

**Rich Gas Research Study**

**Testing of Current Generation Residential Water Heaters**

Prepared by  
The Southern California Gas Company

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Shaena Stewart

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## EXECUTIVE SUMMARY

The purpose of this test was to operate new generation water heaters on a broad range of natural gases and determine if they perform safely and within the South Coast Air Quality Management Districts (SCAQMD) Rule 1121, which requires NO<sub>x</sub> emissions of residential water heaters (<75,000 Btu/hr rating) to be below 10ng/J.

All the 106 tests were conducted following rule 1121 from the SCAQMD as closely as possible, but none of the tests are certifiable because there were a few deviations from the test standard and the Engineering Analysis Center from the Southern California Gas Company is not approved by the SCAQMD to perform this test.

There were no operational, ignition, flame stability, or safety problems during the testing of any of the gases. The highest level of CO emissions observed was 115 ppm, still far below the limits specified in ANSI standard Z21.10.1-2001. Gas 3 and Gas 6 both have WOBBE Indexes far higher than SoCal Gas (SCG) is authorized by the CPUC (1385 WOBBE). Testing on these gases was performed for informational purposes only.

Two of the water heaters that were tested, the 40-Gallon by manufacturer C and the 50-Gallon by manufacturer B, initially had higher than expected values for NO<sub>x</sub> emissions during the uncertified base gas testing. The manufacturers were contacted to arrange for replacements. With these exceptions, Manufacturer A NO<sub>x</sub> emissions remained below 10 ng/J for all of the base and rich gas testing, and Manufacturer B NO<sub>x</sub> emissions remained below 10 ng/J for all testing except for one run with Gas 3, the richest gas. Manufacturer C's NO<sub>x</sub> emissions were above 10 ng/J for all tests except with base gas on the 30 & 50-Gallon heaters, and during one test run with the 30-Gallon heater with Gas 6. Tables summarizing the results are provided below. More detailed analyses are shown in the Results section. Ellipses around the NO<sub>x</sub> emissions in the following tables denote that during these uncertified tests, the NO<sub>x</sub> emissions were higher than 10 ng/J. Detailed tables of average measured and calculated values are presented in Appendix D.

30 Gallon Water Heaters Performance and Emissions Test Results Summary							
Manufacturer	Gas Used	WOBBE Index	HHV (Btu/SCF)	Corrected NOx emissions (ng/J)	Corrected NOx emissions (ppm)	Corrected CO Emissions	Input rate (Btu/hr)
A	Base	1334	1018	5.0	9.3	5.4	25,636
A	Base	1334	1018	4.4	9.1	5.3	25,778
A	Base	1330	1018	4.0	4.5	18.4	25,345
A	Gas 3	1433	1150	5.9	8.5	4.5	27,549
A	Gas 3	1433	1150	5.1	6.9	5.1	28,084
A	Gas 6	1408	1106	6.3	12.0	15.8	29,386
A	Gas 6	1408	1106	6.2	11.5	16.3	27,145
A	Gas 9	1385	1143	4.8	6.5	17.0	26,629
A	Gas 9	1385	1143	4.9	6.6	17.2	27,100
B	Base	1337	1024	5.9	8.8	7.9	29,481
B	Base	1331	1020	5.9	8.7	9.2	28,277
B	Base	1331	1019	5.5	8.1	8.3	29,059
B	Base	1327	1018	5.6	7.9	6.8	28,728
B	Gas 3	1433	1150	9.7	13.0	7.3	31,072
B	Gas 3	1433	1150	9.3	12.6	7.1	31,681
B	Gas 6	1408	1106	7.8	11.0	7.4	30,814
B	Gas 6	1408	1106	7.4	11.0	5.5	31,087
B	Gas 9	1385	1143	7.9	10.9	7.3	30,451
B	Gas 9	1385	1143	8.4	11.6	7.1	30,614
C	Base	1334	1022	7.5	10.4	4.0	26,438
C	Base	1333	1021	7.8	10.1	1.8	26,464
C	Base	1334	1024	7.3	9.8	3.7	26,313
C	Base	1332	1024	7.6	10.5	3.0	26,329
C	Gas 3	1433	1150	10.7	15.5	2.9	28,326
C	Gas 3	1433	1150	10.2	14.9	3.0	28,386
C	Gas 6	1408	1106	10.3	14.2	2.2	28,117
C	Gas 6	1408	1106	9.7	14.0	2.3	27,759
C	Gas 9	1385	1143	11.3	16.1	1.7	27,277
C	Gas 9	1385	1143	11.1	16.1	1.9	27,216

**Table 1: Results Summary of 30-Gallon Water Heaters**

\* The ellipses around some of the emissions in the table above denote that the emissions for that particular test were higher than 10 ng/J NO<sub>x</sub>. None of the tests performed for this report were certified tests.

\*\* Gas 3 is 3.5% over the WOBBE Index permitted by the CPUC

\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

40 Gallon Water Heaters Performance and Emissions Test Results Summary							
Manufacturer	Gas Used	WOBBE Index	HHV (Btu/SCF)	Corrected NOx emissions (ng/J)	Corrected NOx emissions (ppm)	Corrected CO Emissions	Input rate (Btu/hr)
A	Base	1331	1018	5.8	4.5	14.6	34,909
A	Base	1344	1030	6.7	7.9	15.8	34,842
A	Gas 3	1433	1150	8.6	11.9	12.5	37,554
A	Gas 3	1433	1150	9.1	12.9	13.1	37,741
A	Gas 6	1408	1106	7.7	10.5	12.8	36,891
A	Gas 6	1408	1106	9.3	12.6	14.7	36,894
A	Gas 9	1385	1143	9.6	11.4	13.1	41,772
A	Gas 9	1385	1143	8.2	11.5	12.6	36,635
B	Base	1333	1017	6.6	9.9	9.3	37,147
B	Base	1338	1023	7.0	10.5	9.9	35,819
B	Base	1330	1015	7.0	10.3	9.0	37,499
B	Base	1330	1014	7.0	10.3	9.1	37,365
B	Gas 3	1433	1150	10.0	15.0	7.7	40,033
B	Gas 3	1433	1150	10.3	15.2	10.0	39,410
B	Gas 6	1408	1106	9.2	13.5	8.1	39,462
B	Gas 6	1408	1106	9.8	14.4	7.0	39,045
B	Gas 9	1385	1143	8.6	12.7	8.2	39,173
B	Gas 9	1385	1143	8.7	13.0	7.6	38,583
C <sub>1</sub>	Base	1332	1335	13.2	18.3	2.8	36,547
C <sub>1</sub>	Base	1015	1017	13.2	18.4	2.6	36,543
C <sub>1</sub>	Gas 3	1433	1150	15.8	22.5	2.1	39,081
C <sub>1</sub>	Gas 3	1433	1150	15.7	22.6	2.2	39,099
C <sub>1</sub>	Gas 6	1408	1106	16.2	21.7	1.7	38,430
C <sub>1</sub>	Gas 6	1408	1106	15.4	21.8	1.6	38,489
C <sub>1</sub>	Gas 9	1385	1143	15.8	21.8	1.7	38,035
C <sub>1</sub>	Gas 9	1385	1143	15.9	22.4	1.9	37,724
C	Base	1333	1020	13.5	18.4	1.8	28,894
C	Base	1331	1018	13.0	18.1	1.1	34,993
C	Base	1332	1018	13.0	18.0	1.0	35,247
C	Base	1332	1018	13.3	18.3	1.1	35,075
C	Gas 3	1433	1150	17.0	23.8	0.6	38,337
C	Gas 3	1433	1150	16.7	23.6	2.2	38,218
C	Gas 6	1408	1106	15.8	22.7	0.4	34,302
C	Gas 6	1408	1106	16.7	23.0	0.0	36,543
C	Gas 9	1385	1143	16.4	22.4	0.5	36,327
C	Gas 9	1385	1143	16.7	22.4	0.0	36,361

**Table 2: Results Summary for 40-Gallon Water Heaters**

\* The ellipses around some of the emissions in the table above denote that the emissions for that particular test were higher than 10 ng/J NO<sub>x</sub>. None of the tests performed for this report were certified tests.

\*\* C<sub>1</sub> refers to the 40-Gallon water heater made by Manufacturer C after it was reofficed.

\*\*\*Gas 3 is 3.5% over the WOBBE Index permitted by the CPUC

\*\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

50 Gallon Water Heaters Performance and Emissions Test Results Summary							
Manufacturer	Gas Used	HHV (Btu/SCF)	WOBBE Index	Corrected NOx emissions (ng/J)	Corrected NOx emissions (ppm)	Corrected CO Emissions	Input rate (Btu/hr)
A	Base	1334	1020	5.2	8.3	15.7	35,286
A	Base	1334	1020	6.0	8.5	16.1	35,481
A	Base	1333	1016	6.5	8.1	16.3	39,597
A	Base	1332	1016	5.6	8.1	16.1	35,315
A	Base	1331	1016	4.6	8.1	18.2	35,342
A	Gas 3	1433	1150	7.9	11.8	16.3	37,416
A	Gas 3	1433	1150	8.4	11.8	16.7	37,719
A	Gas 6	1408	1106	7.5	11.4	16.0	36,976
A	Gas 6	1408	1106	7.9	10.7	16.1	36,896
A	Gas 9	1385	1143	6.7	9.8	18.3	36,356
A	Gas 9	1385	1143	7.1	10.0	16.7	36,223
B <sub>1</sub>	Base	1334	1018	6.7	10.4	7.7	35,751
B <sub>1</sub>	Base	1333	1017	6.6	10.1	7.2	37,303
B <sub>1</sub>	Base	1339	1020	7.2	10.0	8.9	38,290
B <sub>1</sub>	Base	1337	1019	7.4	10.1	8.8	37,914
B <sub>1</sub>	Gas 3	1433	1150	10.0	14.4	7.3	40,677
B <sub>1</sub>	Gas 3	1433	1150	9.6	14.1	8.1	37,834
B <sub>1</sub>	Gas 6	1408	1106	9.0	13.4	8.3	39,868
B <sub>1</sub>	Gas 6	1408	1106	9.0	13.3	7.8	39,485
B <sub>1</sub>	Gas 9	1385	1143	8.3	12.7	6.9	36,228
B <sub>1</sub>	Gas 9	1385	1143	8.5	12.7	6.9	36,197
B	Base	1332	1015	11.2	16.8	24.1	37,850
B	Base	1338	1024	11.2	16.7	25.9	38,023
B	Base	1338	1024	11.6	17.4	26.6	38,007
B	Base	1338	1024	12.1	19.6	28.0	38,148
B	Gas 3	1433	1150	12.8	20.3	115.7	40,061
B	Gas 3	1433	1150	12.5	20.5	112.9	40,784
B	Gas 6	1408	1106	13.9	20.2	97.5	41,091
B	Gas 6	1408	1106	14.3	19.5	83.0	39,827
B	Gas 9	1385	1143	13.3	19.4	62.4	39,283
B	Gas 9	1385	1143	12.9	18.7	63.2	39,265
C	Base	1335	1020	9.7	12.8	1.9	34,424
C	Base	1335	1018	9.7	12.7	1.7	36,488
C	Base	1338	1022	10.1	12.4	2.3	36,723
C	Base	1316	1006	10.0	12.7	2.4	36,148
C	Gas 3	1433	1150	13.1	18.5	1.2	39,245
C	Gas 3	1433	1150	13.6	18.5	1.3	38,906
C	Gas 6	1408	1106	12.0	17.0	1.3	38,559
C	Gas 6	1408	1106	12.1	16.7	1.0	38,649
C	Gas 9	1385	1143	12.2	16.9	1.0	37,973
C	Gas 9	1385	1143	12.1	16.0	1.2	37,882

**Table 3: Results Summary for 50-Gallon Water Heaters**

\* The ellipses around some of the emissions in the table above denote that the emissions for that particular test were higher than 10 ng/J NO<sub>x</sub>. None of the tests performed for this report were certified tests.

\*\* B<sub>1</sub> refers to the 50-Gallon replacement water heater made by Manufacturer B.

\*\*\*Gas 3 is 3.5% over the WOBBE Index permitted by the CPUC

\*\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

## EQUIPMENT SELECTION CRITERIA

The products used for this study were selected because they represent the new generation of water heaters required to be used in SCAQMD territory. Nine water heaters were provided by 3 different manufacturers for testing in three different sizes, at 30, 40 and 50 gallons.

## EQUIPMENT SPECIFICATIONS

The following water heaters were used for testing. Three different manufacturers were used, and the manufacturer's name is substituted in the report for the letters A, B, or C.

Manufacturer	Size (Gallons)	Year of Manufacture
A	30	2007
A	40	2007
A	50	2007
B	30	2008
B	40	2008
B	50	2008
C	30	2008
C	40	2008
C	50	2008

Table 4: Water Heaters Used for Testing



## STANDARDS

Testing was based on the following test protocol:

- South Coast Air Quality Management District Rule 1121, Control of NO<sub>x</sub> Emission from Residential Type Natural Gas-Fired Water Heaters, last amended December 10, 1999.
- South Coast Air Quality Management District Protocol for Rule 1121, last amended January 1998
- South Coast Air Quality Management District Method 100.1

These tests were not certified and deviated from the protocol in the following ways:

- The burners were not adjusted, and the input rates for many of the heaters fluctuated outside of the 2% range allowed for in the protocol.
- The inlet water went above 76°F during some of the tests runs.
- Gases 3, 6, and 9 are out of spec with Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.
- Method 100.1 was not strictly followed. No sampling system bias was performed.

## INSTALLATION

The test rig and installation was set up following the test protocol for SCAQMD rule 1121, per the protocol “Natural Oxides Emissions Compliance Testing for Natural Gas-Fired Water Heaters and Small Boilers.”

The overall setup of the equipment included a number of sub systems, including gas supply, gas composition analysis, gas appliance, flue gas monitoring, and data acquisition. A schematic of the overall test system is shown in Appendix A (Figure A1).

The water heaters were installed and instrumented in a laboratory test rig according to the manufacturer’s specifications and the test protocol. Thermocouples were installed to measure process temperatures, including water in and out, flue gas, gas input, and six locations in the storage tank. Pressure transducers were installed to measure gas supply, manifold, atmospheric, and water pressures. A schematic of the instrumented water heater set up is shown in Appendix A (Figure A2).

## TEST GASES

Several gases were used for the project, including base gas and three different special blends of rich gases. Base gas is the typical gas available from the natural gas service line at the test facility. Base gas has slightly varying gas composition which is averaged and shown with the range of test gas compositions below in Table 5. Detailed data of the base gas composition for each test can be found in Appendix D.

Gas 9 is close to the upper limit of tariff gas specs, which are a 1385 WOBBE Index and an HHV of 1150. Gas 6 is slightly above these limits, and Gas 3 is far above. Because Gases 3 and 6 are outside of the WOBBE Index range allowed for by the CPUC, testing with these gases was done for informational purposes only.

<b>Test Gas Compositions</b>				
<b>Gases</b>	<b>Base*</b>	<b>Gas 3</b>	<b>Gas 6</b>	<b>Gas 9</b>
<b>C6+</b>	0.025	0.000	0.000	0.000
<b>Nitrogen</b>	0.500	0.100	0.300	4.100
<b>Methane</b>	95.90	86.50	91.20	84.80
<b>Carbon Dioxide</b>	1.280	0.035	0.003	0.000
<b>Ethane</b>	1.788	9.480	5.747	0.000
<b>Propane</b>	0.382	2.725	1.727	11.125
<b>i-Butane</b>	0.060	1.034	0.534	0.000
<b>n-Butane</b>	0.064	0.000	0.531	0.000
<b>Neopentane</b>	0.000	0.000	0.000	0.000
<b>i-Pentane</b>	0.022	0.000	0.000	0.000
<b>n-Pentane</b>	0.017	0.000	0.000	0.000
<b>Oxygen</b>	0.012	0.049	0.016	0.000
<b>Specific Gravity</b>	0.580	0.640	0.620	0.680
<b>WOBBE Index</b>	1341	1433	1408	1385
<b>HHV (Btu/SCF)</b>	1021	1150	1106	1143

**Table 5: Test Gas Compositions**

\* Please note that the base gas data listed above is an average, and the actual base gas composition varied between all of the tests. Exact composition for each test can be found in appendix D.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

## TEST PROCEDURES

The procedure used for testing was South Coast Air Quality Management District's protocol for rule 1121, "Nitrogen Oxides Emissions Compliance Testing for Natural Gas-Fired Water Heaters and Small Boilers."

1. Adjust burner – Input rate needs to be within 10% of stated manifold pressure, within 2% of specified BTU/hr rate (manifold pressure and input rates vary by water heater).
2. Thermostat should be set so that the maximum mean temperature is equal to  $135 \pm 5^\circ\text{F}$ .
3. Turn off water heater.
4. Fill the tank with water (no air, between 40 psig to maximum rate pressure).
5. Turn on the water heater; heat until it reaches operation temperature (can be done overnight).
6. Withdraw 10 gallons of water.
7. Wait for cut-out to occur.
8. Immediately begin measuring the mean tank temperature once a minute until  $135^\circ\text{F} \pm 5^\circ\text{F}$  is reached (this denotes the beginning of the test).
9. Record test start time, mean tank temperature, and gas meter reading.
10. Begin drawing water ( $3 \pm 0.25$  gpm) until  $10.7 \pm 0.5$  gallons are withdrawn OR until burner cut-in occurs (if beyond 10.7 gallons withdrawn).
11. Record inlet and outlet water temperatures 15 seconds after draw initiation; continue recording in 5 second intervals while drawing – record manually and compare with data logger values.
12. Record cut-in time.
13. Record maximum CO during test.
14. Record  $\text{CO}_2$  and  $\text{NO}_x$  concentrations during the last 3 minutes before cut out (one recording for each of the three minutes) and calculate the mean of the recordings.
15. Record cut-out time.
16. Record weight/volume of water withdrawn.
17. Immediately after recovery, record maximum tank temperature and volume of fuel consumed (gas meter reading).
18. Collect natural gas sample for composition analysis.

### *Deviations From Protocol*

1. SCG did not adjust the burners prior to testing and therefore the input rate did not always remain within 2% of the specified BTU/hr rate. Because these water heaters are commercially available products, they were tested "as-is".
2. The inlet water temperature went above  $76^\circ\text{F}$  on some of the runs, which is out of the acceptable range according to the protocol.

3. Method 100.1 was not strictly followed. No sampling system bias was performed.

## RESULTS

No safety, ignition, flame stability, or operational problems were encountered during the testing.

All of the water heaters made by manufacturer A demonstrated NO<sub>x</sub> emissions below 10 ng/J for all of the base and rich gas tests.

Of the water heaters made by manufacturer B, the 30-Gallon heater met NO<sub>x</sub> emissions requirements for all of the tests, and the 40-Gallon heater met NO<sub>x</sub> emissions requirements for all tests but one, which was with Gas 3. Initially, the 50-Gallon heater did not meet requirements for any of the tests, including base gas. The manufacturer was contacted, and they arranged for SCG to replace the defective heater by picking up an existing new unit at the local distribution center. The replacement heater had NO<sub>x</sub> emissions below 10 ng/J for all base and rich gas testing. Manufacturer B performed an analysis on the original heater they provided to SCG and was able to recreate the same emission results as found at the SCG lab, and determined that the cause of the high emissions was due to the baffle being out of spec.

The 30-Gallon heater made by manufacturer C had NO<sub>x</sub> emissions below 10 ng/J for all base gas tests, but did not for any of the rich gas tests, except for one test with Gas 6. The 40-Gallon heater had NO<sub>x</sub> emissions above 10 ng/J during all of the base gas and rich gas tests, so the manufacturer was contacted. The manufacturer offered a replacement orifice, which was installed by SCG. However, the heater still did not get NO<sub>x</sub> emissions below 10 ng/J for any base gas or rich gas tests after being reorificed. The results for the testing of the water heater with both orifices are listed in the summary tables in both the Results Summary section and Appendix D. The 50-Gallon heater made by Manufacturer C had NO<sub>x</sub> emissions below 10 ng/J for 3 of the 4 base gas tests, but did not for any of the rich gas tests.

Detailed tables showing the emissions, measured, and corrected values can be found in Appendix D. A direct correlation was found between the NO<sub>x</sub> emissions and the WOBBE Index. Of the four gases tested, the one with the highest WOBBE index was Gas 3, which also had the highest number of failed tests. However, both Gas 3 and Gas 6 were tested only to identify what would happen beyond SCG's tariff gas specifications. Because Gas 6 and Gas 3 have WOBBE Indexes above 1385, SCG will not have LNG gas that rich in the pipelines.

# Appendix A

## Equipment Schematics

### Overall Setup for the Test Cell

The overall setup of the equipment included a number of sub systems, including gas supply, gas composition analysis, gas appliance, flue gas monitoring, and data acquisition. The overall schematic is shown in Figure A1 below. A schematic of the fully instrumented water heater is shown in Figure A2.

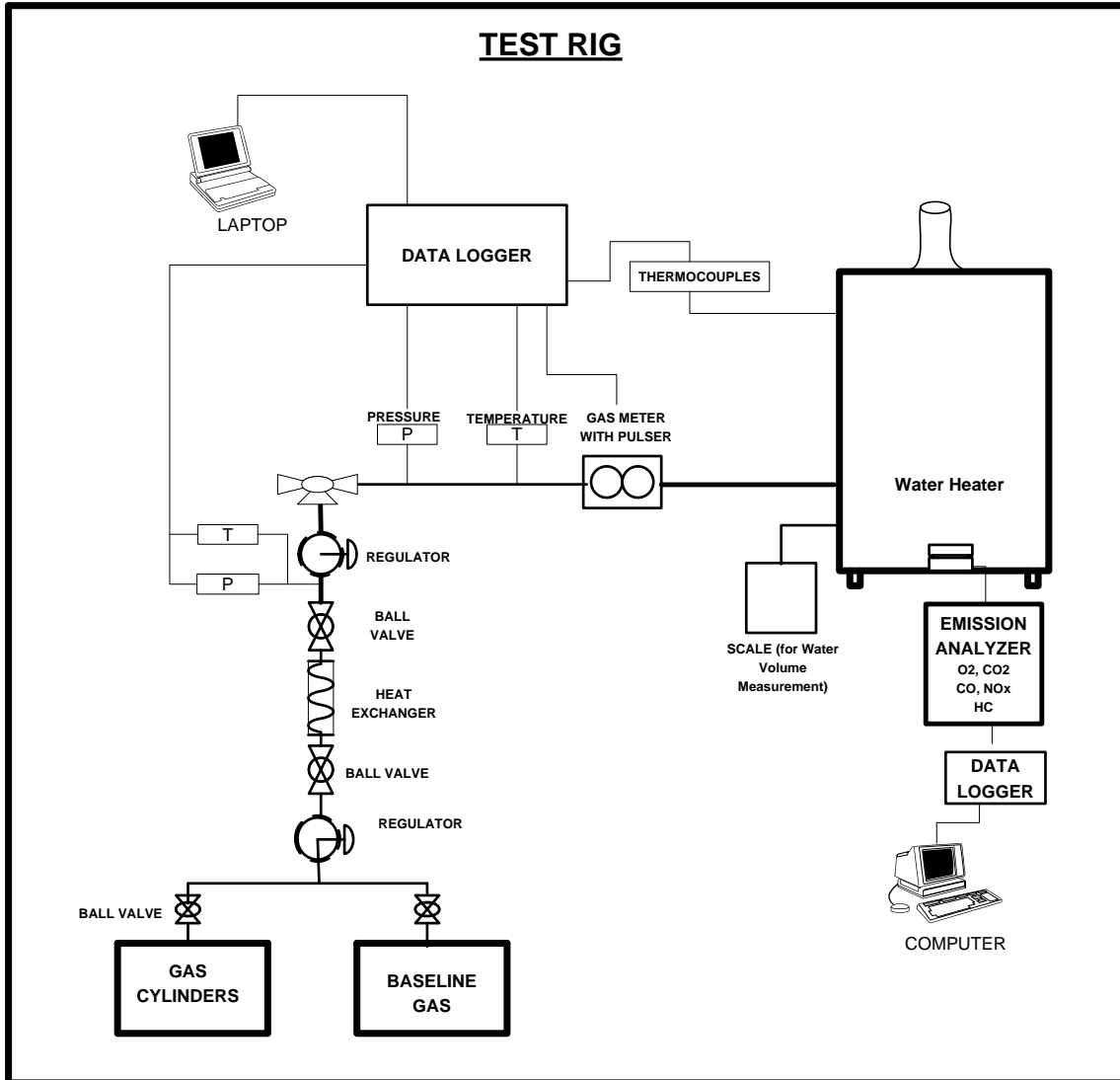


Figure A1 – Overall Equipment Layout

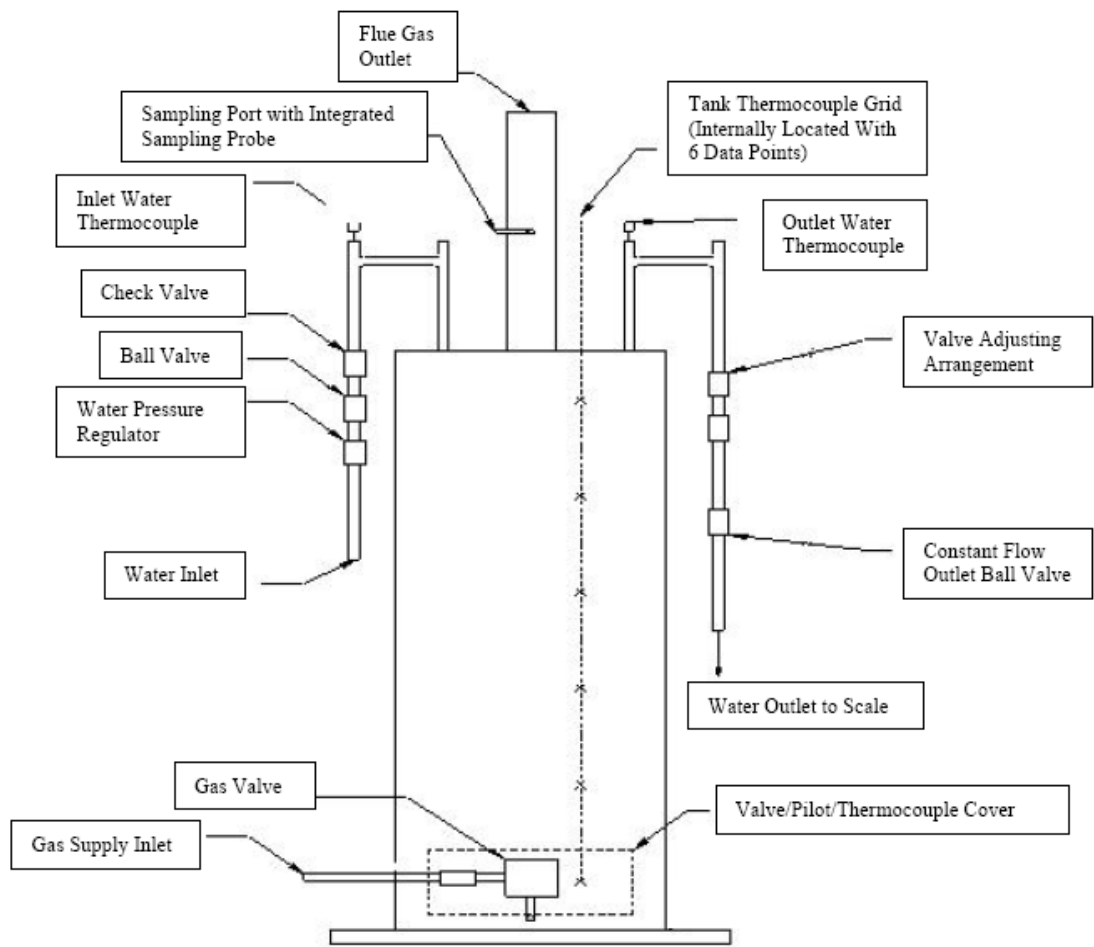


Figure A2 – Residential Water Heater Schematic with Instrumentation

## Appendix B Equipment List

Test Equipment				
Equipment	Manufacturer	Model	Accuracy	
K	Omega Engineering Co.	KMQSS	2.2°C or 0.75%	
T	Omega Engineering Co.	TMQSS	2.2°C or 0.75%	
Gas Meter	American Meter Co.	DTM 200A	±0.46%	
Gas Meter Pulser 1 pulse per 3 cf	Rio Tronics	4008468	n/a	
Pressure Transducer	Omega	PX205-100GI	±0.25% of full scale	
Datalogger	Delphin	D51515 Kurten	n/a	
Gas Divider	STEC	SGD-710C	n/a	
Emissions Analyzer				
Analyzer	Manufacturer	Model	Type	Accuracy
O <sub>2</sub> , NO, and NO <sub>x</sub>	California Analytical Institute	603 Digital	Chemiluminescence	± 1% of Full Scale
CO and CO <sub>2</sub>	California Analytical Institute	650 Noxygen	Infrared Gas Analyzer	± 1% of Full Scale
Calibration & Span Gases				
Gas	Manufacturer	Type		Accuracy
Calibration	Scott Specialty Gases	Certified Master Class - 0%		±2%
NO / NO <sub>x</sub>	Scott Specialty Gases	Certified Master Class - 85.8ppm & 214.7 ppm		±2%
CO	Scott Specialty Gases	Certified Master Class - 43.8, 82.2, & 181 ppm		±2%
CO <sub>2</sub>	Scott Specialty Gases	Certified Master Class - 9.08% & 11.99%		±2%
O <sub>2</sub>	Scott Specialty Gases	Certified Master Class - 8.02% & 20.9%		±2%

## Appendix C

### Calculations

#### Emissions Concentrations

Corrected to 3% O<sub>2</sub>

$$\text{CO and NO}_x \text{ conc. (at 3\% O}_2) = \text{ppm} \times \left[ \frac{20.9 - 3\%}{20.9 - \%O_2} \right]$$

Where:

ppm = measured CO or NO<sub>x</sub> concentration, ppmv  
% O<sub>2</sub> = measured O<sub>2</sub> concentration, percent by volume

#### Corrected Fuel Flow Rate

$$SCFH = ACFH \times GMC \times \left[ \frac{FP + BP}{14.62 \text{ psia}} \right] \times \left[ \frac{519.67^\circ R}{FT + 459.67^\circ F} \right]$$

Where:

SCFH = standard cubic feet per hour  
ACFH = actual cubic feet per hour  
FP = gas supply fuel pressure (psig)  
BP = barometric pressure (psia)  
14.62 psia = standard atmospheric pressure  
519.67 °R = standard atmospheric temperature  
FT = gas supply fuel temperature (°F)



### **Input Rate**

$$\text{Input Rate (Btu/hr)} = \text{SCFH} \times \text{HHV}$$

Where:

SCFH = standard cubic feet per hour of fuel gas

HHV = higher heating value of fuel gas (Btu/cf)

### **Wobbe**

$$W_o = \frac{HHV}{\sqrt{SG}}$$

Where:

$W_o$  = Wobbe number (Btu/cf)

HHV = higher heating value (Btu/cf)

SG = specific gravity of fuel gas

### **Storage Tank Capacity**

$$V_{ST} = \frac{(W_F - W_T)}{D_S}$$

Where:

$V_{ST}$  is the storage capacity of the water heaters in gallons

$W_F$  is the weight of the water heater completely filled with water (pounds)

$W_T$  is the weight of the empty water heater (pounds)

$D_S$  is the density of water at the appropriate temperature (pounds/gallon)

## **Heat Output**

$$H_O = MC_{pi}(T_{del} - T_{in}) + V_{ST} D_n C_{p2}(T_{max} - T_0)$$

Where:

H<sub>O</sub> is heat output (Btu)

M is the mass of the water withdrawn (pounds)

C<sub>pi</sub> is the specific heat of water at the average temperature (T<sub>del</sub> + T<sub>in</sub>)/2  
(Btu/pound °F)

T<sub>del</sub> is the average delivery temperature (°F)

T<sub>in</sub> is average inlet temperature (°F)

V<sub>ST</sub> is the storage capacity of the water heaters in gallons

D<sub>n</sub> is the density of water at the average temperature (T<sub>max</sub> + T<sub>0</sub>)/2  
(pounds/gallon)

C<sub>p2</sub> is the specific heat of water at the average temperature (T<sub>max</sub> + T<sub>0</sub>)/2  
(Btu/pound °F)

T<sub>max</sub> is the maximum mean tank temperature recorded after cutout  
following the test draw (°F)

T<sub>0</sub> is the maximum mean tank temperature recorded after cutout prior to  
the test draw (°F)

## **NO<sub>x</sub> Emission (ng/J Heat Output)**

$$N = \frac{5211 * C_f * P * F}{H_o * C}$$

Where:

N is emissions of NO<sub>x</sub> as NO<sub>2</sub>, nanograms/joule (output)

P is NO<sub>x</sub> concentration in flue gas, ppm (vol)

C<sub>f</sub> is carbon number of fuel

F is volume of fuel burned (cubic feet at 30 in. Hg, 60°F)

C is concentration of CO<sub>2</sub> measured in flue gas (%)

H<sub>o</sub> is heat output (Btu)

## Appendix D Tabulated Results

Manufacturer A

<b>Table of Averages 30 Gallon Water Heater, Manufacturer A Performance Tests</b>									
<b>Gases</b>	<b>Base</b>	<b>Base</b>	<b>Base</b>	<b>Gas 3</b>	<b>Gas 3</b>	<b>Gas 6</b>	<b>Gas 6</b>	<b>Gas 9</b>	<b>Gas 9</b>
HHV (Btu/cf)	1018	1018	1018	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1334	1334	1330	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	25,636	25,778	25,345	27,549	28,084	29,386	27,145	26,629	27,100
SCFH	7.24	7.02	6.81	6.06	6.52	6.06	6.15	6.10	6.10
<b>Emissions (not from certified tests)</b>									
Raw O2 (%)	15.9	15.9	16.0	15.6	15.6	15.0	15.7	15.8	15.8
Raw CO2 (%)	2.8	2.7	2.7	3.0	3.0	3.3	2.9	2.95	2.9
CO (ppm @ 3% O2)	5.4	5.3	18.4	4.5	5.1	15.8	16.3	17.0	17.2
NOx (ppm @ 3% O2)	9.3	9.1	4.5	8.5	6.9	12.0	11.5	6.5	6.6
NOx (ng/J)	5.0	6.3	4.0	5.9	5.1	6.3	6.2	4.8	4.9
<b>Temperatures</b>									
Ambient	74.0	74.5	75.5	73.2	73.3	72.5	72.8	71.8	71.8
Gas	75.9	76.1	77.2	75.2	75.1	75.7	75.6	75.3	74.7
Inlet Water	72.4	71.3	76.0	72.3	72.9	74.8	76.5	74.4	74.9
Outlet Water	132.2	134.2	130.6	132.0	132.2	131.3	130.5	130.8	131.2
Exhaust	237.0	238.0	240.1	239.1	239.1	240.9	240.5	235.2	228.2
<b>Pressures</b>									
Supply (in. w.c.)	6.76	6.75	6.75	6.70	6.70	6.68	6.69	6.70	6.70
Manifold (in. w.c.)	3.95	3.96	3.91	3.98	3.94	3.96	4.10	3.90	3.89

<b>Test Gas Compositions 30 Gallon Water Heater, Manufacturer A</b>									
<b>Gases</b>	<b>Base</b>	<b>Base</b>	<b>Base</b>	<b>Gas 3</b>	<b>Gas 3</b>	<b>Gas 6</b>	<b>Gas 6</b>	<b>Gas 9</b>	<b>Gas 9</b>
<b>C6+</b>	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<b>Nitrogen</b>	0.541	0.700	0.500	0.100	0.100	0.300	0.300	4.100	4.100
<b>Methane</b>	96.20	95.90	95.40	86.50	86.50	91.20	91.20	84.80	84.80
<b>Carbon Dioxide</b>	1.125	1.002	0.986	0.035	0.035	0.003	0.003	0.000	0.000
<b>Ethane</b>	1.730	1.970	2.406	9.480	9.480	5.747	5.747	0.000	0.000
<b>Propane</b>	0.276	0.308	0.542	2.725	2.725	1.727	1.727	11.125	11.125
<b>i-Butane</b>	0.045	0.047	0.108	1.034	1.034	0.534	0.534	0.000	0.000
<b>n-Butane</b>	0.050	0.057	0.096	0.000	0.000	0.531	0.531	0.000	0.000
<b>i-Pentane</b>	0.017	0.018	0.019	0.000	0.000	0.000	0.000	0.000	0.000
<b>n-Pentane</b>	0.012	0.014	0.013	0.000	0.000	0.000	0.000	0.000	0.000
<b>Oxygen</b>	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
<b>Specific Gravity</b>	0.581	0.582	0.590	0.640	0.640	0.620	0.620	0.680	0.680
<b>WOBBE Index</b>	1334	1334	1330	1433	1433	1408	1408	1385	1385
<b>HHV (Btu/SCF)</b>	1018	1018	1018	1150	1150	1106	1106	1143	1143

\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages 40 Gallon Water Heater, Manufacturer A Performance Tests								
Gases	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1018	1030	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1331	1344	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	34,842	34,909	37,554	37,741	36,891	36,894	36,635	41,772
SCFH	7.32	6.77	6.15	5.93	6.53	7.01	6.60	7.85
Emissions (not from certified tests)								
Raw O2 (%)	12.1	11.9	12.5	12.5	14.1	14.1	12.5	14.1
Raw CO2 (%)	4.9	5.0	4.7	4.8	3.8	3.8	4.7	3.9
CO (ppm @ 3% O2)	14.6	15.8	12.5	13.1	12.8	14.7	13.1	12.6
NOx (ppm @ 3% O2)	4.5	7.9	11.9	12.9	10.5	12.6	11.5	11.4
NOx (ng/J)	6.8	5.8	8.6	9.1	7.7	9.3	8.2	9.6
Temperatures								
Ambient	84.6	85.0	80.2	80.5	72.7	71.8	80.4	68.9
Gas	84.9	86.1	84.5	85.3	83.5	83.4	85.4	78.9
Inlet Water	84.8	82.7	84.2	81.9	74.0	73.8	84.9	71.7
Outlet Water	123.3	125.2	129.7	126.2	128.4	127.8	128.2	128.6
Exhaust	337.1	341.1	316.9	315.5	287.1	285.1	323.4	285.7
Pressures								
Supply (in. w.c.)	8.52	8.51	8.66	8.55	7.88	7.88	8.45	7.91
Manifold (in. w.c.)	4.83	4.83	4.78	4.76	4.72	4.71	4.83	4.77

Test Gas Compositions 40 Gallon Water Heater, Manufacturer A								
Gases	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.016	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.400	0.400	0.100	0.100	0.300	0.300	4.100	4.100
Methane	95.50	95.90	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.002	1.390	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	2.310	1.756	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.527	0.373	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.102	0.070	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.098	0.066	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.031	0.021	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.020	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.590	0.590	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1331	1344	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1018	1030	1150	1150	1106	1106	1143	1143

\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

<b>Table of Averages</b>											
<b>50 Gallon Water Heater, Manufacturer A</b>											
<b>Performance Tests</b>											
Gases	Base	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1020	1020	1016	1016	1016	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1334	1334	1333	1332	1331	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	35,286	35,481	39,597	35,315	35,342	37,416	37,719	36,976	36,896	36,356	36,223
SCFH	7.25	7.24	8.61	7.47	7.49	6.72	6.65	7.15	7.05	7.04	7.07
<b>Emissions (not from certified tests)</b>											
Raw O2 (%)	15.2	14.4	15.1	15.10	15.2	14.7	13.9	13.9	14.7	14.9	14.8
Raw CO2 (%)	3.2	3.6	3.2	3.3	3.3	3.6	4.1	4.0	3.5	3.5	3.5
CO (ppm @ 3% O2)	15.7	16.1	16.3	16.1	18.2	16.3	16.7	16.0	16.1	18.3	16.7
NOx (ppm @ 3% O2)	8.3	8.5	8.1	8.1	8.1	11.8	11.8	11.4	10.7	9.8	10.0
NOx (ng/J)	6.0	6.0	6.5	5.6	4.6	7.9	8.4	7.5	7.9	6.7	7.1
<b>Temperatures</b>											
Ambient	72.2	72.1	73.4	73.3	73.1	74.3	73.6	72.5	72.6	72.4	75.3
Gas	82.1	82.1	83.1	83.1	83.5	85.2	84.2	82.3	82.4	83.8	86.4
Inlet Water	71.8	71.9	71.8	71.5	72.2	73.1	72.3	71.9	72.5	73.2	73.6
Outlet Water	131.1	131.4	134.2	132.0	132.6	131.9	130.0	133.3	132.7	132.1	132.4
Exhaust	275.7	280.6	262.9	262.9	263.6	263.7	281.7	263.8	263.9	263.9	265.1
<b>Pressures</b>											
Supply (in. w.c.)	8.88	8.88	8.93	8.94	8.80	8.43	8.41	8.74	8.73	8.43	8.65
Manifold (in. w.c.)	4.99	4.99	4.98	4.98	4.97	4.95	4.94	4.93	4.94	4.93	4.94

<b>Test Gas Compositions</b>											
<b>50 Gallon Water Heater, Manufacturer A</b>											
Gases	Base	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.004	0.004	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.800	0.800	0.500	0.700	0.400	0.100	0.100	0.300	0.300	4.100	4.100
Methane	95.50	95.50	96.20	95.90	96.10	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	0.966	0.966	1.126	1.003	1.240	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	2.183	2.180	1.723	1.970	1.733	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.358	0.357	0.277	0.310	0.319	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.054	0.053	0.045	0.048	0.051	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.066	0.065	0.050	0.057	0.057	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.021	0.021	0.017	0.018	0.018	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.015	0.015	0.012	0.014	0.013	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.580	0.580	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1334	1334	1333	1332	1331	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1020	1020	1016	1016	1016	1150	1150	1106	1106	1143	1143

\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Manufacturer B

Table of Averages 30 Gallon Water Heater, Manufacturer B Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1024	1020	1019	1018	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1337	1331	1331	1327	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	29,481	28,277	29,059	28,728	31,072	31,681	30,814	31,087	30,451	30,614
SCFH	7.26	6.89	7.21	6.30	5.94	6.33	6.25	6.52	6.20	6.07
Emissions (not from certified tests)										
Raw O2 (%)	14.7	14.6	15.3	15.2	14.8	14.8	14.9	14.9	14.4	14.4
Raw CO2 (%)	3.6	3.6	3.2	3.2	3.5	3.5	3.4	3.5	3.8	3.7
CO (ppm @ 3% O2)	7.9	9.2	8.3	6.8	7.3	7.1	7.4	5.5	7.3	7.1
NOx (ppm @ 3% O2)	8.8	8.7	8.1	7.9	13.0	12.6	11.0	11.0	10.9	11.6
NOx (ng/J)	5.9	5.9	5.5	5.6	9.7	9.3	7.8	7.4	7.9	8.4
Temperatures										
Ambient	72.5	72.4	72.4	75.0	70.1	70.1	70.3	70.5	70.6	70.5
Gas	74.6	74.9	74.9	76.6	73.1	73.2	73.5	73.3	73.7	73.7
Inlet Water	74.2	74.0	74.7	76.0	75.0	75.9	74.4	74.5	75.0	74.6
Outlet Water	137.8	141.7	137.7	140.7	141.1	136.4	142.5	142.8	146.5	140.8
Exhaust	230.3	229.2	229.1	229.3	219.7	219.8	217.4	218.0	229.6	229.5
Pressures										
Supply (in. w.c.)	6.72	6.72	6.72	6.71	6.69	6.69	6.69	6.67	6.71	6.72
Manifold (in. w.c.)	4.76	4.81	4.80	4.82	4.82	4.82	4.81	4.81	4.82	4.81

Test Gas Compositions 30 Gallon Water Heater, Manufacturer B										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.010	0.008	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.300	0.200	0.200	0.200	0.100	0.100	0.300	0.300	4.100	4.100
Methane	95.70	95.70	95.80	95.70	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.277	1.547	1.532	1.663	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	2.091	1.987	1.928	1.915	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.413	0.396	0.367	0.374	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.072	0.072	0.067	0.070	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.069	0.066	0.062	0.064	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.023	0.022	0.020	0.022	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.015	0.014	0.013	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.590	0.590	0.590	0.590	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1337	1331	1331	1327	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1024	1020	1019	1018	1150	1150	1106	1106	1143	1143

\*\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages 40 Gallon Water Heater, Manufacturer B Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1017	1023	1015	1014	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1333	1338	1330	1330	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	37,147	35,819	37,499	37,365	40,033	39,410	39,462	39,045	39,173	38,583
SCFH	7.17	7.16	7.87	7.23	6.46	6.53	6.74	6.29	6.68	6.12
Emissions (not from certified tests)										
Raw O2 (%)	14.1	14.1	14.2	14.1	12.8	13.5	13.0	13.0	13.8	13.7
Raw CO2 (%)	3.8	3.8	3.8	3.8	4.7	4.2	4.5	4.5	4.2	4.2
CO (ppm @ 3% O2)	9.3	9.9	9.0	9.1	7.7	10.0	8.1	7.0	8.2	7.6
NOx (ppm @ 3% O2)	9.9	10.5	10.3	10.3	15.0	15.2	13.5	6.4	12.7	13.0
NOx (ng/J)	6.6	7.0	7.0	7.0	10.0	10.3	9.2	9.8	8.6	8.7
Temperatures										
Ambient	72.9	70.8	71.9	72.0	72.8	71.9	71.9	71.9	71.9	72.0
Gas	75.7	74.5	74.8	74.9	76.2	75.5	74.2	74.2	74.8	75.3
Inlet Water	77.5	79.5	79.3	72.9	77.8	80.4	74.4	74.4	80.5	79.3
Outlet Water	133.9	138.7	136.8	142.3	137.4	134.6	144.1	144.1	138.8	134.3
Exhaust	269.8	267.7	267.7	267.8	279.0	266.2	281.2	282.1	271.2	268.9
Pressures										
Supply (in. w.c.)	6.71	6.71	6.70	6.71	6.69	6.69	6.75	6.75	6.68	6.69
Manifold (in. w.c.)	4.89	4.90	4.90	4.91	4.90	4.89	4.88	4.87	4.89	4.89

Test Gas Compositions 40 Gallon Water Heater, Manufacturer B										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.015	0.022	0.014	0.013	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.600	0.900	0.300	0.300	0.100	0.100	0.300	0.300	4.100	4.100
Methane	96.10	95.50	96.40	96.50	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.071	0.832	1.364	1.394	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.765	2.227	1.464	1.388	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.291	0.375	0.306	0.290	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.049	0.060	0.055	0.052	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.051	0.071	0.054	0.051	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.018	0.024	0.018	0.017	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.012	0.017	0.012	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.580	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1333	1338	1330	1330	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1017	1023	1015	1014	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the tables above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages										
50 Gallon Water Heater #1, Manufacturer B										
Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1015	1024	1024	1024	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1332	1338	1338	1338	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	37,850	38,023	38,007	38,148	40,061	40,784	41,091	39,827	39,283	39,265
SCFH	7.24	7.84	7.54	6.94	6.55	6.46	6.34	6.76	6.31	6.34
Emissions (not from certified tests)										
Raw O2 (%)	13.8	13.9	14.0	13.8	13.3	13.3	13.4	14.1	14.3	14.2
Raw CO2 (%)	4.0	4.0	4.0	4.0	4.3	4.3	4.2	3.8	3.8	3.8
CO (ppm @ 3% O2)	24.1	25.9	26.6	28.0	115.7	112.9	97.5	83.0	62.4	63.2
NOx (ppm @ 3% O2)	16.8	16.7	17.4	19.6	20.3	20.5	20.2	19.5	19.4	18.7
NOx (ng/J)	11.1	11.2	11.6	12.1	12.8	12.5	13.9	14.3	13.3	12.9
Temperatures										
Ambient	71.3	71.6	71.5	71.7	72.6	72.5	73.7	73.6	72.6	72.7
Gas	82.2	82.7	82.6	82.8	83.7	83.8	84.6	84.5	83.7	83.8
Inlet Water	73.3	73.2	74.1	71.4	73.6	74.1	75.6	75.9	74.0	75.1
Outlet Water	139.2	137.2	139.6	140.3	136.6	137.7	138.9	139.3	138.0	137.9
Exhaust	278.2	279.0	278.9	279.1	266.8	266.9	282.0	281.9	266.8	266.9
Pressures										
Supply (in. w.c.)	8.07	8.22	8.21	8.23	8.35	8.34	8.59	8.58	8.35	8.36
Manifold (in. w.c.)	5.07	5.07	5.06	5.08	5.07	5.08	5.07	5.08	5.07	5.08

Test Gas Compositions										
50 Gallon Water Heater #1, Manufacturer B										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.012	0.021	0.022	0.023	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.200	0.500	0.600	0.600	0.100	0.100	0.300	0.300	4.100	4.100
Methane	96.70	95.70	95.50	95.50	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.353	1.045	1.028	0.996	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.317	2.081	2.181	2.172	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.306	0.421	0.437	0.431	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.056	0.066	0.068	0.067	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.053	0.040	0.082	0.081	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.017	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.010	0.018	0.018	0.018	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.590	0.590	0.590	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1332	1338	1338	1338	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1015	1024	1024	1024	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the tables above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.



Table of Averages										
50 Gallon Water Heater, Replacement, Manufacturer B										
Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1018	1017	1020	1019	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1334	1333	1339	1337	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	35,751	37,303	38,290	37,914	40,677	37,834	39,868	39,485	36,228	36,197
SCFH	6.91	6.74	7.42	7.41	6.43	5.80	6.61	6.67	6.21	6.20
Emissions (not from certified tests)										
Raw O <sub>2</sub> (%)	13.4	13.3	14.1	14.1	12.7	12.7	12.9	12.9	12.9	12.9
Raw CO <sub>2</sub> (%)	4.3	4.3	3.8	3.8	4.7	4.8	4.6	4.6	4.6	4.6
CO (ppm @ 3% O <sub>2</sub> )	7.7	7.2	8.9	8.8	7.3	8.1	8.3	7.8	6.9	6.9
NO <sub>x</sub> (ppm @ 3% O <sub>2</sub> )	10.4	10.1	10.0	10.1	14.4	14.1	13.4	13.3	12.7	12.7
NO <sub>x</sub> (ng/J)	6.7	6.6	7.2	7.4	10.0	9.6	9.0	9.0	8.3	8.5
Temperatures										
Ambient	71.9	72.0	70.0	70.2	71.5	71.6	72.4	72.5	71.5	71.6
Gas	73.9	73.8	72.5	72.6	73.7	73.8	74.3	74.2	73.7	73.8
Inlet Water	76.1	75.9	74.4	75.7	77.4	78.3	74.4	75.1	76.1	77.6
Outlet Water	140.4	139.5	136.3	137.9	139.8	139.7	139.0	139.2	137.8	138.5
Exhaust	261.5	262.3	262.9	262.7	274.9	274.7	276.7	276.9	274.9	275.1
Pressures										
Supply (in. w.c.)	6.70	6.71	6.74	6.73	6.70	6.71	6.70	6.71	6.70	6.71
Manifold (in. w.c.)	4.79	4.78	4.79	4.79	4.78	4.79	4.78	4.78	4.78	4.79

Test Gas Compositions										
50 Gallon Water Heater, Replacement, Manufacturer B										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.008	0.009	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.200	0.200	0.300	0.200	0.100	0.100	0.300	0.300	4.100	4.100
Methane	96.40	96.40	96.40	96.50	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.354	1.402	1.133	1.192	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.577	1.536	1.674	1.615	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.344	0.326	0.350	0.334	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.063	0.060	0.063	0.062	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.063	0.058	0.061	0.060	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.021	0.019	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.013	0.013	0.012	0.013	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.580	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1334	1333	1339	1337	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1018	1017	1020	1019	1150	1150	1106	1106	1143	1143

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Manufacturer C

Table of Averages 30 Gallon Water Heater, Manufacturer C Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1022	1021	1024	1024	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1334	1333	1334	1332	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	26,438	26,464	26,313	26,329	28,326	28,386	28,117	27,759	27,277	27,216
SCFH	7.14	7.22	7.32	7.09	6.75	6.45	7.08	6.89	6.70	6.46
Emissions (not from certified tests)										
Raw O2 (%)	15.2	15.8	15.8	15.4	14.7	15.3	15.4	15.4	15.0	15.1
Raw CO2 (%)	3.2	2.7	2.8	3.1	3.5	3.1	3.0	3.0	3.3	3.3
CO (ppm @ 3% O2)	4.0	1.8	3.7	3.0	2.9	3.0	2.2	2.3	1.7	1.9
NOx (ppm @ 3% O2)	10.4	10.1	9.8	3.2	15.5	14.9	14.2	14.0	16.1	16.1
NOx (ng/J)	7.5	7.8	7.3	7.6	10.7	10.2	10.3	9.7	11.3	11.1
Temperatures										
Ambient	71.2	71.1	70.7	70.6	72.1	72.0	71.9	72.1	72.8	72.7
Gas	81.8	81.7	81.2	81.2	82.8	82.7	82.7	82.8	83.8	83.7
Inlet Water	75.2	74.6	73.5	75.2	72.4	76.4	73.8	74.6	73.3	75.0
Outlet Water	138.6	137.6	138.0	137.4	139.6	141.7	140.1	142.0	139.1	140.5
Exhaust	230.4	230.3	220.3	220.4	219.7	220.6	228.1	229.0	219.9	219.8
Pressures										
Supply (in. w.c.)	8.15	8.14	8.10	8.09	8.30	8.29	8.42	8.42	8.45	8.44
Manifold (in. w.c.)	5.29	5.28	5.25	5.26	5.28	5.27	5.29	5.28	5.25	5.26

Test Gas Compositions 30 Gallon Water Heater, Manufacturer C										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.012	0.010	0.014	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.440	0.400	0.500	0.600	0.100	0.100	0.300	0.300	4.100	4.100
Methane	95.60	95.70	95.30	95.00	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.328	1.349	1.306	1.321	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.965	1.938	2.157	2.222	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.465	0.438	0.519	0.551	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.078	0.076	0.084	0.086	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.085	0.077	0.095	0.104	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.026	0.024	0.029	0.031	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.018	0.016	0.020	0.023	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.590	0.590	0.589	0.590	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1334	1333	1334	1332	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1022	1021	1024	1024	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the tables above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages 40 Gallon Water Heater, Manufacturer C Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1020	1018	1018	1018	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1333	1331	1332	1332	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	28,894	35,247	34,993	35,075	38,337	39,099	34,302	36,543	36,327	36,361
SCFH	8.04	7.93	7.75	7.84	7.56	6.41	6.88	7.28	6.84	7.04
Emissions (not from certified tests)										
Raw O2 (%)	14.8	14.8	14.8	14.8	14.2	13.2	13.5	13.5	13.6	13.5
Raw CO2 (%)	3.5	3.5	3.4	3.4	3.8	4.3	4.3	4.3	4.2	4.3
CO (ppm @ 3% O2)	1.8	1.1	1.0	1.1	0.6	2.2	0.4	0.0	0.5	0.0
NOx (ppm @ 3% O2)	18.4	18.0	18.1	18.3	18.9	22.6	22.7	23.0	22.4	22.4
NOx (ng/J)	13.5	13.0	13.0	13.3	17.0	15.7	15.8	16.7	16.4	16.7
Temperatures										
Ambient	70.3	70.4	70.2	70.3	68.7	68.9	72.4	72.3	71.5	71.6
Gas	73.0	73.1	72.9	73.0	71.6	71.7	74.7	74.6	74.0	74.1
Inlet Water	73.0	74.0	74.7	74.6	73.0	75.9	75.7	76.0	73.3	74.3
Outlet Water	144.3	141.2	140.7	142.2	138.7	139.7	141.5	140.9	136.7	140.0
Exhaust	270.7	270.5	270.8	270.6	291.6	291.5	300.2	299.8	300.0	299.9
Pressures										
Supply (in. w.c.)	6.72	6.71	6.72	6.71	6.68	6.69	6.67	6.68	6.66	6.67
Manifold (in. w.c.)	4.84	4.83	4.84	4.84	4.89	4.88	4.81	4.82	4.83	4.82

Test Gas Compositions 40 Gallon Water Heater, Manufacturer C										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.008	0.008	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.200	0.200	0.200	0.200	0.100	0.100	0.300	0.300	4.100	4.100
Methane	96.10	96.10	96.10	96.10	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.402	1.480	1.452	1.435	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.715	1.665	1.651	1.647	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.396	0.378	0.373	0.376	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.074	0.070	0.069	0.068	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.071	0.066	0.065	0.065	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.023	0.021	0.021	0.021	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.015	0.014	0.013	0.013	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.590	0.590	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1333	1331	1332	1332	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1020	1018	1018	1018	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the tables above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages 40 Gallon Water Heater, Manufacturer C, Re-orrificed Performance Tests								
Gases	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1015	1017	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1332	1335	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	36,547	36,543	39,081	39,099	38,430	38,489	38,035	37,724
SCFH	8.35	8.35	6.45	6.41	7.66	6.85	7.09	7.34
Emissions (not from certified tests)								
Raw O2 (%)	13.9	13.9	13.2	13.2	13.4	13.4	13.5	13.6
Raw CO2 (%)	3.9	3.9	4.3	4.3	4.2	4.2	4.2	4.2
CO (ppm @ 3% O2)	2.8	2.6	2.1	2.2	1.7	1.6	1.7	1.9
NOx (ppm @ 3% O2)	18.3	18.4	22.5	22.6	21.7	21.8	21.8	22.4
NOx (ng/J)	13.2	13.2	15.8	15.7	16.2	15.4	15.8	15.9
Temperatures								
Ambient	68.2	68.3	75.2	75.3	70.9	72.1	70.8	72.2
Gas	78.4	78.5	85.6	85.7	81.4	82.4	80.7	82.9
Inlet Water	72.4	73.1	75.5	75.9	74.1	76.1	74.4	74.0
Outlet Water	142.6	142.8	142.4	139.7	141.5	142.6	137.6	137.9
Exhaust	296.9	297.1	304.3	304.1	302.2	298.1	298.3	298.3
Pressures								
Supply (in. w.c.)	8.30	8.31	8.21	8.22	7.64	8.17	8.54	8.23
Manifold (in. w.c.)	5.01	5.00	5.02	5.01	4.96	5.02	5.04	5.05

Test Gas Compositions 40 Gallon Water Heater, Manufacturer C, Re-orrificed								
Gases	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.007	0.007	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.200	0.200	0.100	0.100	0.300	0.300	4.100	4.100
Methane	96.50	96.60	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.341	1.233	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.503	1.493	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.303	0.302	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.056	0.056	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.054	0.054	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.018	0.018	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.011	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1332	1335	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1015	1017	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the table above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests.

\*\*Gases 3, 6, and 9 are outside the range allowed in Section 4.4 of SCAQMD Rule 1121, which specifies that the heating value of the natural gas used for NO<sub>x</sub> testing must be 1040 Btu/ft<sup>3</sup> ±25.

Table of Averages 50 Gallon Water Heater, Manufacturer C Performance Tests										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
HHV (Btu/cf)	1020	1018	1022	1006	1150	1150	1106	1106	1143	1143
Wobbe (Btu/cf)	1335	1335	1338	1316	1433	1433	1408	1408	1385	1385
Input rate (Btu/hr)	34,424	36,488	36,723	36,148	39,245	38,906	38,559	38,649	37,973	37,882
SCFH	8.35	8.07	8.29	8.30	7.56	7.39	7.54	7.85	7.46	7.81
Emissions (not from certified tests)										
Raw O2 (%)	13.8	13.9	14.0	14.0	13.5	13.5	13.6	13.7	13.7	14.5
Raw CO2 (%)	3.9	3.9	3.8	3.8	4.2	4.2	4.1	4.0	4.1	3.6
CO (ppm @ 3% O2)	1.9	1.7	2.3	2.4	1.2	1.3	1.3	1.0	1.0	1.2
NOx (ppm @ 3% O2)	12.8	12.7	12.4	12.7	18.5	18.5	17.0	16.7	16.9	16.0
NOx (ng/J)	9.7	9.7	10.1	10.0	13.1	13.6	12.0	12.1	12.2	12.1
Temperatures										
Ambient	72.7	72.7	71.2	71.3	73.0	73.1	73.1	73.0	71.7	71.8
Gas	83.0	82.9	81.6	81.7	83.7	83.6	84.1	84.0	83.0	83.1
Inlet Water	73.5	75.3	73.5	75.3	73.1	74.2	74.6	74.3	73.3	73.5
Outlet Water	136.2	140.0	136.2	140.0	137.1	141.4	142.7	143.0	141.9	143.6
Exhaust	325.8	325.7	326.3	326.2	329.2	329.1	326.9	327.0	305.5	305.4
Pressures										
Supply (in. w.c.)	8.07	8.08	8.16	8.15	7.60	7.61	7.74	7.75	7.64	7.65
Manifold (in. w.c.)	4.91	4.92	4.88	4.89	4.82	4.83	4.82	4.83	4.85	4.84

Test Gas Compositions 50 Gallon Water Heater, Manufacturer C										
Gases	Base	Base	Base	Base	Gas 3	Gas 3	Gas 6	Gas 6	Gas 9	Gas 9
C6+	0.008	0.008	0.010	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.500	0.300	0.800	0.800	0.100	0.100	0.300	0.300	4.100	4.100
Methane	95.90	96.30	95.50	95.60	86.50	86.50	91.20	91.20	84.80	84.80
Carbon Dioxide	1.151	1.270	0.871	0.883	0.035	0.035	0.003	0.003	0.000	0.000
Ethane	1.962	1.673	2.280	2.222	9.480	9.480	5.747	5.747	0.000	0.000
Propane	0.348	0.339	0.365	0.359	2.725	2.725	1.727	1.727	11.125	11.125
i-Butane	0.058	0.059	0.053	0.053	1.034	1.034	0.534	0.534	0.000	0.000
n-Butane	0.061	0.059	0.066	0.066	0.000	0.000	0.531	0.531	0.000	0.000
i-Pentane	0.020	0.019	0.021	0.021	0.000	0.000	0.000	0.000	0.000	0.000
n-Pentane	0.013	0.013	0.016	0.016	0.000	0.000	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000	0.049	0.049	0.016	0.016	0.000	0.000
Specific Gravity	0.580	0.580	0.580	0.580	0.640	0.640	0.620	0.620	0.680	0.680
WOBBE Index	1335	1335	1338	1316	1433	1433	1408	1408	1385	1385
HHV (Btu/SCF)	1020	1018	1022	1006	1150	1150	1106	1106	1143	1143

\* The ellipses around some of the emissions in the tables above denote that the emissions for that particular test were higher than 10 ng/J. None of the tests performed for this report were certified tests

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