composition. These objectives will be met through a series of tests conducted at steady state and transient (sudden gas changing) conditions.

The general protocol for testing each process is described below.

1. Install and set-up end-user equipment according to the appropriate test standard and/or manufacturers' specifications.

2. Record base line performance using Set-up gas #1 defined in Appendix B. Monitor and record emissions (NO_x, CO, CO_2, and O_2), flame lifting, flashback, yellow tipping, efficiency, temperature fluctuations, smooth ignition and production output, quality and safety as described in Steps A thru E below.

3. If input rate is not as specified by the manufacturer, equipment shall be adjusted and Step 2 repeated.

4. Test unit with low btu gas #2

    a. High-speed switch from set-up gas #1 and monitor and record parameters as described in Steps A thru E below.

    b. High-speed switch to gas #1 and monitor and record parameters as described in Steps A thru E below.

5. Test unit with high btu/high Wobbe gas #3

   a. High-speed switch from set-up gas #1 and monitor and record parameters as described in Steps A thru E below.

6. Test unit with high btu/low Wobbe gas #4

   a. High-speed switch from set-up gas #1 and monitor and record parameters as described in Steps A thru E below.

7. If steps 3 – 6 show sensitivities (e.g. high surface temperatures, CO above ANSI safety standard, etc.) in process equipment, repeat tests with secondary and tertiary blend gases listed in Appendix B.

8. The length of the test will depend on the end-user equipment and the process.

A. Combustion emission testing – firing rate and gas selection: Full-blown application of standards such as the ANSI Z21 safety standards for gas appliances would require testing at rated input and at various other conditions including over-fired operation. The testing in this program must be done at two firing rates and with gases limited to those pertinent to LNG questions. One firing rate would be “as found” and the other would be as rated. Gases would include a pipeline gas and one or more gases considered to be at the extremes or gases with compositions of special interest to SCG.

B. Online Gas Analysis: For real-time continuous analysis of gas blend compositions, the Contractor shall use a Stanford Research Institute QMS 200 (mass spectrometer). The QMS system can continuously sample gas at flow rates of several milliliters per minute. The inlet can be equipped to sample at pressures from 1 bar to 10 mbar. Data is acquired continuously, as opposed to batch sampling that is employed by gas chromatographs. The QMS has a fast response time of less than 0.5 seconds. Complete spectra can be recorded in seconds and individual masses can be measured at rates up to 25 points per second. The QMS will be calibrated with a certified hydrocarbon gas blend before and after each set of tests, and will meet the ANSI performance standards for on-line gas analysis.

C. Lifting and yellow tipping: Observations during the gas changeover sequence must include notice of lifting, especially at the cold start and especially for premix systems.

   Observations during the gas changeover sequence must be diligent with respect to yellow tipping. If significant yellow tipping is determined to be a result of change to LNG type gases, a separate investigation of soot deposition must be performed. This can be done by placement of clean surfaces in the path of the combustion products (clean surfaces must not interfere with normal exhaust flow). Yellow-tipping may also be indicated by an increase in CO concentration in the exhaust during or after a gas changeover sequence.

D. Pilot operation: The pilot operation shall be evaluated in two ways. The first must be by simple observation during the gas changeover sequences. The other would be by repetitive ignition tests, conducted essentially per the applicable safety standards, but tailored to the needs of the study. Under the Z21 standards, this would require repetitive on-off cycling at a number of conditions. For this project, conditions are of interest will be as specified in the applicable standard. Fuel gases would be those selected for the basic combustion emission tests.

E. Emissions Testing: Flue gas emissions testing will be conducted for each process tested. These tests will cover both steady-state operations with the selected gas blends and transient conditions occurring when switching blends. For each test, a sample will be extracted from the process exhaust and conveyed to continuous instrumental analyzers through a sample conditioning and moisture removal system. Calibrations, sampling and analytical procedures will follow SCAQMD Method 100. Emissions will be corrected to the appropriate standard oxygen level and reported in both volumetric and mass pollutant/energy consumed (e.g., lbs/MMBTU).

6. References

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10. ILEX Energy Consulting, Ltd., "*Importing Gas into the UK – Gas Quality Issues,*" report to the Department of Trade and Industry, November, 2003

Appendix A

Equipment Matrix

	Burner Type	Equipment Type	Heat Rate MMbtu/hr	Emission Limits CO	NOx	Standards	Selection Criteria	Test Pri. (A,B,C)	On Hand
INDUSTRIAL									
1	Catalytic Heater								
	1.1	Thermoformer					1,3,7,8	C	
	1.2	Curing Oven					1,3,7,8	B	
2	Radiant Heaters/Surface Burners/Ceramic								
	2.1	Drying Oven					1,3,9	B	
	2.2	Boilers	<2,000,000				2,3,5,8,10	A	
	2.3	Water heaters					2,3,5,8,10	B	
3	Low NOx Burners (Powered)								
	3.1	Metal Melters					2,3,4,7	A	
	3.2	Heat-Treat Furnaces					2,4,7,8,9	B	
	3.3	Boilers					2,3,4,5,7	A	
	3.4	Condensing Boilers					2,3,5,8,10	A	
	3.5	Direct Contact Water Heaters (Food Industry)					2,3,4,5,10	A	
COMMERCIAL									
4	Radiant Heaters/Surface Burners/Ceramic								
	4.1	Fryers					1,2,3,4,5,7,9	A 5	
	4.2	Outdoor Heaters					3	B	
	4.3	Grills/Broilers	106,000				1,3,4,7	A 3	
	4.4	Boilers					2,3,5,8,10	A	
	4.5	Water heaters					2,3,5,8,10	A	
5	Low NOx Burners								
	5.1	Boilers	<400,000				2,3,4,5,7	B	
	5.2	Instant Water Heaters	<400,000				2,3,4,5,10	A 4	
	5.3	Condensing Boilers						B	
RESIDENTIAL									
6	Radiant Heaters/Surface Burners/Ceramic								
	6.1	Space Heaters					3	B	
7	Low NOx Burners								
	7.1	Instant Water Heaters					2,3,4,5,8,10	B	
	7.2	Furnaces (Condensing)	106,000				2,3,4,5,8,10	A 1	Y
	7.3	Flammable Vapor Resistant Gas Water Heater	40,000				2,3,4,5,10	A 2	Y
8	Atmospheric Burners								
	8.1	Furnaces (FAU's) Legecy		400ppm	40Ng/J		4,6,7,8	A 6	
	8.2	Stoves/Ovens					4,7	C	
	8.3	Clothes Dryers					4,7,8	C	
	8.4	Tank-Type Water Heaters Legacy					4,5,7	C	
	8.5	Wall Heaters Legacy					6,7	B	
9	Power Assisted Combustion								
	9.1	Pool Heaters (low NOx, Pre-mix)	400,000				2,3,5,7	A 7	

SELECTION CRITERA

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

Appendix B

Test Gas Compositions

Test Gas

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	0.80	68	1375	1150
or 4 component mix	84.45		11.55						3.00	1.00	68	1375	1150
	84.92	4.79	2.40	1.20	1.20	0.60	0.60	0.30	0.00	4.00	68	1392	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
or 4 component mix	90.85		7.00						1.40	0.75	79	1376	1099
Tertiary													
If passes test gas 5													
6 Increase BTU or Wobbe													
If fails test gas 5													
7 Decrease BTU or Wobbe													