Arnold Schwarzenegger
Governor

NATURAL GAS VARIABILITY IN CALIFORNIA: ENVIRONMENTAL IMPACTS AND DEVICE PERFORMANCE

EXPERIMENTAL EVALUATION OF POLLUTANT EMISSIONS FROM RESIDENTIAL APPLIANCES

APPENDIX E. SUMMARY REPORTS FOR OVENS OV01–OV07

PIER INTERIM PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Lawrence Berkeley National Laboratory

June 2010
CEC-500-2009-099-APE

Prepared By:
Brett C. Singer (Principal Investigator and Lead Author),
Michael G. Apte, Douglas R. Black, Toshifumi Hotchi, Donald Lucas,
Melissa M. Lunden, Douglas P. Sullivan
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720
Commission Contract No. 500-05-026

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Marla Mueller
Contract Manager

Linda Spiegel
Program Area Lead
Energy-Related Environmental Research

Kenneth Koyama
Office Manager
Energy Generation Research

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Introduction

This document is an appendix to an interim project report for California Energy Commission Contract 500-05-026, *Natural Gas Variability in California: Environmental Impacts and Device Performance*. The full interim project report caries the same base report number as this document and should be cited as the primary source of information about the work described in this appendix. As its title suggests, the main report describes objectives, methods, primary results, and analysis related to the experimental evaluation of pollutant emissions from residential appliances. The material contained in this appendix was originally compiled as a series of individual burner reports that were used to present interim results to the Project Advisory Committee. The appendices to the main report compile these individual burner reports by appliance, with cooktops and ovens each divided between two appendices to satisfy Energy Commission file size limits. A complete list of appendices is provided in the main report.

An overview of the information contained in the main report is presented below.

The effect of liquefied natural gas (LNG) on pollutant emissions was evaluated experimentally with used and new appliances in the laboratory and appliances installed in residences, targeting information gaps from previous studies. This report describes methods and provides summary results with analysis. Burner selection targeted available technologies projected to comprise the majority of installed appliances over the next decade. Experiments were conducted on 13 cooktop sets, 12 ovens, 5 broiler burners, 5 storage water heaters, 4 forced air furnaces, 1 wall furnace, and 6 tankless water heaters. Air-free concentrations and fuel-based emission factors were determined for carbon monoxide, nitrogen oxides, nitrogen dioxide, and the number of (predominantly ultrafine) particles over complete burns—including transient effects following ignition—and during more stable end-of-burn conditions. Formaldehyde was measured over multi-burn cycles. The baseline fuel was PG&E line gas with Wobbe numbers of 1320–1340; test fuels were simulated LNGs with Wobbe numbers of roughly 1390 and 1420, and in some cases 1360. No ignition or operational problems were observed during simulated LNG use. Baseline emissions varied widely across and within burner groups, and with burner operational mode. Statistically significant emissions changes were observed for some pollutants on some burners.

Table of Contents

Introduction i
List of Figures iii
List of Tables vi
1.0 Oven OV01 1
1.1. Experimental information for OV01 1
1.2. Results for OV01 8
2.0 Oven OV02 17
2.1. Experimental information for OV02 17
2.2. Results for OV02 25
3.0 Oven OV03 39
3.1. Experimental information for OV03 39
3.2. Results for OV03 45
4.0 Oven OV05 54
4.1. Experimental information for OV05 54
4.2. Results for OV05 58
5.0 Oven OV06 64
5.1. Experimental information for OV06 64
5.2. Results for OV06 69
6.0 Oven OV07 76
6.1. Experimental information for OV07 76
6.2. Results for OV07 80

List of Figures

Figure 1. Oven compartment of OV01. 2

Figure 2. Oven bottom burner OV01. 3

Figure 3. Spreader plate for oven bottom burner OV01. Note that spreader is non-symmetrical, i.e. deformed. 3

Figure 4. Analytical sampling configuration for CT01 / OV01 / BR01. 5

Figure 5. Installation and sampling configuration for CT01 / OV01 / BR01. Front panel of collection hood is not installed in picture, but it was used during experiments. 6

Figure 6. Measured analyte concentrations for oven OV01 with PG&E line gas (L044). 11

Figure 7. Measured analyte concentrations for oven OV01 with PG&E line gas (L063). 11

Figure 8. Measured analyte concentrations for oven OV01 with fuel 3A + N_2 (L059). 12

Figure 9. Measured analyte concentrations for oven OV01 with fuel 1C (L068). 12

Figure 10. Measured analyte concentrations for oven OV01 with fuel 3A (L047). 13

Figure 11. Measured analyte concentrations for oven OV01 with fuel 3A (L050). 13

Figure 12. Measured analyte concentrations for oven OV01 with fuel 3A (L055). 14

Figure 13. Measured analyte concentrations for oven OV01 with fuel 3A (L062). 14

Figure 14. Oven OV02 burner. 18

Figure 15. OV02 spreader plate, front. Note irregular shape. 19

Figure 16. Pollutant sampling configuration for oven OV02, experiments L032-L035. 20

Figure 17. Pollutant sampling configuration for oven OV02, experiments L036-L039. 21

Figure 18. Pollutant sampling configuration for oven OV02, experiments L130-L130. 21

Figure 19. Laboratory installation and sampling configuration of range featuring oven OV02. . 22

Figure 20. Measured analyte concentrations for oven OV02 with fuel 3A + N_2 (Exp. L032). 28

Figure 21. Measured analyte concentrations for oven OV02 fuel 3A (Exp. L033). 29

Figure 22. Measured analyte concentrations for oven OV02 with PG&E line gas (Exp. L034). ... 29

Figure 23. Measured analyte concentrations for oven OV02 fuel 1C (Exp. L127). 30

Figure 24. Measured analyte concentrations for oven OV02 fuel 3C (Exp. L128). 30

Figure 25. Measured analyte concentrations for oven OV02 with PG&E line gas (L129). 31

Figure 26. Measured analyte concentrations for oven OV02 with PG&E line gas (L130). 31

Figure 27. Measured analyte concentrations for oven OV02 with PG&E line gas, broiler protocol (L035). 34

Figure 28. Measured analyte concentrations for oven OV02 with PG&E line gas, broiler protocol (L036). 35

Figure 29. Measured analyte concentrations for oven OV02 with fuel 3A, broiler protocol (L037). 35

Figure 30. Measured analyte concentrations for oven OV02 with fuel 3A + N_2, broiler protocol (L038). 36

Figure 31. Measured analyte concentrations for oven OV02 with fuel 3A + N_2, broiler protocol (L039). 36

Figure 32. Placement of OV03 burner; oven bottom plate and convection fan cover removed. .. 40

Figure 33. Underside of bottom plate showing spreader for OV03 bottom burner. 40

Figure 34. Pollutant sampling configuration for oven OV03 (Expts L015-L017). 41

Figure 35. Pollutant sampling configuration for oven burner OV03, experiments L089-L092)... 42

Figure 36. Laboratory installation and sampling configuration of range featuring oven OV03 (Expts L015-L017). 42

Figure 37. Measured analyte concentrations for oven OV03 with PG&E line gas (Exp. L008). ... 47

Figure 38. Measured analyte concentrations for oven OV03 with PG&E line gas (Exp. L015). ... 48

Figure 39. Measured analyte concentrations for oven OV03 fuel 3A (Exp. L016). 48

Figure 40. Measured analyte concentrations for oven OV03 with fuel 3A + N_2 (Exp. L017)..... 49

Figure 41. Measured analyte concentrations for oven OV03 with PG&E line gas (L089). 49

Figure 42. Measured analyte concentrations for oven OV03 with fuel 3C (L090). 50

Figure 43. Measured analyte concentrations for oven OV03 with fuel 1C (L091). 50

Figure 44. Measured analyte concentrations for oven OV03 with PG&E line gas (L092). 51

Figure 45. Oven bottom burner OV05. 55

Figure 46. Profile of spreader plate for oven bottom burner OV05. 55

Figure 47. Analytical sampling configuration for CT05 / OV05. 56

Figure 48. Measured analyte concentrations for oven OV05 with PG&E line gas (L073). 60

Figure 49. Measured analyte concentrations for oven OV05 with fuel 1C (L074). 61

Figure 50. Measured analyte concentrations for oven OV05 with fuel 3C (L075). 62

Figure 51. Measured analyte concentrations for oven OV05 with fuel 1C (L076). 62
Figure 52. Oven compartment of OV06. 65
Figure 53. OV06 raised bottom plate lifted to reveal top of spreader. 65
Figure 54. Analytical sampling configuration for OV06. 66
Figure 55. Installation of OV06. 67
Figure 56. Measured analyte concentrations for oven OV06 with PG&E line gas (L096). 71
Figure 57. Measured analyte concentrations for oven OV06 with fuel 1C (L097). 72
Figure 58. Measured analyte concentrations for oven OV06 with fuel 3C (L098). 72
Figure 59. Measured analyte concentrations for oven OV06 with fuel 1C (L104). 73
Figure 60. Measured analyte concentrations for oven OV06 with PG&E line gas (L105). 73
Figure 61. Oven compartment for OV07. 77
Figure 62. OV07 flame with PG&E line gas. 77
Figure 63. Analytical sampling configuration for OV07. 78
Figure 64. Measured analyte concentrations for oven OV07 with PG&E line gas (L116). 82
Figure 65. Measured analyte concentrations for oven OV07 with fuel 3C (L117). 83
Figure 66. Measured analyte concentrations for oven OV07 with fuel 1C (L118). 83
Figure 67. Measured analyte concentrations for oven OV07 with PG&E line gas (L119). 84

List of Tables

Table 1. Appliance and burner information OV01. 2

Table 2. Interchangeability experiments for oven bottom burner OV01. 4

Table 3. Fuel analysis for interchangeability experiments with OV01. 4

Table 4. Analyte ranges and calibration levels for experiments with CT01 / OV01 / BR01. 7

Table 5. Aerosol instrumentation used for CT01 / OV01 / BR01. 7

Table 6. Other measurements for experiments with CT01 / OV01 / BR01. 8

Table 7. Burner operating parameters for experiments with oven OV01. Information provided for first burner firing at each temperature setting. 9

Table 8. Environmental conditions[1] for experiments with OV01. 10

Table 9. Sampling system conditions for experiments with bottom oven burner OV01. 10

Table 10. Formaldehyde samples for experiments with cooktop OV01. 10

Table 11. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for CO, PG250 NO and PN. 15

Table 12. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 15

Table 13. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN. 16

Table 14. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 16

Table 15. Appliance and burner information, OV02. 18

Table 16. Interchangeability experiments for oven OV02. 19

Table 17. Fuel analysis for interchangeability experiments with oven OV02, September 2007. 20

Table 18. Analyte ranges and calibration levels for experiments with oven OV02. 23

Table 19. Analyte ranges and calibration levels for experiments with oven OV02 (L127-L130). 23

Table 20. Aerosol instrumentation used for oven OV02. 24

Table 21. Other measurements for experiments with oven OV02. 24

Table 22. Burner operating parameters for experiments with oven OV02 (December 2008). Information provided for first burner firing at each temperature setting. 26

Table 23. Burner operating parameters for experiments with bottom burner OV02 operating with broiler protocol. 26

Table 24. Environmental conditions[1] for experiments with oven OV02. 27

Table 25. Sampling system conditions[1] for experiments with oven OV02. 27

Table 26. Sample location temperatures and dilution ratios for first burn at each temperature setting. 28

Table 27. Formaldehyde samples for experiments with oven OV02. 28

Table 28. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for CO, PG250 NO and PN, September 2007. 32

Table 29. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for CO, PG250 NO_X and PN, December 2008. 32

Table 30. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, September 2007. 32

Table 31. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, December 2008. 32

Table 32. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN, September 2007. 33

Table 33. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN, December 2008. 33

Table 34. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, September 2007. 33

Table 35. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, December 2008. 33

Table 36. Calculated formaldehyde emission rates over entire period of burner operation. 34

Table 37. Calculated air-free concentrations (using CO_2) 10-15 min after start of each broil burn for OV02. 38

Table 38. Calculated emission rates over 15 min of each broil burn for OV02. 38

Table 39. Appliance and burner information. 39

Table 40. Interchangeability experiments for oven OV03. 40

Table 41. Fuel analysis for interchangeability experiments with oven OV03 in September 2007. 41

Table 42. Fuel analysis for interchangeability experiments with oven OV03 in April 2008. 41

Table 43. Analyte ranges and calibration levels for experiments with cooktop OV03. 43

Table 44. Aerosol instrumentation used for oven OV03, experiments L008, L015-L017. 43

Table 45. Aerosol instrumentation used for CT03 experiments L089-L092. 44

Table 46. Other measurements for experiments with oven OV03. 44

Table 47. Burner operating parameters for experiments with oven OV03, September 2007. Information provided for burner firings to achieve each new temperature setting. 45

Table 48. Burner operating parameters for experiments with oven OV03, April 2008. 46

Table 49. Environmental conditions[1] for experiments with oven OV03. 46

Table 50. Gas sampling manifold T, RH [1] for experiments with oven OV03. 46

Table 51. Sample location temperatures and dilution ratios for each burn, April 2008 experiments. 47

Table 52. Formaldehyde samples for experiments with oven OV03, April 2008. 47

Table 53. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO_X and PN. 51

Table 54. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 52

Table 55. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN. 52

Table 56. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 53

Table 57. Calculated formaldehyde emission rates over entire period of burner operation. 53

Table 58. Appliance and burner information OV05. 54

Table 59. Interchangeability experiments for oven bottom burner OV05. 56

Table 60. Fuel analysis for interchangeability experiments with OV05. 56

Table 61. Analyte ranges and calibration levels for experiments with OV05. 57

Table 62. Aerosol instrumentation used for CT05 / OV05. 57

Table 63. Other measurements for experiments with CT05 / OV05. 58

Table 64. Burner operating parameters for experiments with oven OV05. Information provided for first burner firing at each temperature setting. 59

Table 65. Environmental conditions[1] for experiments with OV05. 59

Table 66. Sampling system conditions[1] for experiments with bottom oven burner OV05. 59

Table 67. Sample location temperatures and dilution ratios for each burn. 60

Table 68. Formaldehyde samples for experiments with oven OV05. 60

Table 69. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO and PN. 62

Table 70. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 63

Table 71. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN. 63

Table 72. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 63

Table 73. Calculated formaldehyde emission rates over entire period of burner operation. 63

Table 74. Appliance and burner information OV06. 64

Table 75. Interchangeability experiments for oven bottom burner OV06. 66

Table 76. Fuel analysis for interchangeability experiments with OV06. 66

Table 77. Analyte ranges and calibration levels for experiments with OV06. 67

Table 78. Aerosol instrumentation used for CT06 / OV06. 68

Table 79. Other measurements for experiments with CT06 / OV06. 68

Table 80. Environmental conditions[1] for experiments with OV06. 69

Table 81. Burner operating parameters for experiments with oven OV06. Information provided for first burner firing at each temperature setting. 70

Table 82. Sample location temperatures and dilution ratios for each burn. 70

Table 83. Formaldehyde samples for experiments with oven OV06. 71

Table 84. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for CO, PG250 NO_X and PN. 74

Table 85. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 74

Table 86. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN. 74

Table 87. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 74

Table 88. Calculated formaldehyde emission rates over entire period of burner operation. 75

Table 89. Appliance and burner information OV07. 76

Table 90. Interchangeability experiments for oven bottom burner OV07. 78

Table 91. Fuel analysis for interchangeability experiments with OV07. 78

Table 92. Analyte ranges and calibration levels for experiments with OV07. 79

Table 93. Aerosol instrumentation used for OV07. 79

Table 94. Other measurements for experiments with OV07. 80

Table 95. Burner operating parameters for experiments with oven OV07. Information provided for first burner firing at each temperature setting. 81

Table 96. Environmental conditions[1] for experiments with OV07. 81

Table 97. Sample location temperatures and dilution ratios for each burn. 81

Table 98. Formaldehyde samples for experiments with oven OV07. 82

Table 99. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO and PN. 84

Table 100. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 84

Table 101. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN. 84

Table 102. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i. 85

Table 103. Calculated formaldehyde emission rates over entire period of burner operation. 85

1.0 Oven OV01

1.1. Experimental information for OV01

A total of 8 experiments were conducted with OV01. These include 4 experiments with fuel 3A (WN = 1418), 1 experiment with mix 3A diluted with N_2 (WN = 1417-1419), 1 experiment with mix 1C (WN = 1388) and 2 experiments with PG&E line gas (WN = 1326-1334). Experiments for the three burners of this free-standing range – cooktop CT01, oven OV01 and waist-high broiler BR01 – were interwoven to minimize the number of purge burns required when switching fuels. Whereas most burners are tested with three different fuels in a single day, the burners on this range were tested with different fuels on different days. Experiments were conducted over 4 intensive periods: Dec 18-20, 2007; Jan 16-18, Jan 23-24, and Feb 8-11, 2008. This test schedule may have increased the variance in emissions across replicate experiments with a given fuel owing to day to day variations in combustion air RH and burner operational changes over time. For all experiments, the heater on the dilution sampler inlet was set to automatic mode. The SMPS used to collect size-resolved particle number concentrations for the experiments on Feb 8-11: L063 (PG&E) and L068 (1C).

High relative humidity was measured in the gas sampling manifold during experiments L044 (PG&E) and L047 & L050, (fuel 3A). This is not expected to impact most gaseous analytes as the PG-250 combustion gas analyzer (used to quantify CO_2, O_2, CO and NO in the direct sampling stream) has an internal water removal system. However, the high RH and potential condensation of water in the sampling lines or glass manifold could have affected NO_2 concentrations. During experiment L055 (3A) the room (and combustion) air relative humidity was much lower than during other experiments.

In experiment L059, the gas supply pressure dropped below the design appliance manifold pressure of 6 in. H_2O; manifold pressure dropped in parallel.

Formaldehyde results are not presented for experiments through L062 owing to questions regarding sample flow rates. For these experiments, aldehyde sample flows were controlled by critical orifices with pre-determined flow rates. A check of these flow rates in early Feb 2008 indicated reductions of 71% and 27% in the flow rates for the orifices used for the primary and replicate exhaust sampling lines. These flow changes are presumed to result from partial blockages of the critical orifices. It is not known when the blockages occurred. Starting with L063, flow rates were measured and confirmed for each aldehyde sample.

Table 1. Appliance and burner information OV01.

Burner ID	CT01 / OV01 / BR01
Appliance manufacturer	Amana (Raytheon)
Model number	AGS730W
Serial number	9504170893
Design manifold P	6 in. H_2O
Age (years)	~12 years at time of testing (based on ANSI 1993 label and assumption that first 4 digits are manufacture year, week)
Burner technologies	Hot surface ignition; oven bottom burner inside oven compartment; bottom and waist high tube burners
Burner ratings (Btu/h)	Oven (bottom burner): 15,500
Other information	Procured Jan 31, 2007
Test location	Laboratory
History notes	Offered for sale as part of kitchen remodel following existing home purchase; seller had no knowledge of use level by previous owner. Food residue in oven and wear on burners suggest substantial use.

Figure 1. **Oven compartment of OV01.**

Figure 2. **Oven bottom burner OV01.**

Figure 3. **Spreader plate for oven bottom burner OV01. Note that spreader is non-symmetrical, i.e. deformed.**

Table 2. Interchangeability experiments for oven bottom burner OV01.

Exp.	Fuel	Date	Burner operation
L044	PG&E	12/18/07	Ramp plus 2 maintenance cycles for each oven setting of 350F, 425F and 500F. Oven temperature was set at the end of the last maintenance cycle as indicated by the CO_2 concentrations. A single purge burn occurred for each fuel change; experiments were then conducted for CT01, OV01, and BR01 before switching to next fuel.[1]
L047	3A	12/19/07	
L050	3A	12/20/07	
L055	3A	1/16/08	
L059	3A+N_2	1/23/08	
L062	3A	1/24/08	
L063	PG&E	2/7/08	
L068	1C	2/12/08	

Table 3. Fuel analysis for interchangeability experiments with OV01.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L044[3]	*PG&E*	*L046*	*95.5*	*2.49*	*0.28*	*0.07*	*0.98*	*0.73*	*1017*	*1334*
L050	3A	350F	90.0	5.84	3.06	1.15	0.00	0.00	1126	1419
L050	3A	500F	90.1	5.81	3.01	1.11	0.00	0.00	1125	1418
L055	3A	-	90.1	5.84	2.93	1.09	0.00	0.00	1123	1417
L059	3A+N_2	350F	88.6	5.65	2.79	1.05	1.93	0.00	1099	1382
L059	3A+N_2	500F	88.6	5.68	2.78	1.04	1.92	0.00	1099	1382
L062	3A	350F	89.9	6.14	2.87	1.10	0.00	0.00	1125	1418
L062	3A	500F	90.5	5.74	2.74	1.05	0.00	0.00	1119	1415
L063	PG&E	-	95.3	2.29	0.25	0.07	1.45	0.67	1011	1326
L068	1C	-	92.2	7.76	0.00	0.04	0.00	0.00	1070	1389

[1] Samples generally drawn from fuel supply line while burner is operating; B1 or B2 indicated sampling during first or second burn for cooktop or broiler experiments; 350F indicates sample drawn during oven setting at 350 F.
[2] Calculated using the American Gas Association interchangeability program.
[3] Sample collected during experiment L046, conducted during same day as L044.

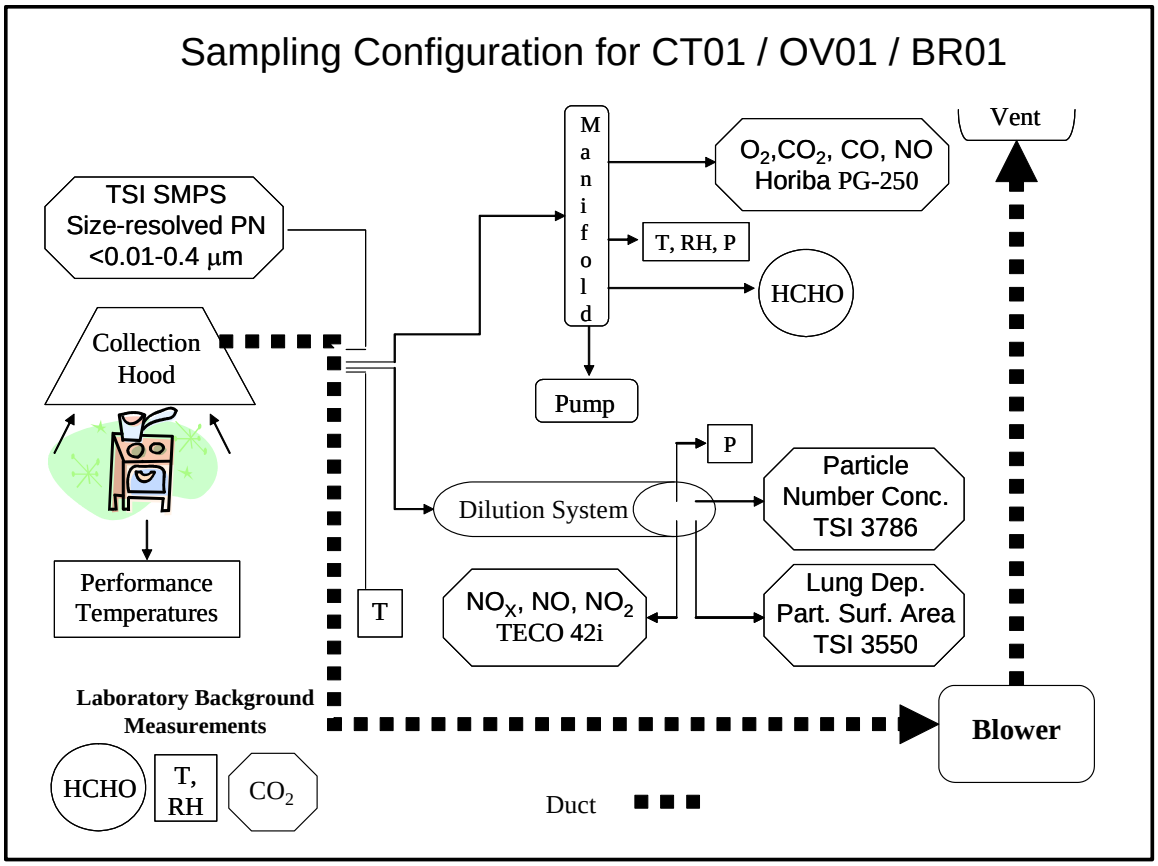

Figure 4. Analytical sampling configuration for CT01 / OV01 / BR01.

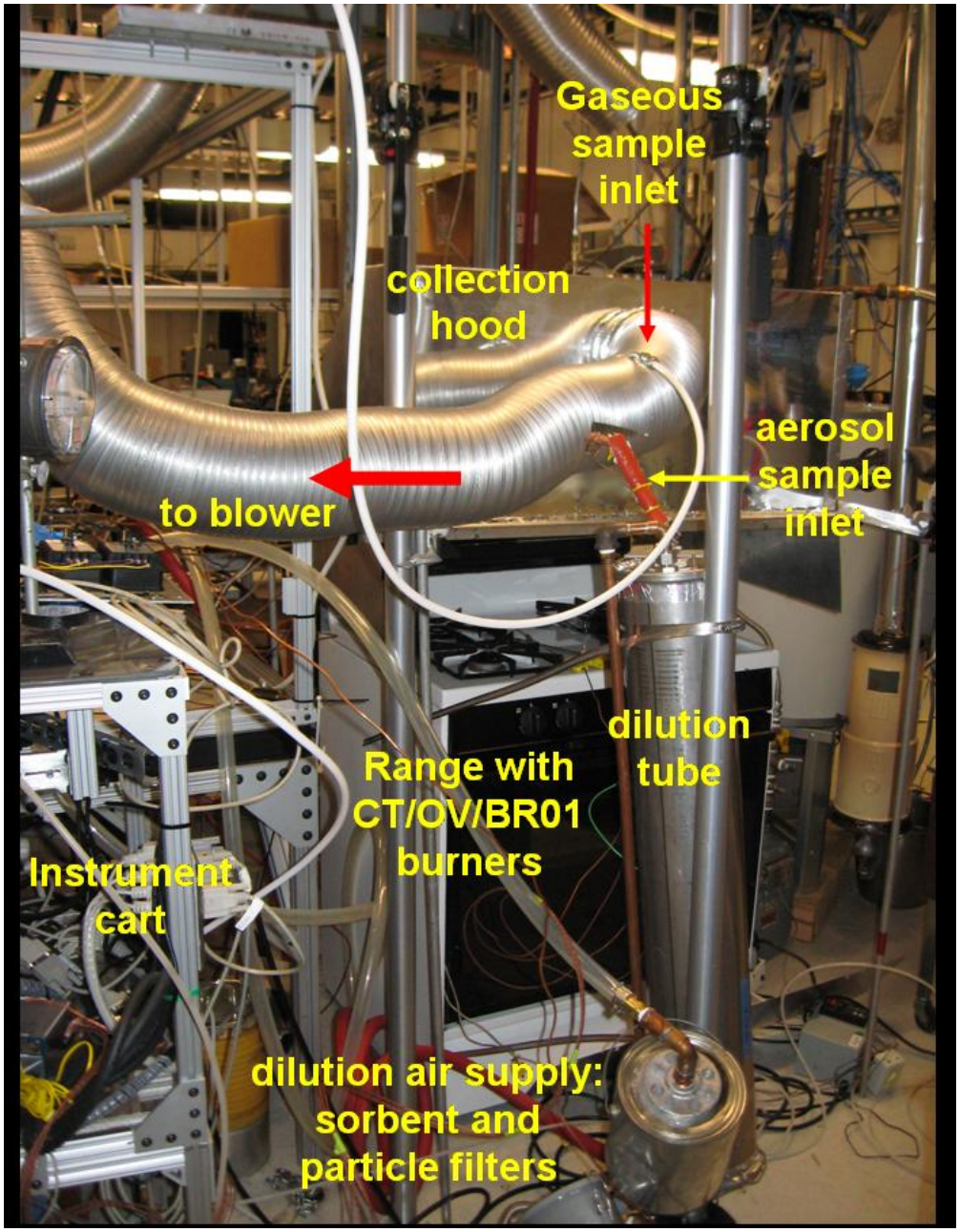

Figure 5. Installation and sampling configuration for CT01 / OV01 / BR01. Front panel of collection hood is not installed in picture, but it was used during experiments.

Table 4. Analyte ranges and calibration levels for experiments with CT01 / OV01 / BR01.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-5%	0, 0.77%
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-200 ppm	0, 50 ppm
Nitrogen oxide (NO)	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 5.0 ppm[3]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 5.0 ppm[3]
Carbon dioxide (CO_2)	ambient air in laboratory[4]	PPSystems EGM-4	5000 ppm	check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold.
[2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com);
[3] Calibrated from mixture of NO in N_2.

Table 5. Aerosol instrumentation used for CT01 / OV01 / BR01.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
Surface area of particles (SA) depositing in lung alveolar region[4]	TSI 3550 nanoparticle surface area monitor	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	10 nm	10^5 um^2 cm^{-3}	±20% at 20-200 um^2 cm^{-3}
TSI SMPS[5]: 3071A classifier, 3025A ultrafine CPC	PN resolved by size (aerodynamic diameter)	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature.
[2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm.
[3] Product 3001788, purchased from TSI.
[4] Monitor has settings available for tracheobronchial (TB) or alveolar (A) regions; specifications are provided for the alveolar option which is being used in this study.
[5] SMPS used for experiments on Feb 8-12 (L064-L068).

Table 6. Other measurements for experiments with CT01 / OV01 / BR01.

Measured Quantity	Location(s)	Device(s)[1]
Fuel pressure	Gas supply line Outlet of appliance regulator	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Dilution sampler vacuum	Dilution tube	Setra Model 264 transducer
Temperature, combustion air	In vicinity of range	Precision NTC thermistor (APT)
Relative humidity, combustion air	In vicinity of range	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in hood	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, oven	Oven interior, shelf middle at lowest, highest positions	Thermocouple (K), screw-mount, Omega XCIB-K-4-2-3

[1]APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com); American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com)

1.2. Results for OV01

CO emissions were very low and mostly associated with a small burst of CO at the beginning of the first burn; all full-burn emission rates were below 50 μg KJ^{-1}. The highest NO_X emission rates were measured during experiment L055 on a day with exceptionally low RH (25% on 1/16). Excluding this experiment, replicate experiments with fuel 3A (WN ~1418) yielded NO_X emission rates that varied (high-to-low) by <10%. There was not a clear trend of NO_X emissions with fuel Wobbe number. The speciation of NO_X varied for the three burns within each experiment and across fuels without an obvious trend. For all experiments, PN emissions were much higher during the first burn to 350 F, compared with burns to 425 and 500 F. PN emission rates varied widely for replicate experiments conducted with fuels having similar Wobbe numbers (2 experiments with PG&E line gas; 2 experiments with fuel WN of ~1380-1390; 4 experiments with mix 3A at WN ~1420). Full burn emission rates were <50 ng/J for CO (all temperature settings), 36-40 ng/J for NO_X (500 F setting; highest for NO_X), 26-320 $x10^4$ J^{-1} for PN at 350 F setting, <1 to 50 $x10^4$ J^{-1} for PN at 425 F and 500 F settings, and 0.70-0.74 ng/J for HCHO (based on data from two experiments).

Table 7. Burner operating parameters for experiments with oven OV01. Information provided for first burner firing at each temperature setting.

Exp.	Fuel	Duration of initial burn at T setting (min)			Firing rate [1] (kBtu/h)	Supply P [3] (in. H_2O)	Manifold pressure [3] (in. H_2O)		
		350 F	425 F	500 F	350F	350F	350 F	425 F	500 F
L044	PG&E	6.2	2.0	2.5	15.3	8.2	6.0	6.0	6.0
L047	3A	5.7	2.5	2.2	16.7	8.6	6.0	6.3	6.0
L050	3A	5.7	1.7	2.3	16.7	9.9	6.0	6.0	6.0
L055	3A	5.5	2.0	2.7	17.2	6.1	5.9	5.8	5.8
L059[4]	*3A/N_2*	*6.2*[4]	*2.3*[4]	*3.0*[4]	*15.0*[4]	*5.3*[4]	*5.2*[4]	*4.9*[4]	*4.6*[4]
L062	3A	5.3	2.0	2.3	16.4	7.1	6.0	6.0	6.0
L063	PG&E	5.7	2.2	2.7	16.1	7.5	6.0	6.0	6.0
L067	1C	5.2	2.2	1.8	17.4	7.8	6.1	6.0	6.0

[1] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over period of burner operation; firing rate calculated from fuel flow rate and higher heating value from fuel composition; calculation is for initial burn to reach 350 F.
[2] Pressure at outlet of appliance regulator during first burn at 350 F.
[3] Pressure in fuel supply line and at outlet of appliance regulator, during burn.
[4] Supply pressure dropped below the rated manifold P, with consequent decrease in actual manifold P and firing rate; time required to reach temperatures increased.

Table 8. Environmental conditions[1] for experiments with OV01.

Date	Burner	Exp.	T (°C)	RH (%) [2]
12/18/07	OV01	L044	19.6 ± 0.1	59 ± 1
12/19/07	OV01	L047	20.0 ± 0.1	50 ± 1
12/20/07	OV01	L050	19.9 ± 0.1	51 ± 1
1/16/08 [2]	OV01	L055 [2]	20.7 ± 0.1	*25 ± 0*
1/23/08	OV01	L059	19.6 ± 0.3	41 ± 1
1/24/08	OV01	L062	20.1 ± 0.1	40 ± 1
2/7/08	OV01	L063	20.5 ± 0.0	45 ± 0
2/12/08	OV01	L068	21.5 ± 0.0	49 ± 0

[1] Measured over period of formaldehyde sample.
[2] Room RH was very low on 1/16/08 (L053-L055).

Table 9. Sampling system conditions for experiments with bottom oven burner OV01.

Exp.	Fuel	Gas manifold T (°C)			Gas manifold RH (%)			Dilution ratio		
		350 F	425 F	500 F	350 F	425 F	500 F	350 F	425 F	500 F
L044	PG&E	19.6	19.5	19.5	97 [2]	89 [2]	91 [2]	27	29	26
L047	3A	20.3	20.2	20.2	96 [2]	83	84	23	25	23
L050	3A	19.9	20.0	20.1	97 [2]	82	86	27	28	25
L055	3A	20.9	20.7	20.7	64	55	58	30	33	29
L059	3A	19.8	19.5	19.4	82	76	77	29	29	29
L062	3A/N_2	20.6	20.4	20.3	82	74	76	26	26	25
L063	PG&E	20.3	20.3	20.4	74	72	73	34	29	27
L068	1C	21.5	21.5	21.5	75	72	74	27	29	29

[1] Measured in gas sampling manifold over last min of each burn to achieve new temperature setting.
[2] High sample manifold RH indicates potential for water condensation in gas sampling stream with possible losses of non-NO NO_X species (primarily NO_2). PG-250 gas analyzer has internal water removal system and measurements of CO_2, O_2, CO and NO should be accurate.

Table 10. Formaldehyde samples for experiments with cooktop OV01.

Exp(s)	Location	Date	Sample times		Air vol. [1] (L)	Extract conc. (ng/μL)	Air conc.[1,2] (μg/m^3)
			Start	Start			
L063	Bkg	2/7/08	15:03	15:34	30	0.065	4.3
L063	Exhaust	2/7/08	15:06	15:34	28	0.724	52
L068	Bkg	2/12/08	11:26	13:07	115	0.308	5.3
L068	Exhaust	2/12/08	12:38	13:07	28	0.696	50

[1] For experiments through L062, sample flow rates are uncertain (see method note above). Air volumes and concentrations are based on critical orifice flow rates measured months earlier and just following L062. Change in flow rate for background samples was 2%; sample volumes and concentrations calculated with the lower flow rate. Starting with L063, flow rates were verified during sampling.
[2] Average formaldehyde concentrations in the air drawn through the sampler; the effect of gas quality on formaldehyde emissions is indicated in a subsequent table.

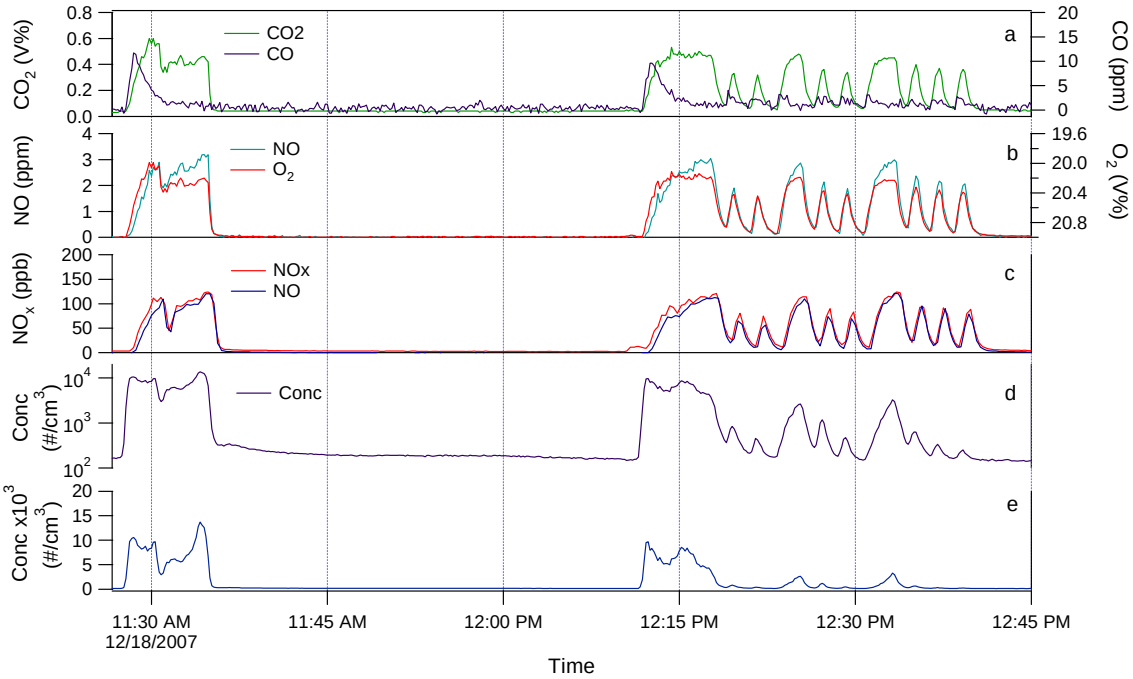

Figure 6. Measured analyte concentrations for oven OV01 with PG&E line gas (L044). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction). The three burns at 350, 425 and 500 F are shown at right; the burn at left was not analyzed as part of the experiment.

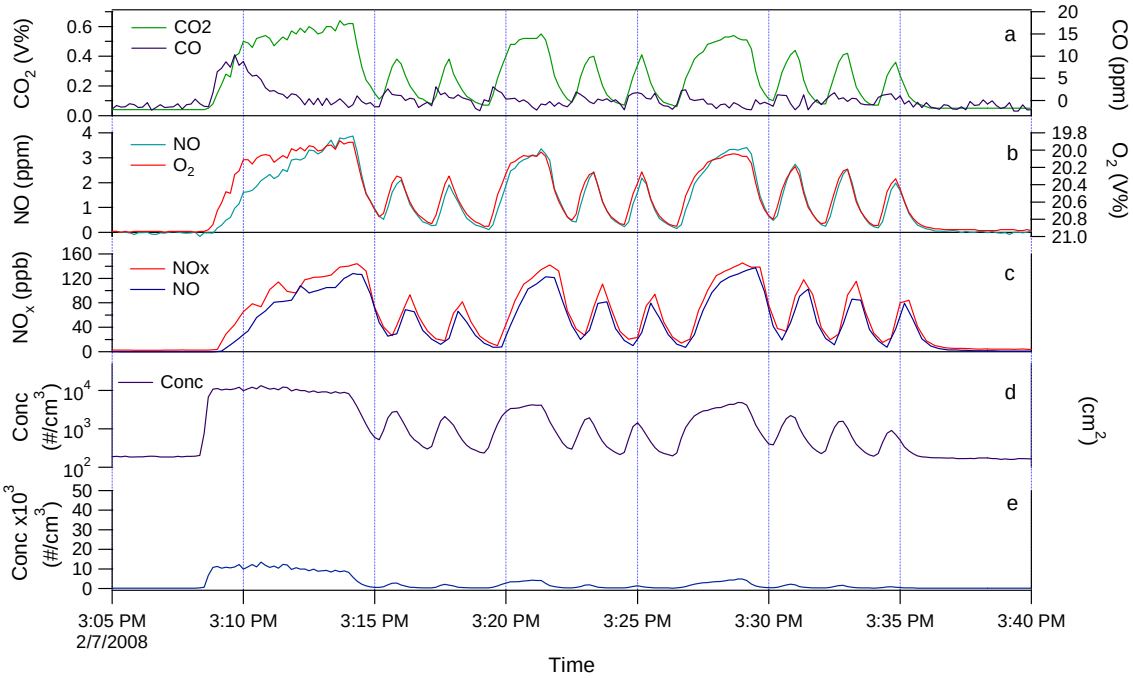

Figure 7. Measured analyte concentrations for oven OV01 with PG&E line gas (L063). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

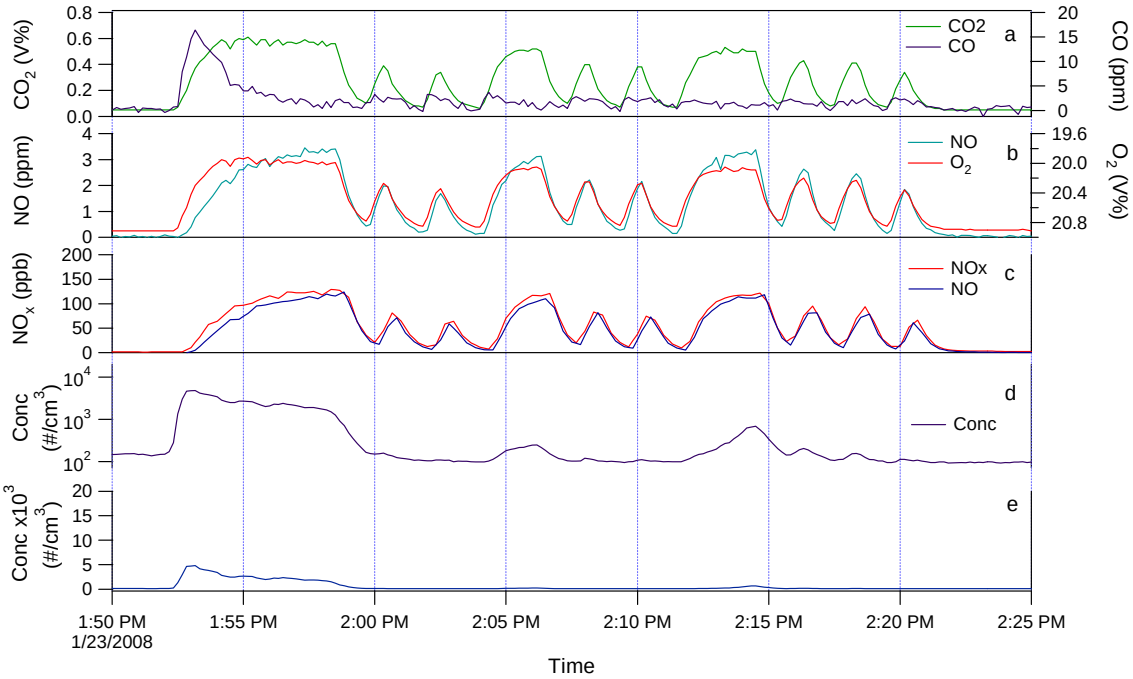

Figure 8. Measured analyte concentrations for oven OV01 with fuel 3A + N_2 (L059).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

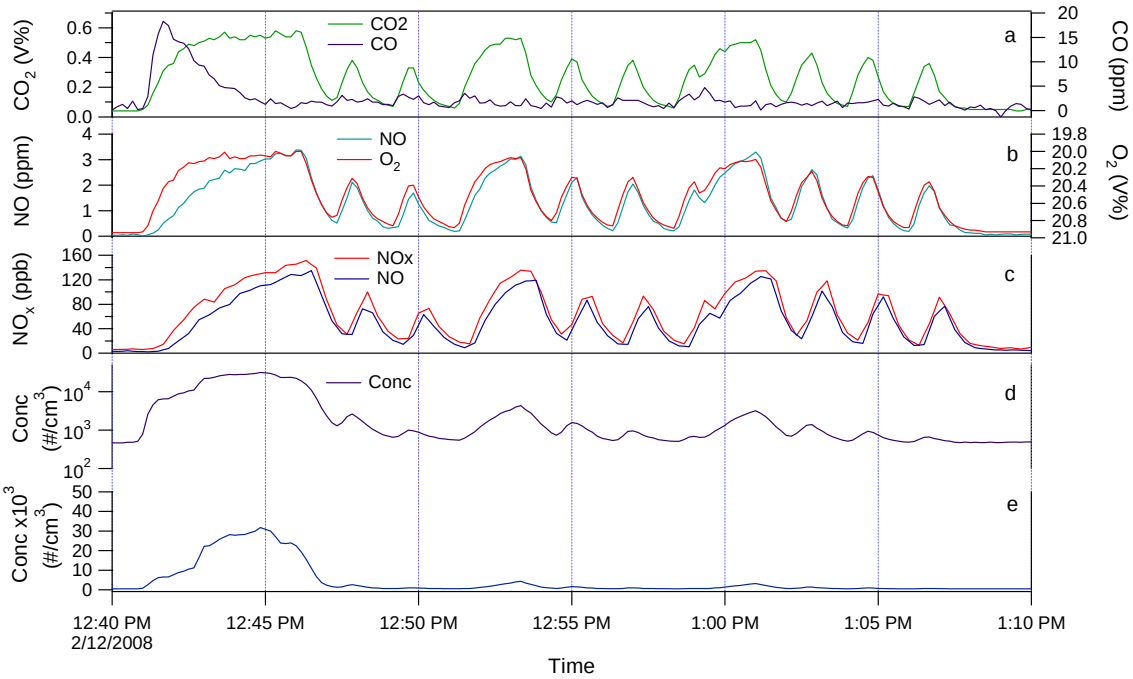

Figure 9. Measured analyte concentrations for oven OV01 with fuel 1C (L068).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

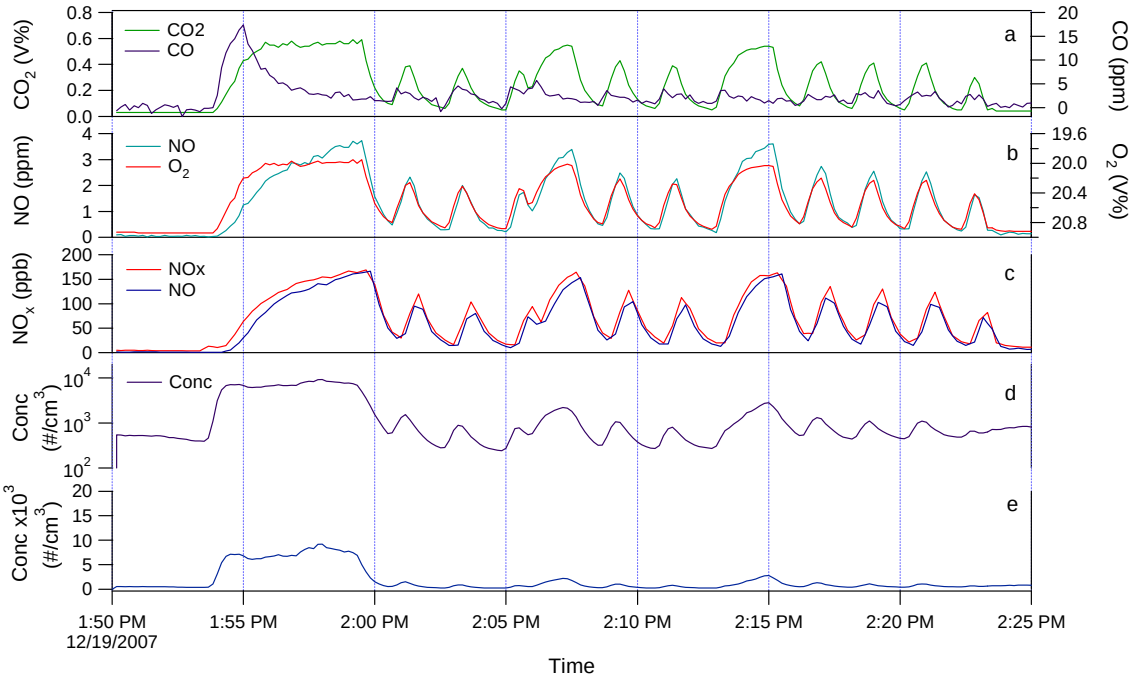

Figure 10. Measured analyte concentrations for oven OV01 with fuel 3A (L047).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

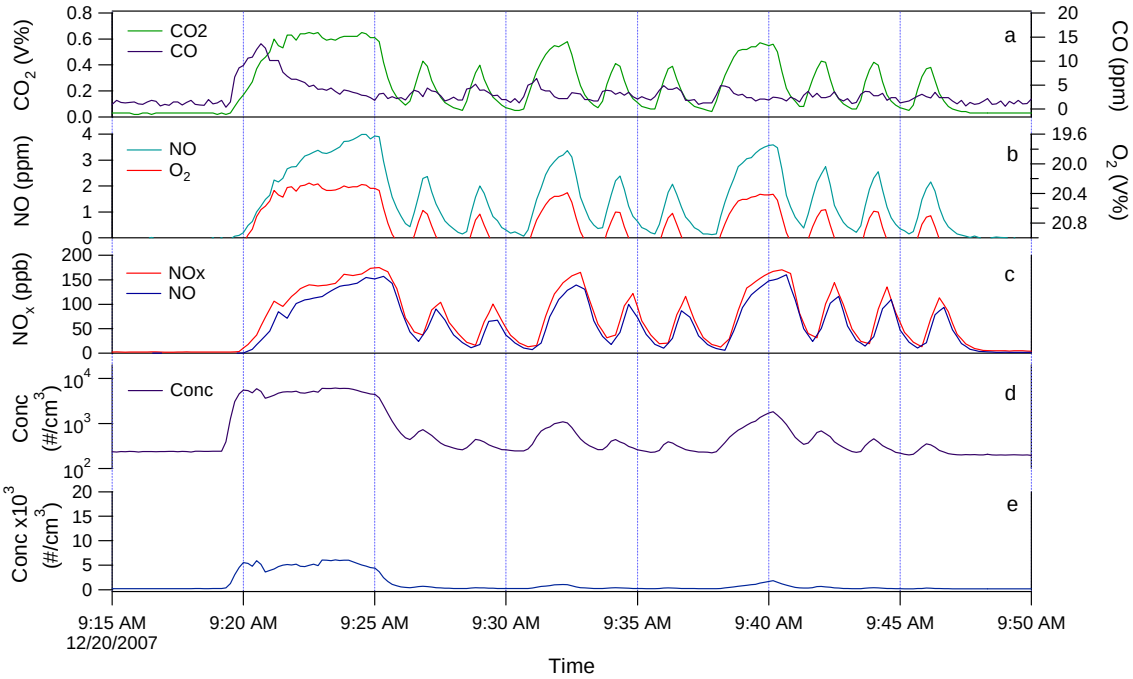

Figure 11. Measured analyte concentrations for oven OV01 with fuel 3A (L050).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

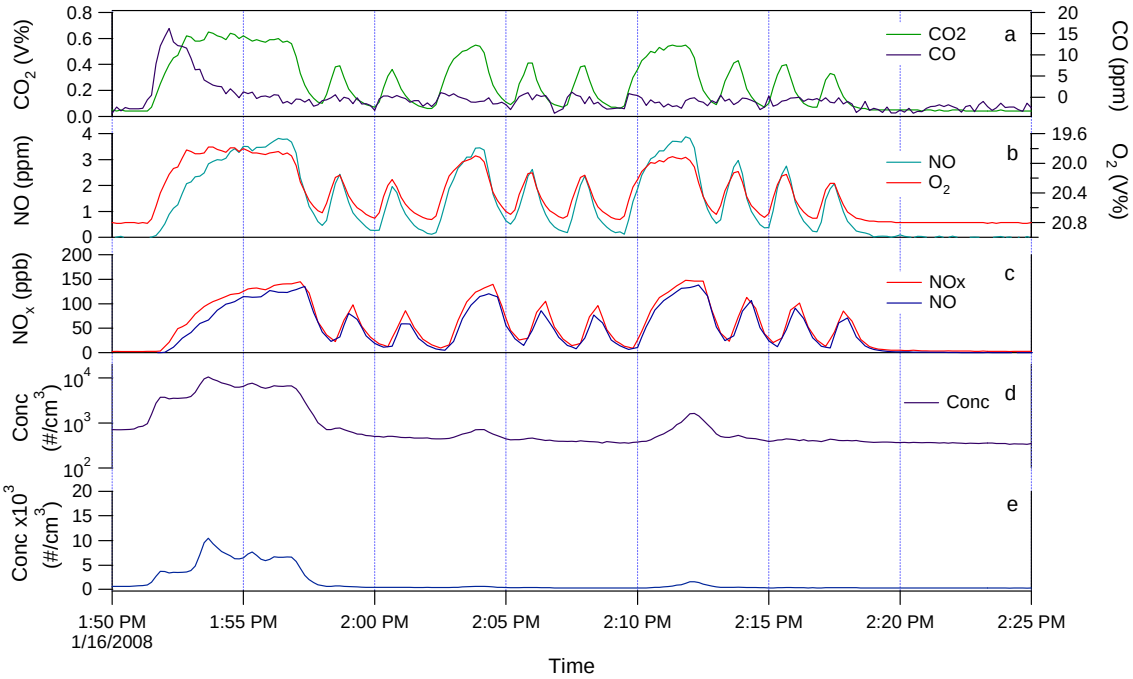

Figure 12. Measured analyte concentrations for oven OV01 with fuel 3A (L055).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

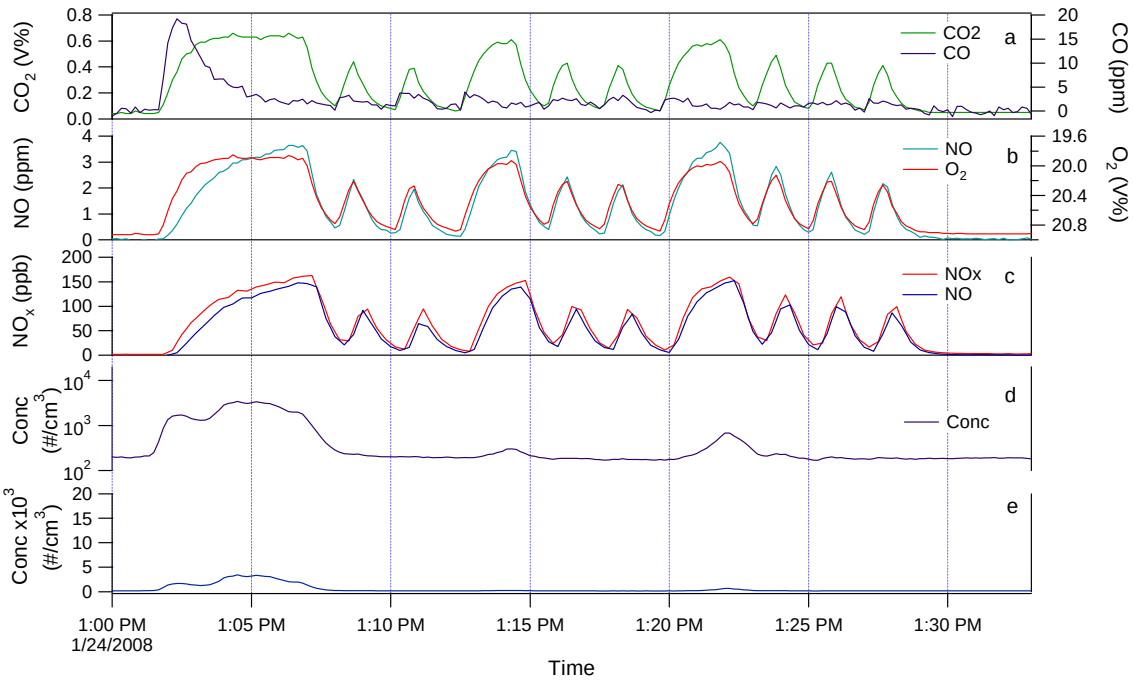

Figure 13. Measured analyte concentrations for oven OV01 with fuel 3A (L062).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (potential instrument malfunction).

Table 11. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L044[1]	PG&E	1334	21	10	18	81	77	86	36	14	15
L047[1]	3A	1418	67	52	37	81	78	84	42	9.8	9.7
L050[1]	3A	1419	42	23	19	80	75	83	32	4.7	6.2
L055	3A	1417	68	43	31	82	82	93	38	0.4	2.2
L059[2]	3A+N2	1382	19	28	18	78	76	85	12	0.7	1.9
L062	3A	1417	37	26	13	71	71	80	14	0.2	0.8
L063	PG&E	1326	26	3	5	77	77	83	63	27	26
L068	1C	1390	26	17	18	74	73	80	190	15	13

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream. PG-250 gas analyzer has internal water removal system and measurements of CO_2, O_2, and CO should be accurate. PN and other NO_X data may be impacted by calculated dilution ratio if PG-250 NO is affected.
[2] L059 results may be affected by low supply and resulting low manifold pressure).

Table 12. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L044[1]	PG&E	1334	83	83	84	81	77	86	1.6	5.8	-1.2
L047	3A	1418	83	87	88	81	78	84	2.8	9.6	4.2
L050	3A	1419	88	89	91	80	75	83	8	14.6	8.5
L055	3A	1417	87	93	101	82	82	93	5.1	11.5	7.4
L059[2]	3A+N2	1382	82	85	87	78	76	85	3.7	8.9	2.4
L062	3A	1417	76	77	83	71	71	80	5.4	5.7	3.7
L063	PG&E	1326	91	86	90	77	77	83	14.8	8.9	7.3
L068	1C	1390	83	86	90	74	73	80	9.2	12.8	9.8

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream. PG-250 gas analyzer has internal water removal system and measurements of CO_2, O_2, and CO should be accurate. PN and other NO_X data may be impacted by calculated dilution ratio if PG-250 NO is affected.
[2] L059 results may be affected by low supply and resulting low manifold pressure.

Table 13. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO (μg KJ^{-1})			PG250 NO (μg KJ^{-1})			PN (10^7 KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L044[1]	PG&E	1334	25	12	12	29	33	35	120	27	24
L047[1]	3A	1418	45	31	20	29	34	37	91	15	20
L050[1]	3A	1419	32	20	13	30	33	36	72	8.8	13
L055	3A	1417	45	22	16	29	36	39	95	0.2	4.9
L059[2]	3A+N2	1382	34	14	11	27	32	35	40	1.0	3.8
L062	3A	1417	42	16	12	26	31	33	27	0.5	2.5
L063	PG&E	1326	28	12	8	28	33	35	180	49	48
L068	1C	1390	44	11	12	27	33	35	340	37	26

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream. PG-250 gas analyzer has internal water removal system and measurements of CO_2, O_2, and CO should be accurate. PN and other NO_X data may be impacted by calculated dilution ratio if PG-250 NO is affected.
[2] L059 results may be affected by low supply and resulting low manifold pressure.

Table 14. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L044[1]	PG&E	1334	33	35	36	29	33	35	3.5	2.3	0.8
L047[1]	3A	1418	33	38	40	29	34	37	3.6	4.4	2.6
L050[1]	3A	1419	35	40	40	30	33	36	5.5	6.3	4.4
L055	3A	1417	34	42	43	29	36	39	5.1	5.3	3.5
L059[2]	3A+N2	1382	31	36	37	27	32	35	4.1	4.1	2.1
L062	3A	1417	30	35	36	26	31	33	4.3	4.0	2.8
L063	PG&E	1326	34	39	38	28	33	35	6.3	6.1	3.7
L068	1C	1390	33	38	40	27	33	35	6.1	5.4	5.5

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream. PG-250 gas analyzer has internal water removal system and measurements of CO_2, O_2, and CO should be accurate. PN and other NO_X data may be impacted by calculated dilution ratio if PG-250 NO is affected.
[2] L059 results may be affected by low supply and resulting low manifold pressure.

.

2.0 Oven OV02

2.1. Experimental information for OV02

Two groups of experiments were conducted with this oven.

In the first group, experiments were conducted with this oven bottom burner operating with early versions of both the oven and broiler protocols. The oven protocol included five burner firings to maintain each temperature setting (350, 425, 500 F). The broiler protocol included a set 30-min period in which the burner control was set to “broil”.

Three experiments with the oven protocol were conducted on the same day: PG&E line gas (L032, WN = 1362), mix 3A undiluted (L033, WN = 1418) and 3A diluted with N_2 (L034, WN = 1384) were all tested on the same day. The PG&E line gas distributed on this day had an atypically high Wobbe number. For these experiments, particle number concentrations were measured directly in the exhaust stream coming from the collection hood and the Thermo NO_X analyzer monitored alongside the Horiba PG-250 analyzer from the gas sampling manifold.

Five experiments were conducted with the broiler protocol (L035-L039). L035 (PG&E line gas, WN=1362) was conducted with the CPC (particle number concentrations) and Thermo NO_X analyzer connected directly to hood outlet (i.e. not to dilute sampling system). L036-L039 used the dilution sampling system for particles. L036 (PG&E, WN=1348) and L037 (3A, WN=1418) were conducted one day following L032-L035. During L038 (3A+N_2, WN=1387) the hood air flow setting was too high leading to lower than desirable analyte concentrations. The hood flow was decreased and this experiment repeated as L039 (same fuel).

Air-free concentrations and emission rates were calculated for the first 15 min of the broil burns to be consistent with later broiler protocols; the burner fired continuously over this period in all experiments. End of burn concentrations and emission rates were calculated for the last 5 min of this 15 min period.

It was determined in February 2008 that the critical orifices used in the aldehyde sampling trains had reduced flow at that time. OV02 experiments were conducted in September 2007; a few dozen experiments were conducted between the time the critical orifice flows were measured in June 2007 and these experiments. Flow rates were not measured during the OV02 oven or broiler experiments. Aldehyde results are not presented for these experiments owing to uncertainty in sample flow rates, concentrations, and emission rates.

Four additional experiments were conducted on December 15, 2008 to obtain data on formaldehyde emission rates. These included L127 (fuel 1C, WN=1390), L128 (fuel 3C, WN=1419), and duplicate experiments L129-L130 with PG&E line gas (WN=1334).

Table 15. Appliance and burner information, OV02.

Burner ID	OV02
Burner category	Oven
Burner technology	Tube burner under spreader-shaped bottom plate (legacy)
Appliance manufacturer	Frigidaire
Model	6F82000796
Serial number	MPF500PBWB
Other information	24” range with single burner (no waist-high burner); not self-cleaning
Design manifold P	4 in. H_2O
Burner ratings (Btu/h)	18,000
Age (years)	Purchased new in 1995
Test location	Laboratory
History notes	Procured from original owner for $50; advertised by owner on Craig’s List. Stated reason for sale: purchased new, full-size range. Owner reported regular use for cooking.

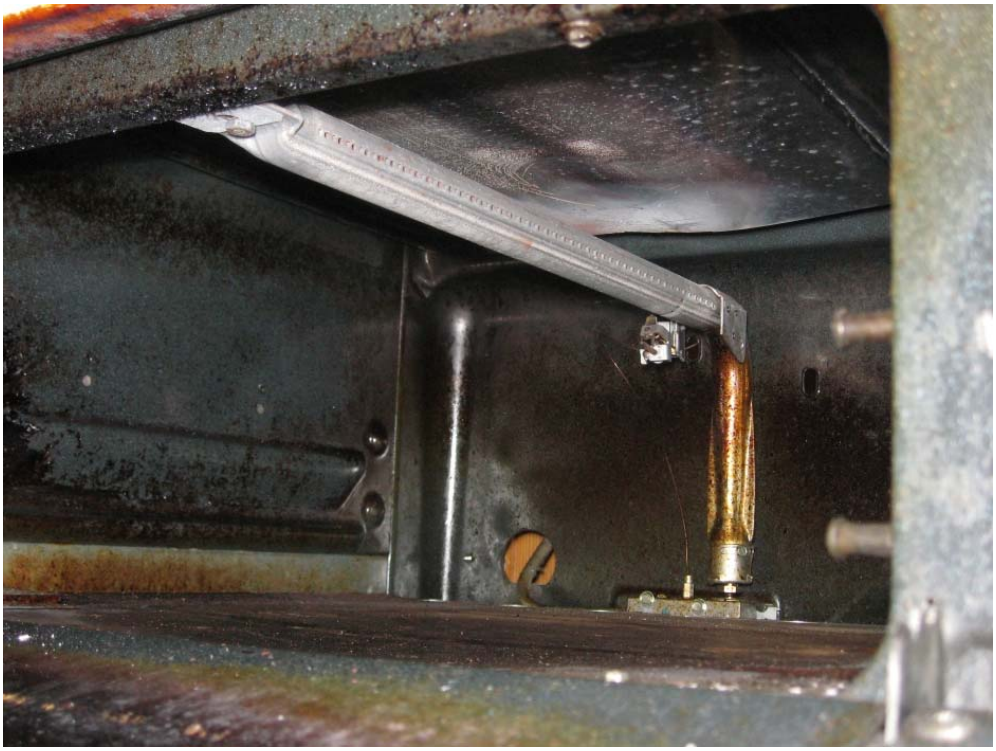

Figure 14. Oven OV02 burner.

Figure 15. **OV02 spreader plate, front. Note irregular shape.**

Table 16. Interchangeability experiments for oven OV02.

Exp.	Fuel	Date	Burner operation
September 2007 experiments			
L032	3A+N_2	09/20/07	Set to bake at 350°F for initial ramp + 5 maintenance cycles; repeat at 425°F and 500°F. No purge burn with fuel switching on experiments L033, L034.[1]
L033	3A	09/20/07	
L034	PG&E	09/20/07	
L035	PG&E	09/20/07	Set to "broil" for 30 min. Burner fired continuously to reach/approach temperature setting, then fired intermittently to maintain temperature. No purge burn when switching fuels.
L036	PG&E	09/21/07	
L037	3A	09/21/07	
L038	3A+N_2	09/27/07	
L039	3A+N_2	09/27/07	
December 2008 experiments			
L127	1C	12/15/08	Set to bake at 350°F for initial ramp + 2 maintenance cycles; repeat at 425°F and 500°F.
L128	3C	12/15/08	
L129	PG&E	12/15/08	
L130	PG&E	12/15/08	

[1] The protocol calls for a short "purge" burn to flush fuel from the previous experiment, for oven experiments, the purge burn is done using the cooktop burners without load (no pots).

Table 17. Fuel analysis for interchangeability experiments with oven OV02, September 2007.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
September 2007 experiments										
L032	3A+N_2	pre	88.7	5.54	2.88	1.05	1.80	0.00	1101	1384
		post	88.9	5.34	2.95	1.07	1.79	0.00	1101	1384
L033	3A	pre	90.1	5.79	2.99	1.08	0.00	0.00	1123	1418
		post	90.2	5.76	2.97	1.06	0.00	0.00	1122	1417
L034	PG&E	pre	90.8	5.60	1.55	0.41	0.79	0.89	1068	1362
L035	PG&E	L034	90.8	5.60	1.55	0.41	0.79	0.89	1068	1362
L036	PG&E	pre	93.0	3.91	1.07	0.29	0.61	1.08	1045	1348
L037	3A	pre	90.0	5.84	3.05	1.09	0.00	0.00	1125	1418
L038	3A+N_2	pre	88.7	5.65	2.91	1.06	1.69	0.00	1104	1387
L039	3A+N_2	pre	88.7	5.65	2.91	1.06	1.69	0.00	1104	1387
December 2008 experiments										
L127	1C	Cylinder[2]	92.0	8.00	-	-	-	-	1071	1390
L128	3C	Cylinder[2]	86.4	12.0	1.60	-	-	-	1125	1419
L129	PG&E	Distrib[3]	95.4	2.49	0.28	0.09	1.00	0.74	1018	1334
L130	PG&E	Distrib[3]	95.4	2.49	0.28	0.09	1.00	0.74	1018	1334

[1] Calculated using the American Gas Association interchangeability program.
[2] Certified composition in cylinder (determined by the supplier, AirLiquide).
[3] Composition of gas distributed to LBNL, as measured by PG&E online GC.

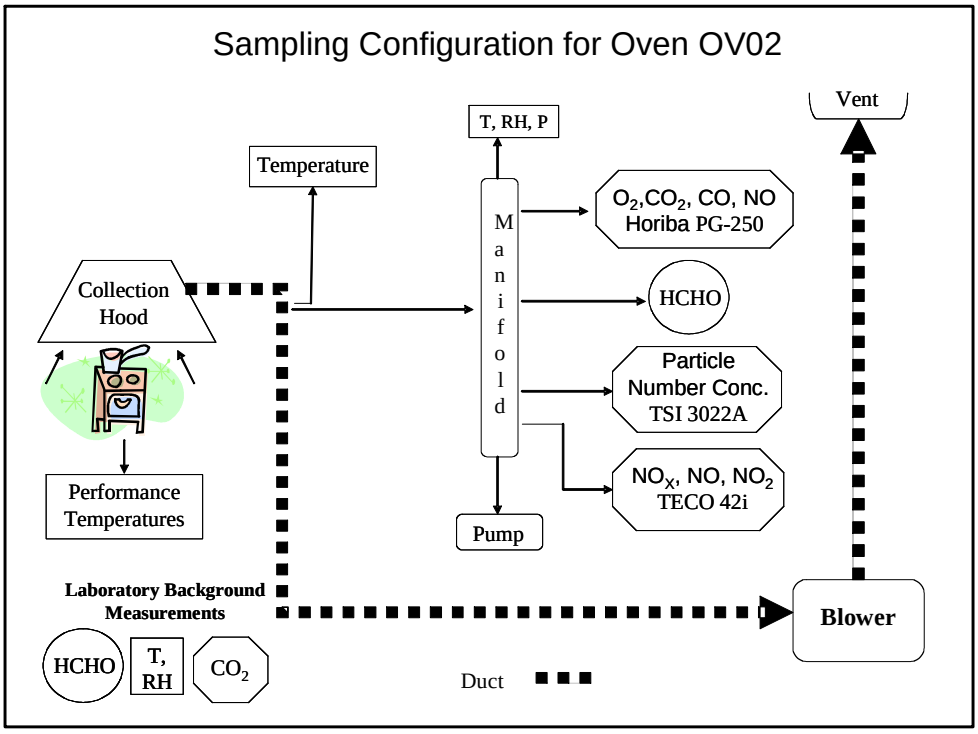

Figure 16. Pollutant sampling configuration for oven OV02, experiments L032-L035.

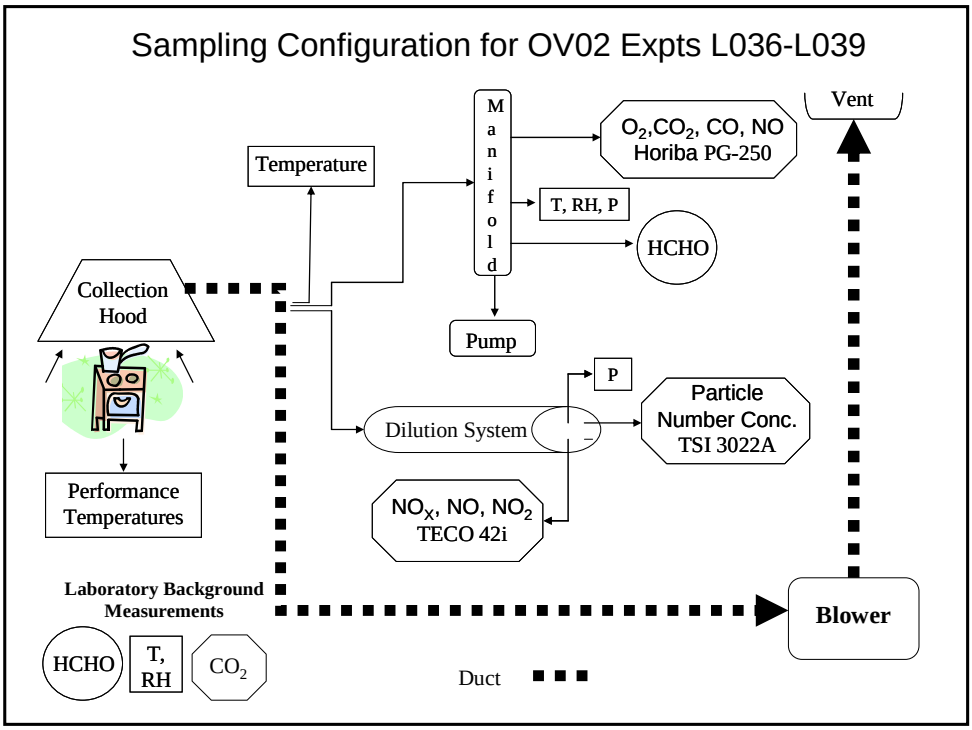

Figure 17. Pollutant sampling configuration for oven OV02, experiments L036-L039.

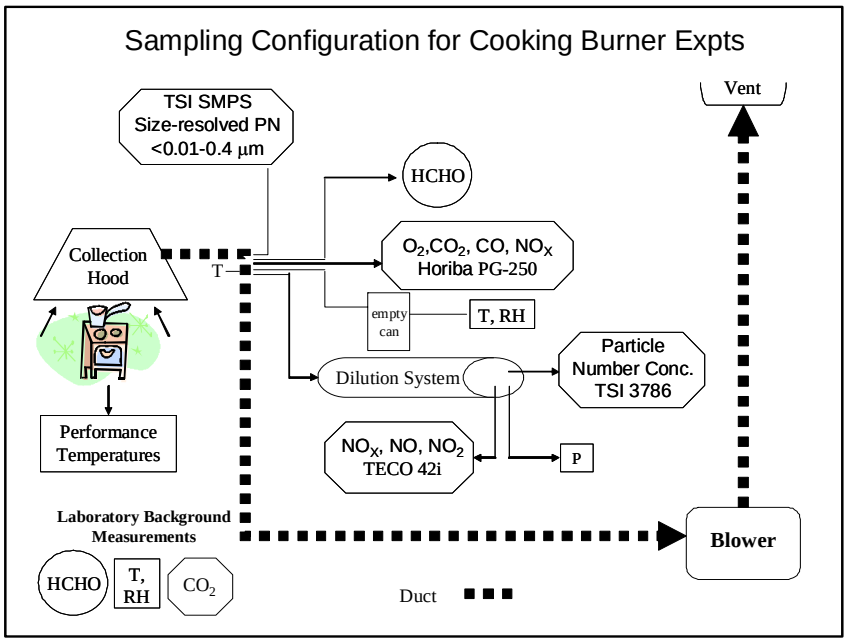

Figure 18. Pollutant sampling configuration for oven OV02, experiments L130-L130.

The empty can is used to measure RH of the airstream from the collection hood at room temperature. This indicates the potential for condensation in sampling system. PG-250 also has water removal system. HCHO sampled through 30-cm Teflon tubing (nominal ¼" diameter) for primary sample, duplicate sampled through 90-cm Teflon tubing.

Figure 19. **Laboratory installation and sampling configuration of range featuring oven OV02.** This photograph was taken with set-up for experiments L036-L039. Note the thermocouples inserted through the left side of the oven door. The dilution aerosol sampler, installed vertically at left of photograph, was not used for L032-L035 as described in notes at front of report.

Table 18. Analyte ranges and calibration levels for experiments with oven OV02.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-10%	0, 0.77%
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-500 ppm	0, 50 ppm
Nitrogen oxide (NO)	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 5.0 ppm[3]
Nitrogen oxides (NO, NO_X)	outlet of collection hood	Thermo 42i	0-10 ppm	0, 5.0 ppm[3]
Carbon dioxide (CO_2)[4]	ambient air in laboratory	TSI Q-Trak Model 8554	0-5000 ppm	Factory calibrated
Carbon dioxide (CO_2)[5]	ambient air in laboratory	PPSystems EGM-4	5000 ppm	factory calibrated; check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold.
[2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com);
[3] Calibrated from mixture of NO in N_2.
[4] Used for September 2007 experiments.
[5] Used for December 2008 experiments.

Table 19. Analyte ranges and calibration levels for experiments with oven OV02 (L127-L130).

Analyte	**Sample location**	**Equipment[1]**	**Range**	**Calibration levels**
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-5%	0, 1%
Oxygen (O_2)			0-25%	0, 20.95%
Carbon monoxide (CO)			0-200 ppm	0, 40 ppm
Nitrogen oxides (NO_X)			0-25 ppm	0, 2.0 ppm
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 2.0 ppm
Carbon dioxide (CO_2)	laboratory air	PP Systems EGM-4	5000 ppm	Periodic[2]

[1] Horiba Environmental and Process Instruments (environ.hii.horiba.com); Thermo Fisher Scientific (thermo.com); PP Systems (ppsystems.com). [2] Not checked daily; observed to remain within 10s of ppm at ambient conditions.

Table 20. Aerosol instrumentation used for oven OV02.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
September 2007 experiments					
Total particle number conc. (PN), # cm^{-3}	TSI 3022A CPC	sample direct from hood outlet via 2.2 m × 0.48 cm ID conductive tubing[3]	7 nm	10^7 cm^{-3}	±12% to 5×10^5 cm^{-3}; ±20% at $>5\times10^5$ cm^{-3}
December 2008 experiments					
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
PN resolved by size (aerodynamic diameter)	TSI SMPS: 3071A classifier, 3025A ultrafine CPC	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1]TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature. [2]50% detection. [3] Product 3001788, purchased from TSI.

Table 21. Other measurements for experiments with oven OV02.

Measured Quantity	**Location(s)**	**Device(s)[1]**
Fuel pressure	Gas supply line Outlet of appliance regulator	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Fuel volume & flow	Just upstream of appliance in lab	Singer DTM-115 calibrated against AC-250-TC
Dilution sampler vacuum	Dilution tube	Setra Model 264 transducer
Gas sampling manifold P	Gas sampling manifold	Magnehelic gauge
Temperature, combustion air	Air temperature near appliance	Precision NTC thermistor (APT)
Relative humidity, combustion air	Air temperature near appliance	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in duct	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, oven	Oven interior, shelf middle at lowest, highest positions	Thermocouple (K), screw-mount, Omega XCIB-K-4-2-3

[1] APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com); American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com).

2.2. Results for OV02

In both rounds of experiments in which the oven protocol was used, CO concentrations and emissions were the highest during the initial burn – heating to 350 F – owing to a peak occurring at ignition. Both the end of burn and full burn CO concentrations and emission rates were higher in the first round of oven experiments (L032-L034. Full burn CO emission rates for the 350 F burn were about 280-300 $\mu g\ KJ^{-1}$ during L032-L034 and 80-120 $\mu g\ KJ^{-1}$ during L127-L130. CO emissions during the 500 F burn were about 100-125 $\mu g\ KJ^{-1}$ in the first set and 50-55 $\mu g\ KJ^{-1}$ for the second set. Full-burn CO increased modestly at each temperature with increasing fuel WN in the first set of oven experiments, but no clear trend with WN was observed for CO in L127-130. During broil burns in the September 2007 experiments, CO increased by about 20% between replicate PG&E experiments and the fuel 3A experiment; full burn emission rates were 142-178 ng/J.

In L032-L034, particle emissions during the higher temperature (500 F) burns were 2 orders of magnitude higher than during other burns. In L127-130, PN was again highest at 500 F, but emission rates at this temperature were an order of magnitude lower than in the earlier set of experiments. In both sets, PN emissions at 500 F were highest for the mid-Wobbe fuel, which also was the first fuel tested each day. PN emissions at 350 F and 425 F were similar across fuels and for the two sets of experiments. In broiler experiments, PN emissions decreased over the course of experiments with relatively larger differences observed between replicates for both PG&E line gas and fuel 3A diluted with N_2.

NO_X and NO emissions increased with oven temperature during each oven experiment. At each temperature setting for L032-L034, NO_X and NO varied (high-low) among experiments by less than 10%. There was slightly more variance in the second set of experiments, owing mostly to the higher NOX and NO emission rates in L127 (fuel 1C). In L032-L034, side-by-side NO measurements with two analyzers were comparable within 10%. For the first set of oven protocol experiments, NO_X emissions were slightly higher for the two higher Wobbe fuels. In the second set of experiments, NO_X results were very similar for 3A and PG&E, suggesting no robust effect of fuel WN on NO_X emissions for this burner. In experiments with the broil protocol, NO_X emissions were very tight (30-31 ng/J) for all but one experiments with $3A+N_2$ (35 ng/J).

Formaldehyde emission rates measured in L127-L130 suggest a possible modest effect of fuel WN. The replicate experiments with PG&E (WN = 1334, L129-L130) yielded emission rates of 0.52 and 0.62 ng/J compared with duplicate samples for L127 (fuel 1C, WN = 1390) of 0.64 and 0.66 ng/J and a single sample yielding 0.68 ng/J emission rate for L128 (fuel 3C, WN = 1419).

Table 22. Burner operating parameters for experiments with oven OV02 (December 2008). Information provided for first burner firing at each temperature setting.

Experiment	Burn	Start Time	End Time	Fuel Flowrate ($ft^3\ h^{-1}$)[1]	Firing Rate ($kBTU\ h^{-1}$)[1]
September 2007 experiments					
L032	350F	12:19	12:24	16	17
L032	425F	12:37	12:40	11	13
L032	500F	12:48	12:53	14	16
L033	350F	13:30	13:35	15	17
L033	425F	13:48	13:52	14	15
L033	500F	14:01	14:05	12	14
L034	350F	14:39	14:45	15	16
L034	425F	14:58	15:02	11	12
L034	500F	15:11	15:15	12	13
December 2008 experiments					
L127	350F	09:23	09:28	17	19
L127	425F	09:34	09:38	16	17
L127	500F	09:41	09:44	17	18
L128	350F	10:20	10:26	17	19
L128	425F	10:33	10:36	16	18
L128	500F	10:41	10:44	15	17
L129	350F	12:17	12:23	17	18
L129	425F	12:30	12:34	16	16
L129	500F	12:39	12:42	16	17
L130	350F	13:22	13:29	17	17
L130	425F	13:35	13:39	16	16
L130	500F	13:44	13:47	16	16

[1] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over period of burner operation; firing rate calculated from fuel flow rate and higher heating value from fuel composition; calculation is for initial burn to reach 350 F.

Table 23. Burner operating parameters for experiments with bottom burner OV02 operating with broiler protocol.

Exp. (fuel)	Start time	End time	Fuel flow rate (ft^3/h)[2]	Firing rate (kBtu/h)[2]	Dilution ratio[3]
L035	15:51	16:06	16	16	No dilution
L036	12:18	12:33	16	17	14
L037	13:38	13:52	16	17	14
L038	13:52	14:07	15	16	18
L039	15:34	15:49	15	16	16

[1] Period over which results were calculated. Protocol included 30 min total of operation at "broil" setting.
[2] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over entire period of burner operation; firing rate calculated from measured fuel flow rate and higher heating value from fuel composition.
[3] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 24. Environmental conditions[1] for experiments with oven OV02.

Exp.	T (°C)	RH (%)
September 2007 experiments		
L032	21.1 ± 0.2	49 ± <1
L033	21.6 ± 0.2	49 ± <1
L034	22.1 ± 0.2	50 ± <1
L035	22.5 ± 0.2	48 ± 1
L036	22.4 ± 0.2	47 ± 0
L037	23.0 ± 0.1	48 ± 0
L038	24.5 ± 0.2	45 ± 1
L039	24.2 ± 0.1	45 ± 0
December 2008 experiments		
L127	20.8 ± 0.1	41 ± 0
L128	21.3 ± 0.1	41 ± 0
L129	21.5 ± 0.1	38 ± 1

[1] Measured over entire experiment.

Table 25. Sampling system conditions[1] for experiments with oven OV02.

Exp.	Gas manifold T (°C)			Gas manifold RH (%)		
Oven protocol, September 2007						
Temp:	350 F	425 F	500 F	350 F	425 F	500 F
L032	23.4	23.6	23.7	60	56	55
L033	23.8	24.0	24.3	60	56	55
L034	24.4	24.6	24.8	61	56	55
Broiler protocol, September 2007						
L035	25.0	±	0.1	58	±	1
L036	24.8	±	0.1	65	±	2
L037	26.0	±	0.1	63	±	1
L038	27.0	±	0.1	49	±	1
L039	27.2	±	0.1	60	±	1
Oven protocol, December 2008						
L127	18.8	18.4	18.4	53	54	55
L128	18.8	18.6	18.6	54	55	55
L129	19.1	18.9	19.0	52	53	52
L130	19.5	19.3	19.3	49	50	50

[1] Measured in gas sampling manifold over last min of each burn to achieve new temperature setting.

Table 26. Sample location temperatures and dilution ratios for first burn at each temperature setting.

	Sample location T (°C)[1]			Dilution ratio[2]		
Exp.	350 F	425 F	500 F	350 F	425 F	500 F
L127	31 ± 1	38 ± 0	42 ± 0	25	27	28
L128	32 ± 0	38 ± 1	42 ± 0	30	29	31
L129	32 ± 1	39 ± 1	43 ± 0	30	30	31
L130	32 ± 1	39 ± 0	43 ± 0	30	31	31

[1] Measured in exhaust duct from collection hood alongside pollutant sampling inlets. Mean ± standard deviation measured over last min of each burn to achieve new temperature setting.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) over last min of each burn.

Table 27. Formaldehyde samples for experiments with oven OV02.

Exp(s)	Location	Date	Sample start/end time		Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m^3)
Bkg	Lab air	12/15/2008	9:08	13:54	283	0.317	2.2
L127a	Collection hood outlet	12/15/2008	9:20	9:51	35.3	0.358	20.3
L127b			9:20	9:51	38.4	0.402	20.9
L128			10:18	10:52	40.0	0.505	25.3
L129			12:15	12:50	42.1	0.536	25.4
L130			13:20	13:54	38.7	0.399	20.6

[1] Concentration in the air stream being sampled for other gaseous analytes.

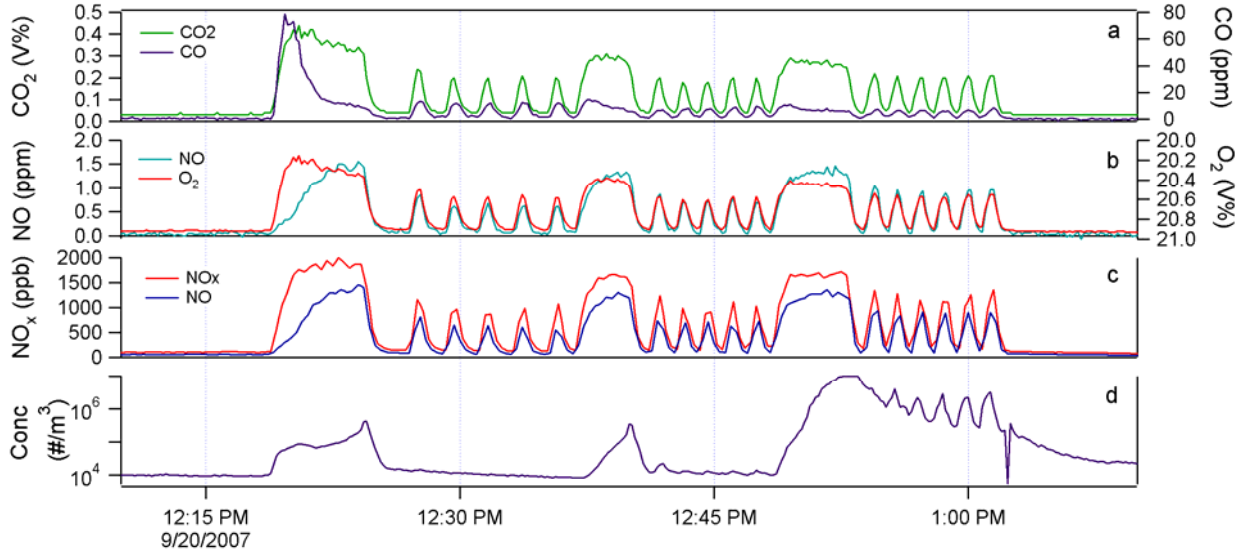

Figure 20. Measured analyte concentrations for oven OV02 with fuel 3A + N_2 (Exp. L032). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood.

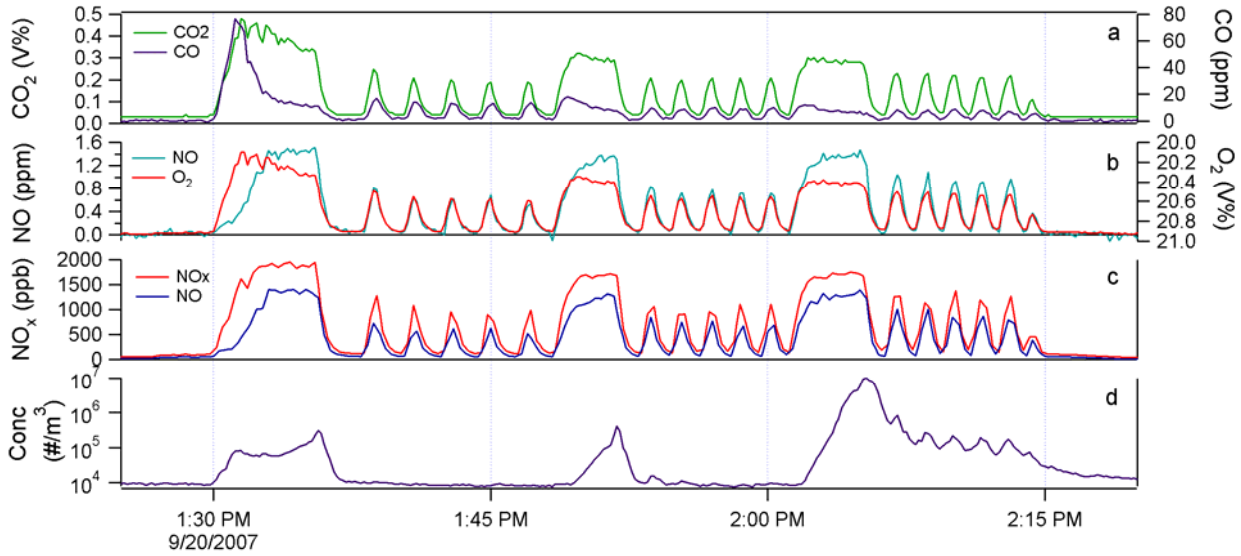

Figure 21. **Measured analyte concentrations for oven OV02 fuel 3A (Exp. L033).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood.

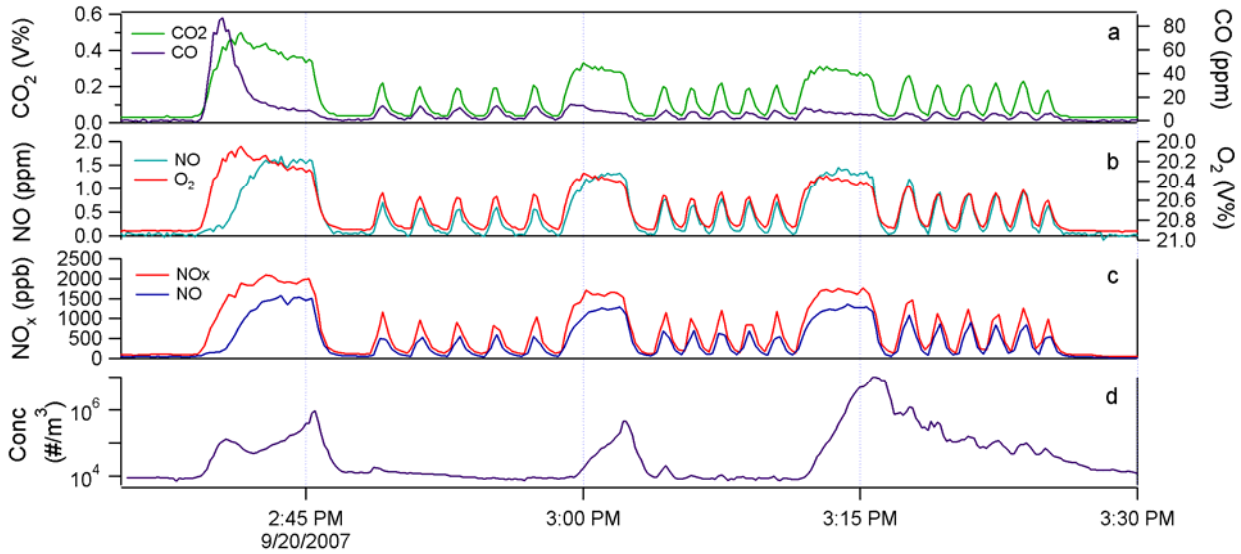

Figure 22. **Measured analyte concentrations for oven OV02 with PG&E line gas (Exp. L034).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood.

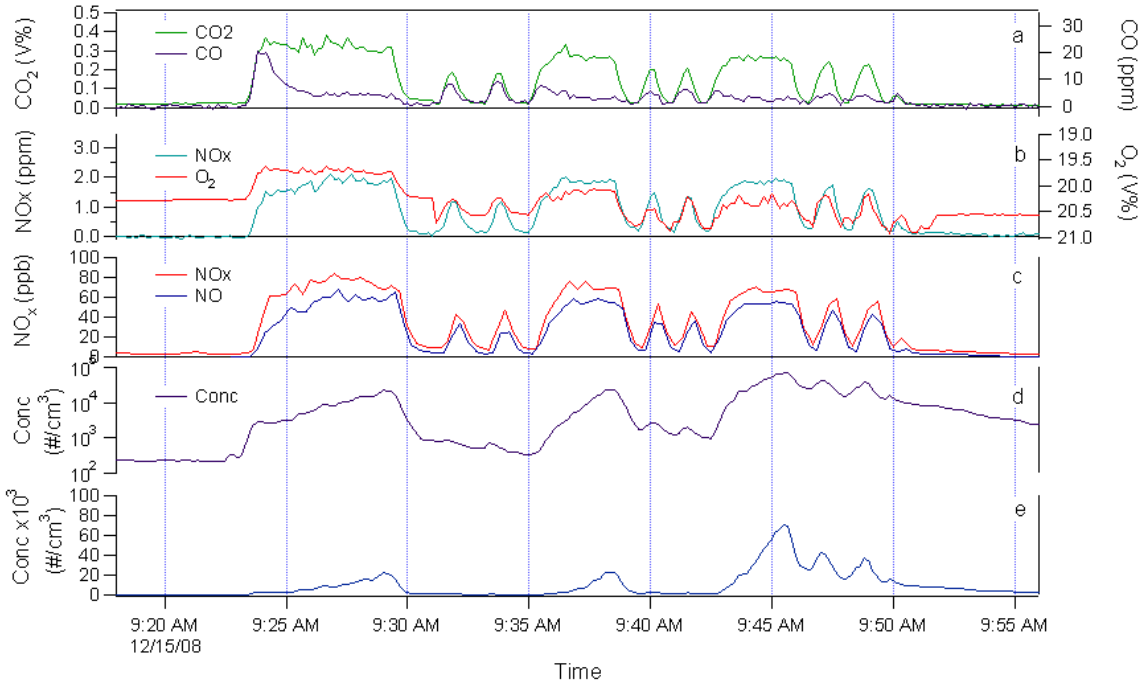

Figure 23. **Measured analyte concentrations for oven OV02 fuel 1C (Exp. L127).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

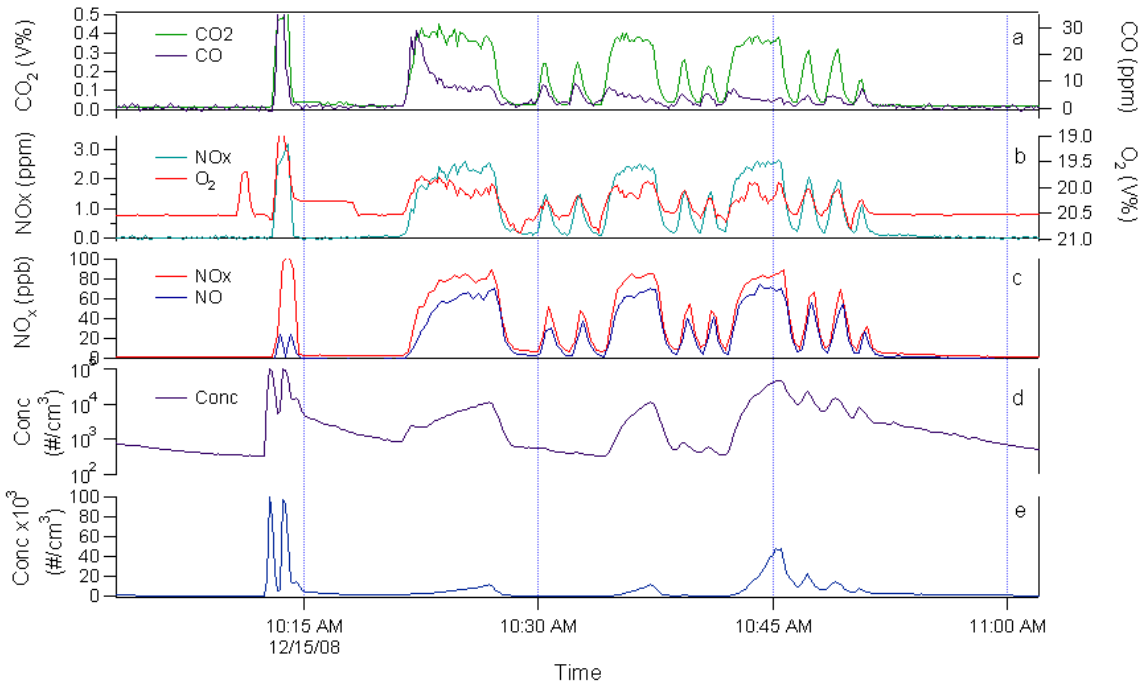

Figure 24. **Measured analyte concentrations for oven OV02 fuel 3C (Exp. L128).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

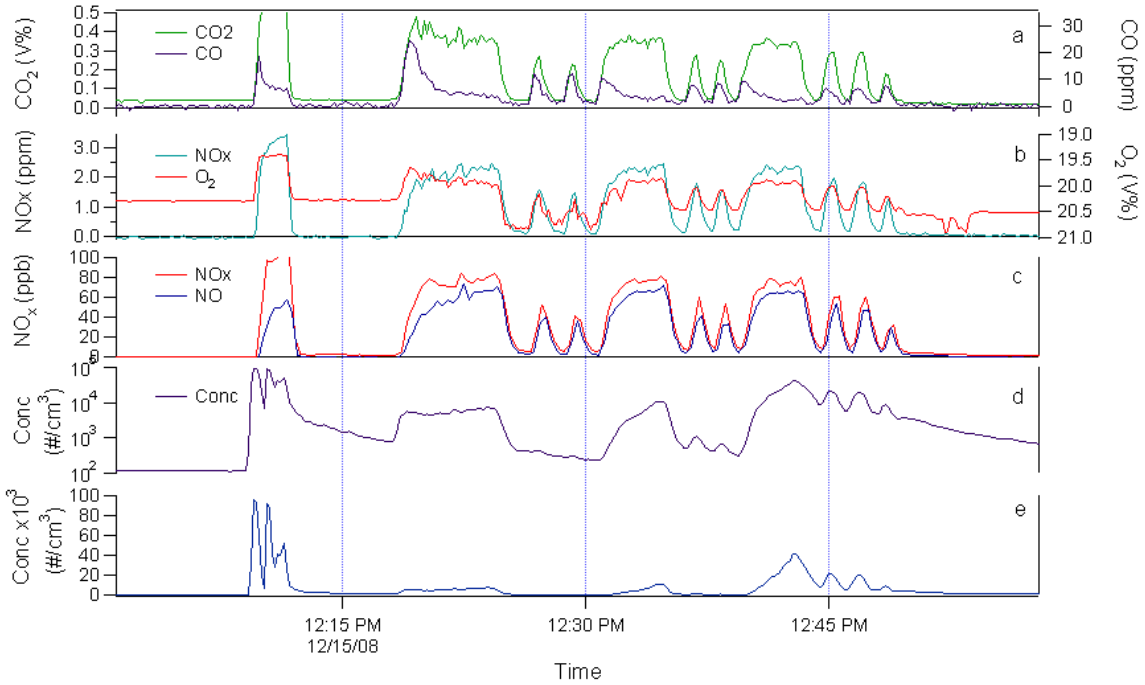

Figure 25. **Measured analyte concentrations for oven OV02 with PG&E line gas (L129).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

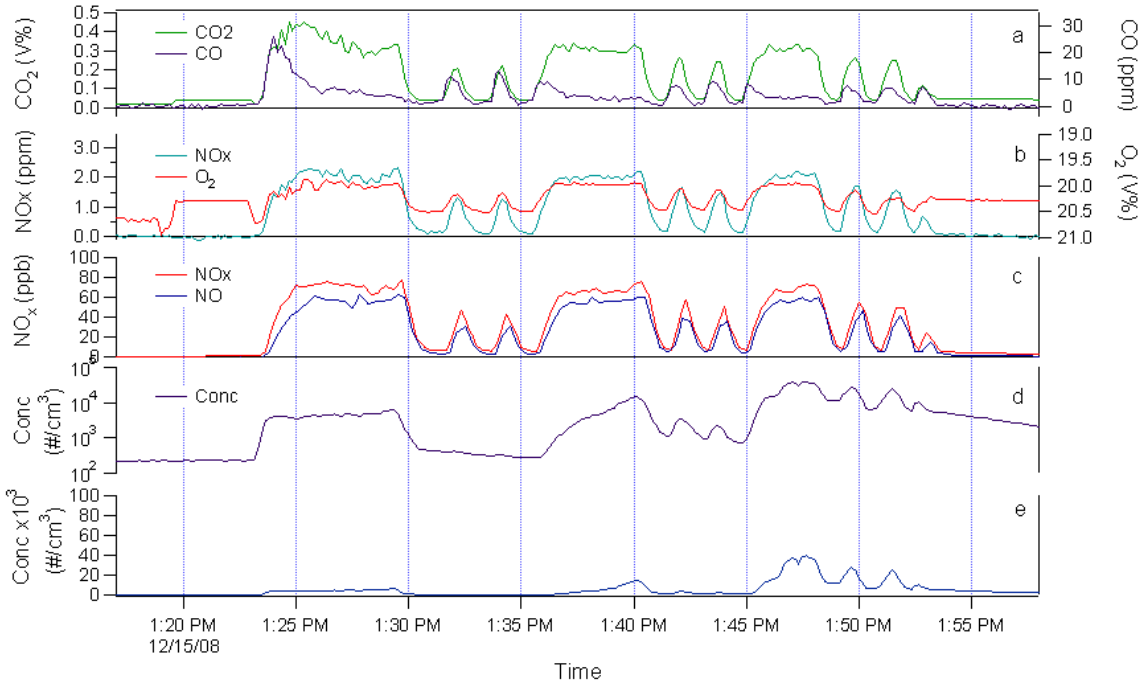

Figure 26. **Measured analyte concentrations for oven OV02 with PG&E line gas (L130).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 28. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for CO, PG250 NO and PN, September 2007.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L032	3A+N_2	1384	419	398	340	62	64	76	81	42	4900
L033	3A	1418	479	431	337	60	69	73	53	73	3100
L034	PG&E	1362	340	345	288	62	67	72	130	110	3200

Table 29. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for CO, PG250 NO_X and PN, December 2008.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO_X (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L127	1C	1390	199	160	153	83	100	99	150	130	440
L128	3C	1419	266	149	119	88	87	92	72	39	190
L129	PG&E	1334	168	109	97	85	87	94	63	60	270
L130	PG&E	1334	184	125	145	89	93	90	58	82	360

Table 30. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, September 2007.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L032	3A+N_2	1384	76	78	92	58	60	70	18	18	22
L033	3A	1418	75	84	87	55	62	69	20	22	17
L034	PG&E	1362	72	78	86	58	63	68	15	16	18

Table 31. Calculated air-free concentrations (using CO_2) over last 1 min of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, December 2008.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L127	1C	1390	83	100	99	66	81	79	17.4	18.8	19.4
L128	3C	1419	88	87	92	70	68	79	17.7	18.8	12.7
L129	PG&E	1334	85	87	94	71	76	83	13.9	10.9	10.7
L130	PG&E	1334	89	93	90	75	81	77	13.8	11.9	13.2

Table 32. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN, September 2007.

Exp.	Fuel	Wobbe	CO (μg KJ^{-1})			PG250 NO (μg KJ^{-1})			PN (10^7 KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L032	3A+N_2	1384	297	144	111	17.8	26	30	94	89	6300
L033	3A	1418	295	170	124	17.5	26	29	75	89	3600
L034	PG&E	1362	276	128	101	17.4	25	28	130	120	4000

Table 33. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN, December 2008.

Exp.	Fuel	Wobbe	CO (μg KJ^{-1})			PG250 NO_X (μg KJ^{-1})			PN (10^7 KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L127	1C	1390	83	66	56	32	43	45	190	260	970
L128	3C	1419	118	52	45	34	37	40	110	85	390
L129	PG&E	1334	81	54	49	31	37	39	110	99	460
L130	PG&E	1334	90	55	53	33	38	39	100	120	650

Table 34. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, September 2007.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L032	3A+N_2	1384	28	34	37	16.3	24	28	11.8	9.4	9.1
L033	3A	1418	27	35	37	16.4	24	27	10.3	10.8	9.6
L034	PG&E	1362	26	32	35	16.1	24	26	9.9	8.3	9.0

Table 35. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i, December 2008.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L127	1C	1390	32	43	45	24	34	35	8.5	9.2	9.3
L128	3C	1419	34	37	40	24	29	33	9.5	8.2	6.6
L129	PG&E	1334	31	37	39	23	31	33	7.9	6.0	6.0
L130	PG&E	1334	33	38	39	26	31	32	7.6	6.7	6.5

Table 36. Calculated formaldehyde emission rates over entire period of burner operation.

Exp.	Fuel	Wobbe	HCHO (μg KJ^{-1})
L127a[1]	1C	1390	0.64
L127b[1]	1C	1390	0.66
L128	3C	1419	0.68
L129	PG&E	1334	0.62
L130	PG&E	1334	0.52

[1] Duplicate samples collected for this experiment.

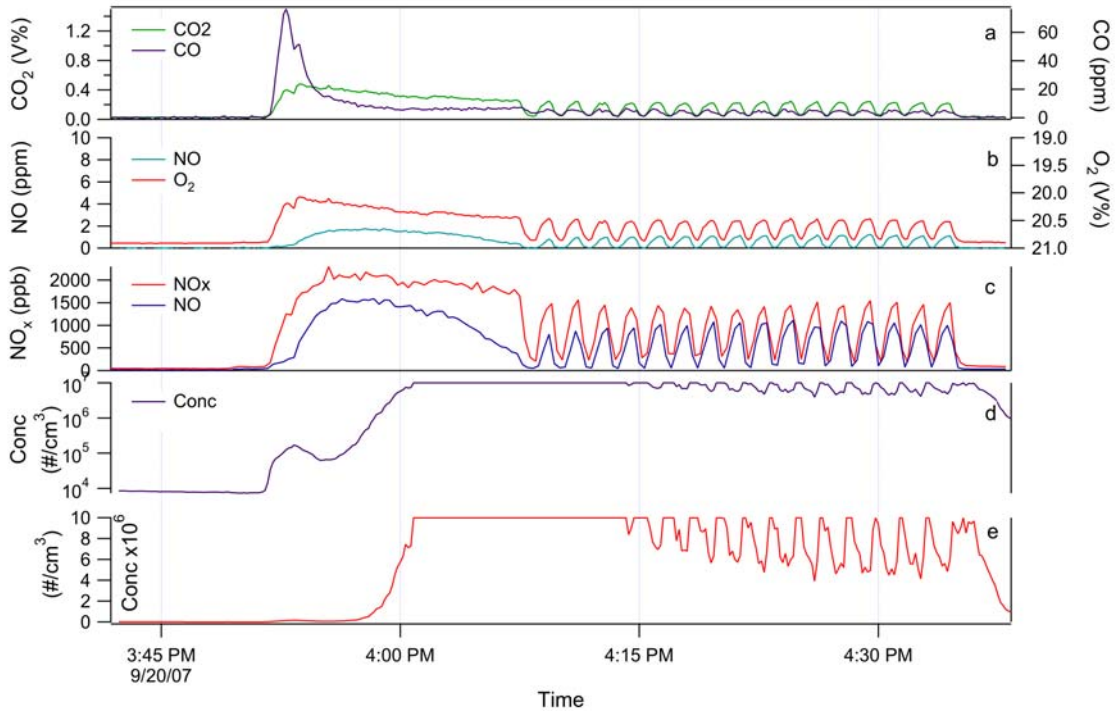

Figure 27. Measured analyte concentrations for oven OV02 with PG&E line gas, broiler protocol (L035).

Panels (a)-(b) present data measured with the Horiba PG-250 analyzer; panel (c) presents data from the Thermo NO_X analyzer (also from gas manifold) and panels (d)-(e) present measurements of particle number concentration. The dilution system was not used in this experiment. PN concentrations in the direct sample line were above the instrument range.

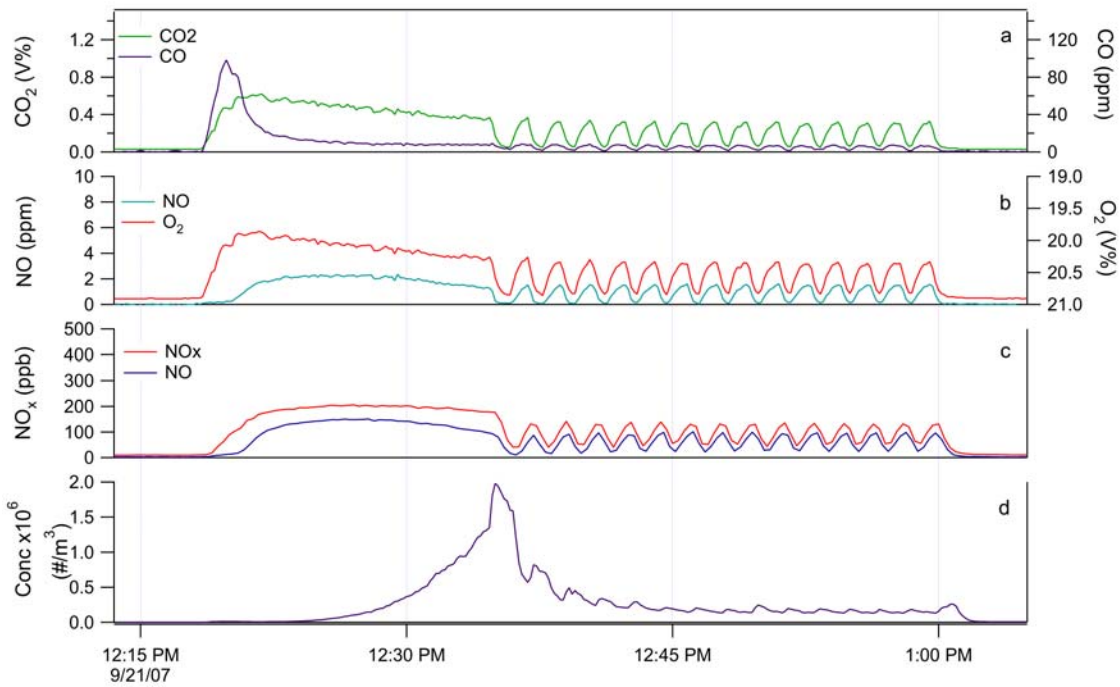

Figure 28. Measured analyte concentrations for oven OV02 with PG&E line gas, broiler protocol (L036).

Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. (d) displays particle number concentration.

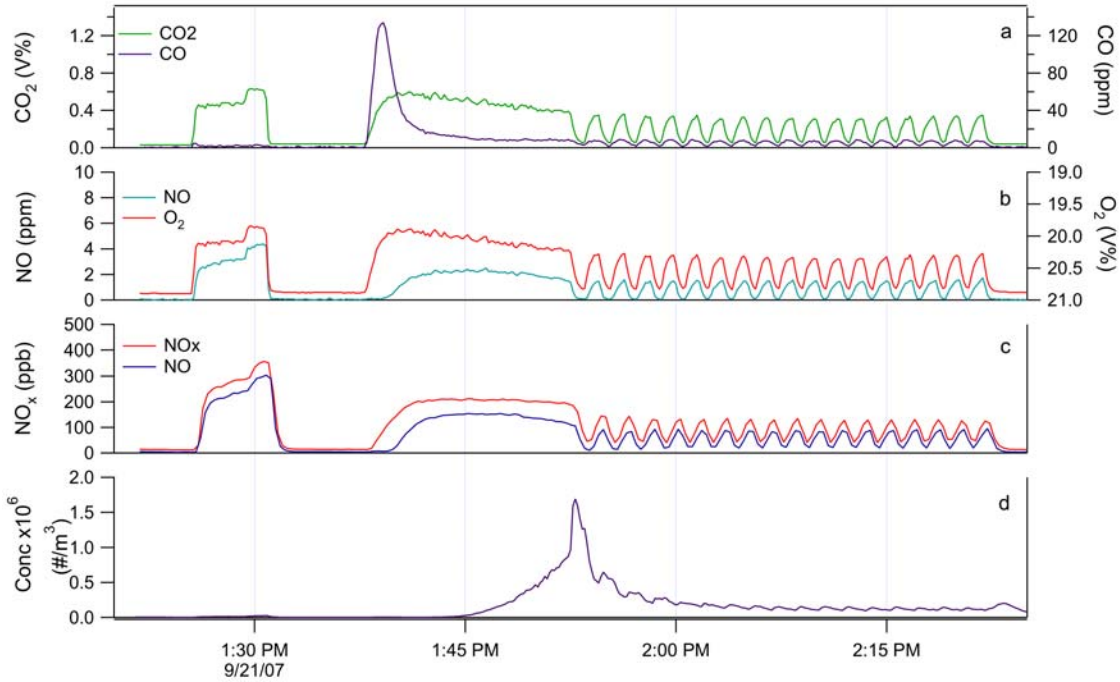

Figure 29. Measured analyte concentrations for oven OV02 with fuel 3A, broiler protocol (L037).

Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panel (d) displays particle number concentration.

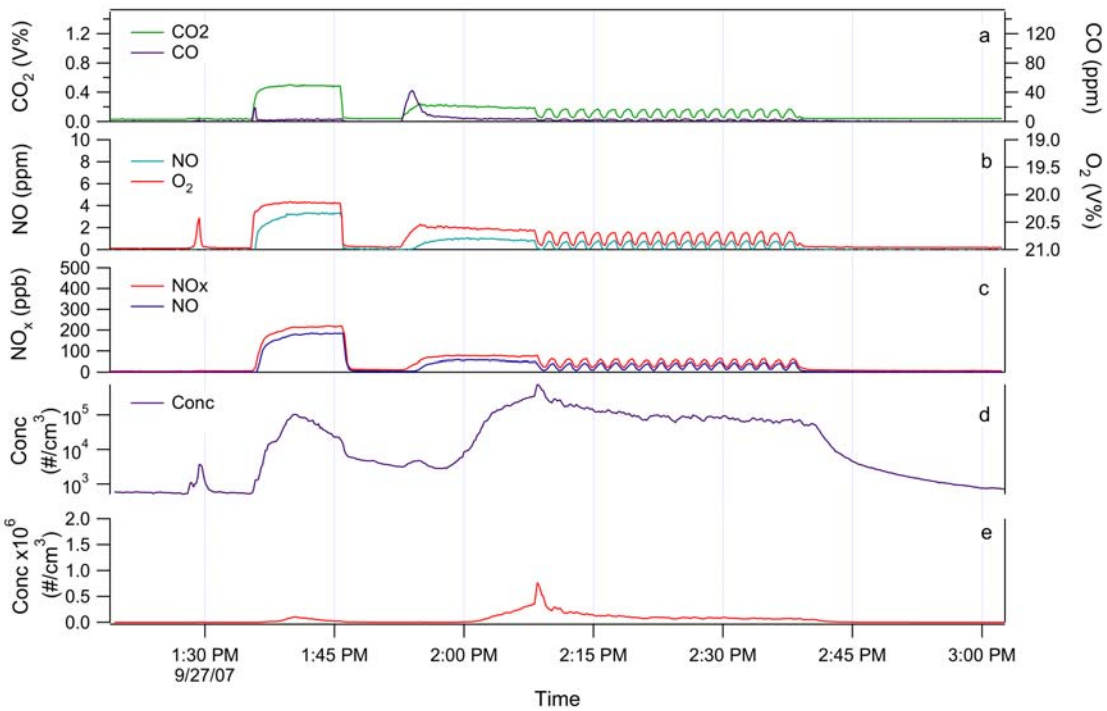

Figure 30. Measured analyte concentrations for oven OV02 with fuel 3A + N_2, broiler protocol (L038). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) display particle number concentrations.

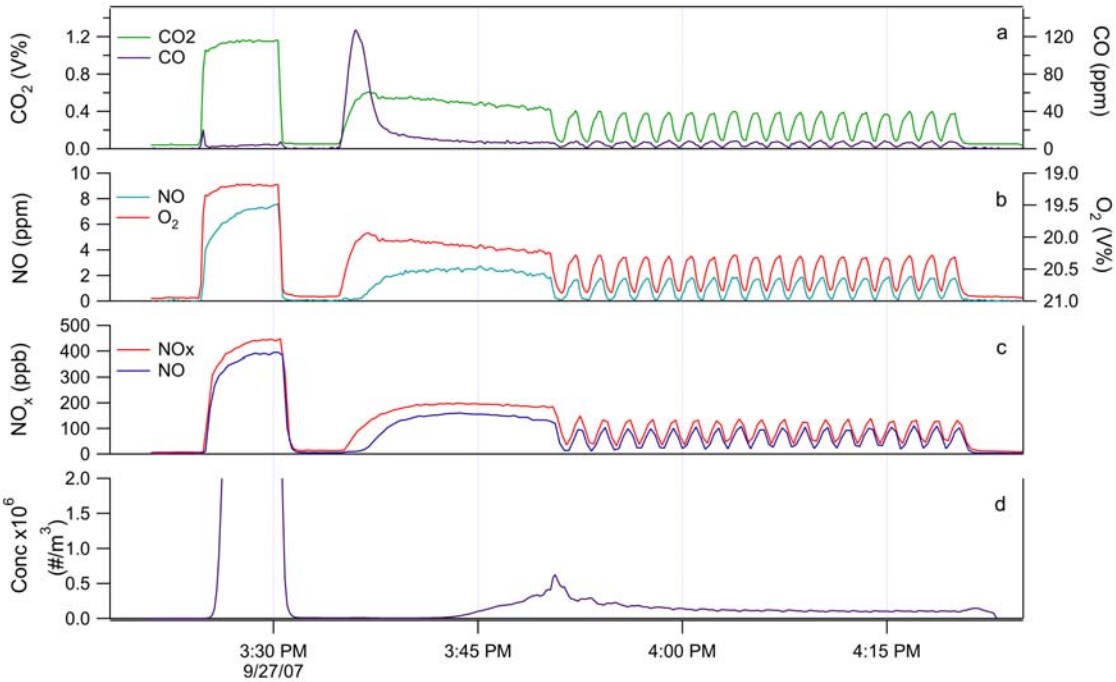

Figure 31. Measured analyte concentrations for oven OV02 with fuel 3A + N_2, broiler protocol (L039). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panel (d) displays particle number concentration. The peak just before 3:30 pm is a purge burn using the cook top.

Table 37. Calculated air-free concentrations (using CO_2) 10-15 min after start of each broil burn for OV02.

Calculation period selected to be consistent with later experiments featuring 15-min broil burns.

Exp	Fuel	Wobbe	CO (ppm)	PG250 NO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	PN (10^5 cm^{-3})
L035	PG&E	1362	284	53	86	48	38.2	4700
L036	PG&E	1348	242	59	83	59	24.4	2200
L037	3A	1418	246	59	83	59	24.8	2000
L038	3A+N2	1387	292	69	92	69	23.8	2300
L039	3A+N2	1387	204	67	84	67	17.0	860

Table 38. Calculated emission rates over 15 min of each broil burn for OV02.

Calculation period selected to be consistent with later experiments featuring 15-min broil burns.

Exp	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)	PG250 NO ($\mu g\ KJ^{-1}$)	NO_X ($\mu g\ KJ^{-1}$)	NO ($\mu g\ KJ^{-1}$)	NO_2 ($\mu g\ KJ^{-1}$)	PN (10^7 KJ^{-1})
L035	PG&E	1362	148	20	30	18	12.3	4300
L036	PG&E	1348	142	20	30	20	10.2	2500
L037	3A	1418	178	20	31	20	11.1	2600
L038	3A+N2	1387	163	25	35	25	10.6	2700
L039	3A+N2	1387	158	22	31	22	8.2	950

3.0 Oven OV03

3.1. Experimental information for OV03

Two sets of experiments were conducted on this burner. The first set, conducted on 9/4/2007 included experiments with PG&E line gas (WN=1332), fuel 3A undiluted (WN=1417) and fuel 3A diluted with N_2 (WN = 1385). A follow-up set of 4 experiments, conducted on 4/28/2008, included (in order) experiments with PG&E line gas (WN = 1320), fuel mix 3C (WN = 1419), fuel mix 1C (WN = 1390), and a replicate with PG&E line gas (WN = 1326). Included for reference is experiment L009 conducted during the range finding series in July 2007.

The following notes apply to the first set of experiments. Particle number concentrations were measured directly in the outlet stream from the collection hood and the Thermo NO_X analyzer measured from the gas sampling manifold alongside the PG-250 exhaust gas analyzer. It was determined in February 2008 that the critical orifices used in the aldehyde sampling trains had reduced flow at that time. OV03 experiments were conducted in September 2007 after the critical orifice flows were measured in June 2007. Flow rates were not measured during experiments. Aldehyde results are not presented owing to uncertainty in sample flow rates, concentrations, and emission rates.

The following notes apply to experiments in April 2008. The heater for the dilution sampler inlet was set to automatic mode. The SMPS was used to sample size-resolved particle number concentrations in the ultrafine mode (<100 nm particle diameter). Appliance manifold pressure was not measured because access was not possible without dismantling the internal fuel transfer lines. The temperature and RH in the glass sampling manifold was also not recorded. RH was relatively low (31-35%) but similar in all three experiments. For L089 (PG&E fuel), the oven was initially set to 300 F instead of 350 F. L092 included only the first temperature setting of 350 F to measure emissions for PG&E fuel at this temperature.

In the range finding experiment with line gas (L008, WN = 1329), particles were sampled via the dilution system. In this experiment the aerosol inlet heater was not functioning; the inlet was therefore heated only by the exhaust gas stream.

Table 39. Appliance and burner information.

Burner ID	OV03
Burner category	Oven
Burner technology	Tube burner under spreader-shaped bottom plate
Appliance manufacturer	Jenn-Air (Maytag)
Model	23650441ZD
Serial number	JGR8850ADW
Other information	30” self-cleaning range with waist-high burner and convection feature
Design manifold P	4 in. H_2O
Burner ratings (Btu/h)	18,000
Age (years)	<15 years (certified to 1993 ANSI standard)
Test location	Laboratory
History notes	Procured for $300, as advertised by owner on Craig’s List. No reason stated for sale. Oven showed evidence of some use from food spillage at bottom; cooktop very clean. Range purchased for convective oven.

Figure 32. Placement of OV03 burner; oven bottom plate and convection fan cover removed.

Figure 33. Underside of bottom plate showing spreader for OV03 bottom burner.

Table 40. Interchangeability experiments for oven OV03.

Exp.	Fuel	Date	Burner operation

L008	PG&E	07/03/07	Set to bake at 350°F for initial ramp + maintenance cycles (n=5 for L008; n=3 for L015-L017; n=2 for L089-L092); repeat at 425°F and 500°F. Use cooktop for purge burn when switching fuels.
L015	PG&E	09/04/07	
L016	3A+N_2		
L017	3A		
L089	PG&E	04/28/08	
L090	3C		
L091	1C		
L092	PG&E		

Table 41. Fuel analysis for interchangeability experiments with oven OV03 in September 2007.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L008	PG&E	n=3	95.95%	2.16%	0.09%	0.06%	0.97%	0.80%	1011	1329
L015	PG&E	-	95.91%	2.25%	0.15%	0.04%	0.84%	0.82%	1013	1332
L016	3A	pre	89.93%	5.88%	3.02%	1.17%	0.00%	0.00%	1127	1419
		post	90.55%	5.71%	2.70%	1.04%	0.00%	0.00%	1117	1414
L017	3A+N_2	pre	88.45%	5.88%	2.78%	1.08%	1.81%	0.00%	1103	1385
		post	88.42%	5.82%	2.81%	1.10%	1.85%	0.00%	1103	1384

[1] Calculated using the American Gas Association interchangeability program.

Table 42. Fuel analysis for interchangeability experiments with oven OV03 in April 2008.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L089	PG&E	L086	95.4%	2.29%	0.22%	0.06%	1.28%	0.76%	1012	1326
L090	3C	3C	86.4%	12.0%	1.60%	-	-	-	1125	1419
L091	1C	1C	92.0%	8.00%	-	-	-	-	1071	1390
L092	PG&E	L086	95.4%	2.29%	0.22%	0.06%	1.28%	0.76%	1012	1326

[1] Calculated using the American Gas Association interchangeability program.

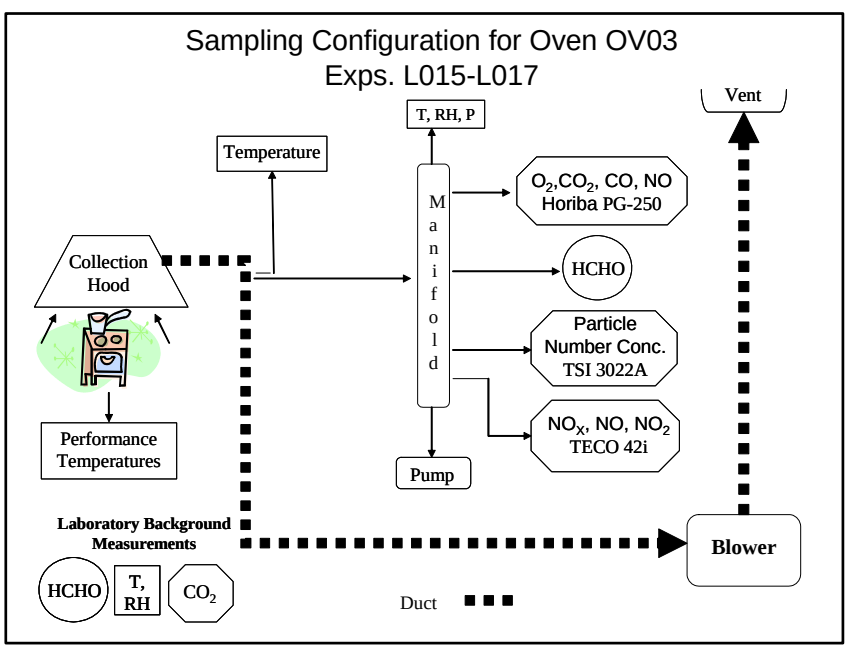

Figure 34. Pollutant sampling configuration for oven OV03 (Expts L015-L017).

Aerosol dilution system was not used in these experiments.

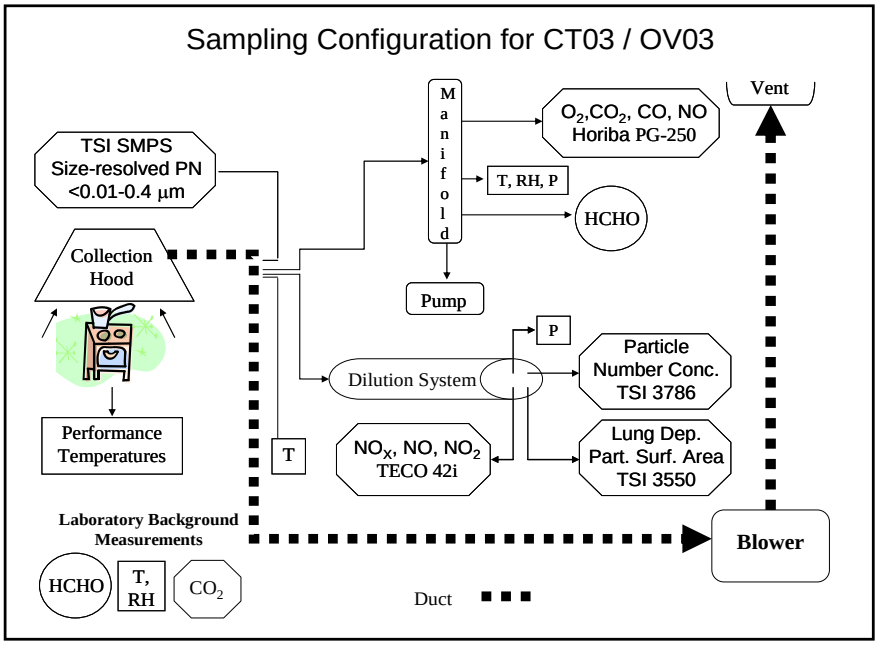

Figure 35. Pollutant sampling configuration for oven burner OV03, experiments L089-L092).
Set up for L008 was similar but did not include SMPS or TSI3550, and used CPC model 3022A.

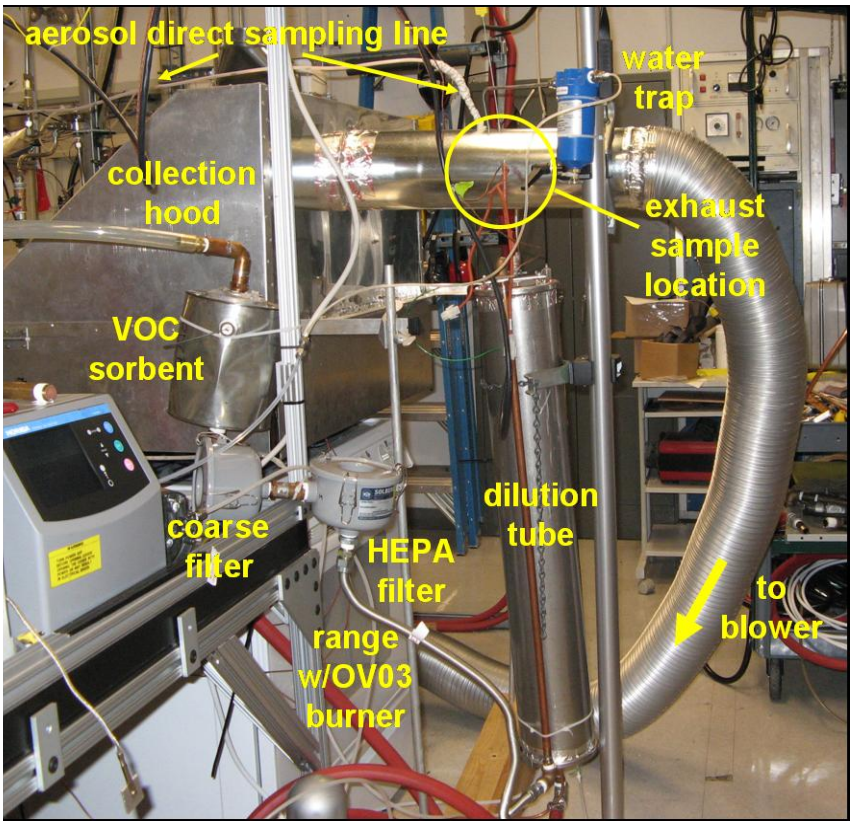

Figure 36. Laboratory installation and sampling configuration of range featuring oven OV03 (Expts L015-L017).

Table 43. Analyte ranges and calibration levels for experiments with cooktop OV03.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-10%	0, 0.77%[4] 0, 1.0%[5]
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-500 ppm[5] 0-200 ppm[6]	0, 50 ppm[4] 0, 40 ppm[5]
Nitrogen oxide(s): NO[5], NO_X[6]	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 5.0 ppm[3,4] 0, 2.4 ppm[5]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-10 ppm[5] 0-5 ppm[6]	0, 5.0 ppm[3,4] 0, 2.4 ppm[5]
Carbon dioxide (CO_2)	ambient air in laboratory	PPSystems EGM-4	5000 ppm	factory calibrated; check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold. [2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com); PP Systems, Amesbury, MA (ppsystems.com). [3] Calibrated from mixture of NO in N_2.
[4] Experiments L013-L022. 5 Expts L086-L088.

Table 44. Aerosol instrumentation used for oven OV03, experiments L008, L015-L017.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3022A CPC	Draw sample via 2.2 m × 0.48 cm ID conductive tubing[3]; L008: dilution tube L015-L017: direct from hood outlet	7 nm	10^7 cm^{-3}	±12% to 5×10^5 cm^{-3}; ±20% at $>5\times10^5$ cm^{-3}

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature.
[2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm.
[3] Product 3001788, purchased from TSI.

Table 45. Aerosol instrumentation used for CT03 experiments L089-L092.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
Surface area of particles (SA) depositing in lung alveolar region[4]	TSI 3550 nanoparticle surface area monitor	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	10 nm	10^5 um^2 cm^{-3}	±20% at 20-200 um^2 cm^{-3}
TSI SMPS: 3071A classifier, 3025A ultrafine CPC	PN resolved by size (aerodynamic diameter)	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature. [2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm. [3] Product 3001788, purchased from TSI. [4] Monitor has settings available for tracheobronchial (TB) or alveolar (A) regions; specifications are provided for the alveolar option which is being used in this study.

Table 46. Other measurements for experiments with oven OV03.

Measured Quantity	Location(s)	Device(s)[1]
Fuel pressure	Gas supply line	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Fuel volume & flow (2007 expts only)	Just upstream of appliance in lab	Singer DTM-115 calibrated against AC-250-TC
Dilution sampler vacuum	Dilution tube (Expt L008 only; no dilution tube Expts L015-L017)	Setra Model 264 transducer
Gas sampling manifold P (2007 expts only)	Gas sampling manifold	Magnehelic gauge
Temperature, combustion air	Air temperature near appliance	Precision NTC thermistor (APT)
Relative humidity, combustion air	Air temperature near appliance	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in duct	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, oven	Oven interior, shelf middle at lowest, highest positions	Thermocouple (K), screw-mount, Omega XCIB-K-4-2-3

[1] APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com);

American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com)

3.2. Results for OV03

Each set of experiments produced similar trends of emissions varying with fuel Wobbe number. CO full burn emission factors increase by roughly a factor of 2 between PG&E line gas and the 13985-1390 WN fuels. Full burn CO emissions increased another 50-80% between these fuels and the 1420 WN fuels (3A and 3C). CO end of burn concentrations were several times higher with the 1420 WN fuels relative to line gas. NO_X concentrations and emissions varied as much between replicate experiments and burns with PG&E line gas as between burns with different fuels. PN emissions were much higher during the earliest experiment (L008) compared with later experiments, and PN emissions during the first burn of the earliest experiment (530×10^7 KJ^{-1}) were an order of magnitude higher than during the other two burns ($60\text{-}80 \times 10^7$ KJ^{-1}) for this experiment. Full-burn PN emissions for the other experiments were in the range $3\text{-}34 \times 10^7$ KJ^{-1}, with no clear trend by fuel WN. NO_X emissions increased with oven temperature within each experiment. Directly measured NO_X varied by less than 10% as a function of fuel for the first set of experiments; variability was even lower for the second set of experiments. Side-by-side measurements of NO with the Horiba and Thermo instruments yielded substantially different values for both end-of-burn and full-burn periods; the cause of this difference is undetermined.

During L008-L015, full burn emission rates were 40-240 ng/J for CO, 33-37 ng/J for direct NO_X, and 3-530 x 10^4 J^{-1} for PN. During L089-L092, full burn emission rates were 30-180 ng/J for CO, 34-43 ng/J for direct NO_X, and 37-140 x 10^4 J^{-1} for PN. Full-cycle HCHO emission rates were 0.39-0.46 μg KJ^{-1}.

Table 47. Burner operating parameters for experiments with oven OV03, September 2007. Information provided for burner firings to achieve each new temperature setting.

Exp.	Duration of initial burn at T setting (min)			Firing rate[1] during initial burn at T setting (kBtu/h)			Manifold pressure[2]
	350 F	425 F	500 F	350 F	425 F	500 F	(in. H_2O)
L008	18.4	18.1	17.9	18.6	18.3	18.1	NA
L015	18.2	18.2	18.4	18.4	18.4	18.7	NA
L016	17.7	17.4	17.4	19.9	19.6	19.6	NA
L017	17.4	17.2	17.0	19.2	18.9	18.7	NA

[1] Fuel flow rate ft^3 h^{-1} calculated from measured fuel use over period of burner operation; firing rate calculated from measured fuel flow rate and higher heating value from fuel composition.

[2] Manifold pressure could not be accessed/measured without dismantling the appliance internal gas supply line.

Table 48. Burner operating parameters for experiments with oven OV03, April 2008.

Experiment	Burn	Start Time	End Time	Fuel Flow[1] ($ft^3\ h^{-1}$)	Firing Rate[1] (kBTU h^{-1})	Supply P (in. H_2O)	Appliance Manifold P (in. H_2O)[2]
L089	300F	12:41	12:48	NA	NA	7.7	NA
L089	425F	13:10	13:16	16	16	7.6	NA
L089	500F	13:31	13:36	18	18	7.7	NA
L090	350F	14:29	14:36	16	18	7.9	NA
L090	425F	14:53	14:57	16	17	8.0	NA
L090	500F	15:11	15:16	NA	NA	8.0	NA
L091	350F	16:06	16:13	18	19	8.0	NA
L091	425F	16:31	16:35	20	21	8.0	NA
L091	500F	16:50	16:55	19	20	8.0	NA
L092	350F	17:33	17:41	17	18	7.6	NA

[1] Fuel flow rate $ft^3\ h^{-1}$ estimated by stopwatch timing of ¼-foot dial on calibrated gas meter; NA indicates burn for which no gas measurements were made. Firing rate calculated from fuel flow rate and higher heating value from fuel composition. Gas volume counter did not function properly during these experiments.
[2] Appliance manifold pressure readings not taken.

Table 49. Environmental conditions[1] for experiments with oven OV03.

Exp.	T (°C)[2]	RH (%)[2]
L008	23.1 ± 0.1	53 ± <1
L015	22.5 ± 0.3	67 ± 1
L016	22.8 ± 0.4	63 ± <1
L017	23.9 ± 0.2	60 ± <1
L089	23.8 ± 0.4	43 ± 1
L090	24.5 ± 0.3	41 ± 1
L091	24.9 ± 0.3	40 ± 1
L092	25.1 ± 0.2	39 ± <1

[1] Measured over period of formaldehyde sampling.

Table 50. Gas sampling manifold T, RH [1] for experiments with oven OV03.

Exp.	Gas manifold T (°C)			Gas manifold RH (%)		
	350 F	425 F	500 F	350 F	425 F	500 F
L008	25.8	25.4	25.5	76	70	70
L015	24.8	25.6	25.8	66	70	68
L016	25.2	25.6	26.0	70	70	70
L017	26.6	26.9	27.1	76	67	65

[1] Measured in gas sampling manifold over last min of each burn to achieve new temperature setting.

Table 51. Sample location temperatures and dilution ratios for each burn, April 2008 experiments.

	T at sample location in hood (°C)[1]			Dilution ratio[2]		
Exp.	350 F	425 F	500 F	350 F	425 F	500 F
L089	31 ± 0	41 ± 1	48 ± 0	19	20	19
L090	35 ± 1	43 ± 1	48 ± 0	19	19	20
L091	36 ± 0	43 ± 0	48 ± 0	18	18	19
L092	36 ± 1	- ± -	- ± -	17	-	-

[1] Measured in exhaust duct from collection hood alongside pollutant sampling inlets. Mean ± standard deviation measured over last min of each burn to achieve new temperature setting.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) over last min of each burn.

Table 52. Formaldehyde samples for experiments with oven OV03, April 2008.

Exp(s)	Location	Date	Sample start time	Sample end time	Air vol. (L)	Extract conc. (ng/µL)	Air conc.[1] (µg/m^3)
Bkg	Lab air	4/28/2008	11:53	17:06	348	0.816	4.7
L089	Glass Manifold		12:37:30	13:46:00	70	0.789	22.4
L090			14:25:00	15:28:00	65	0.709	21.8
L091			16:02:00	17:06:00	66	0.649	19.6

[1] Average formaldehyde concentration in the air drawn through the sampler; the effect of gas quality on formaldehyde emissions is indicated in a subsequent table.

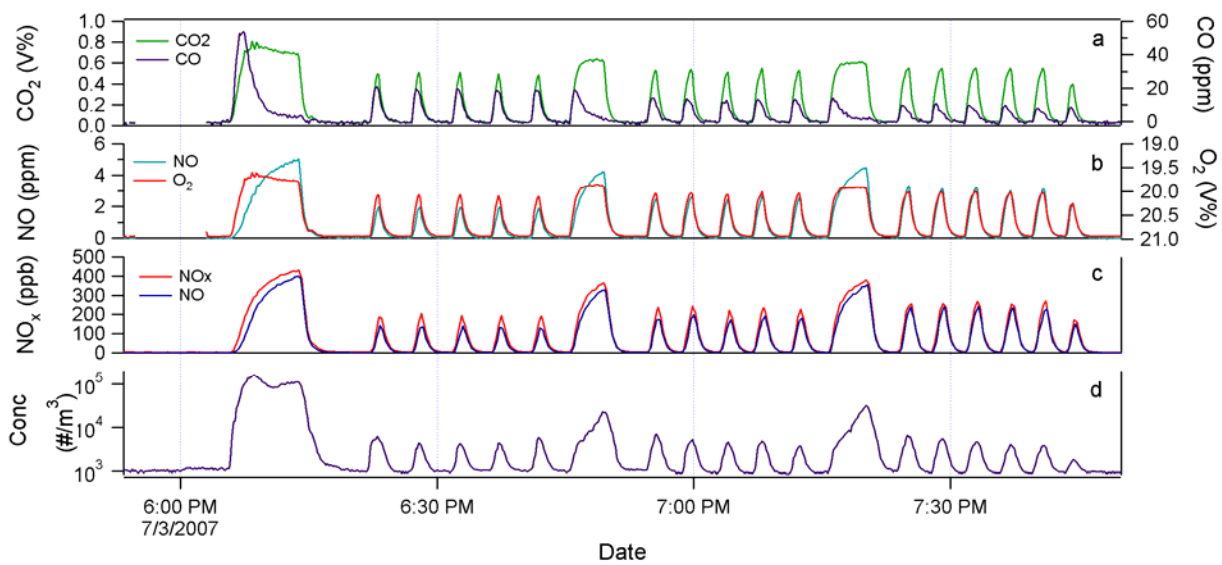

Figure 37. Measured analyte concentrations for oven OV03 with PG&E line gas (Exp. L008). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

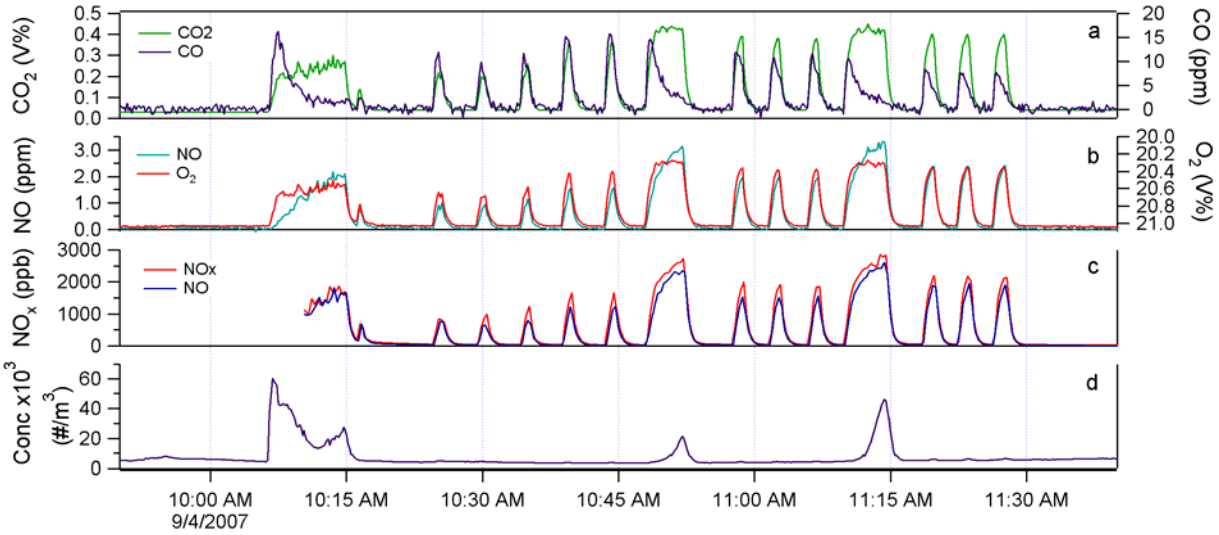

Figure 38. **Measured analyte concentrations for oven OV03 with PG&E line gas (Exp. L015).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood. The communication cable for the Thermo 42i was inadvertently disconnected during the first part of the experiment. Collection hood dilution flow was reduced between the 3rd and fourth maintenance cycle at 350 F.

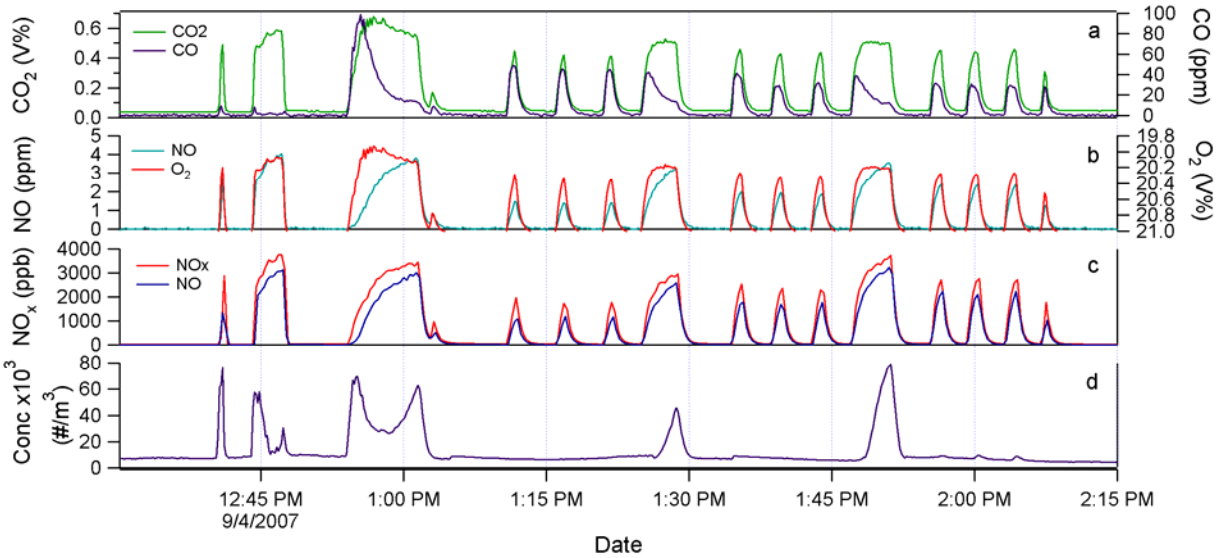

Figure 39. **Measured analyte concentrations for oven OV03 fuel 3A (Exp. L016).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood. The first two burns were for purging of gas lines.

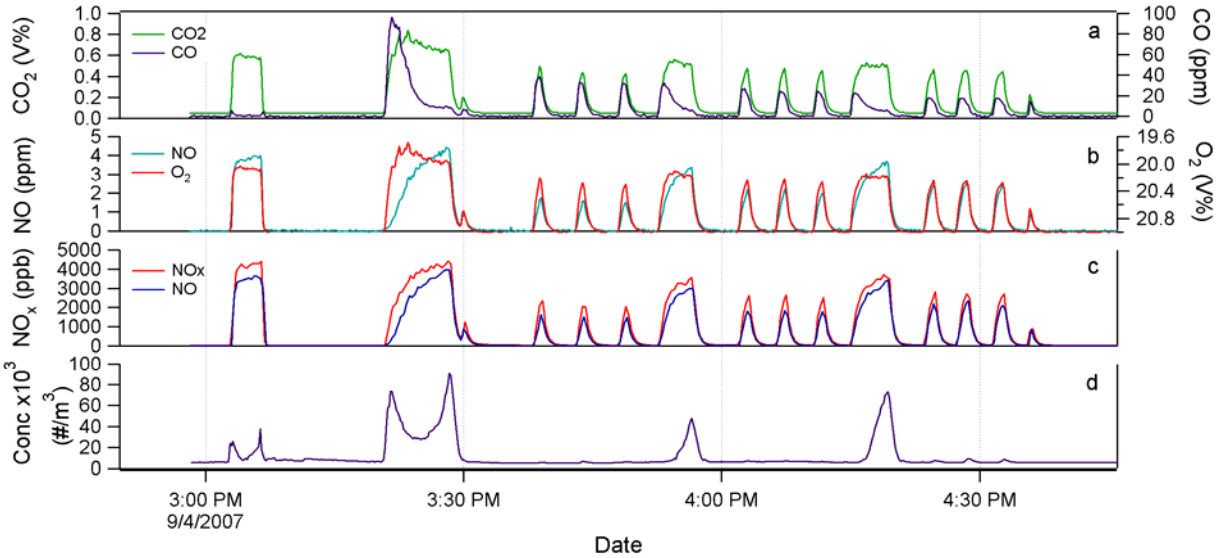

Figure 40. **Measured analyte concentrations for oven OV03 with fuel 3A + N_2 (Exp. L017).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panel (c) presents data from the Thermo 42i, also from the gas manifold. Particle number concentrations shown in pane (d) are direct from the outlet of the collection hood. The first burn was for the purpose of purging the gas lines.

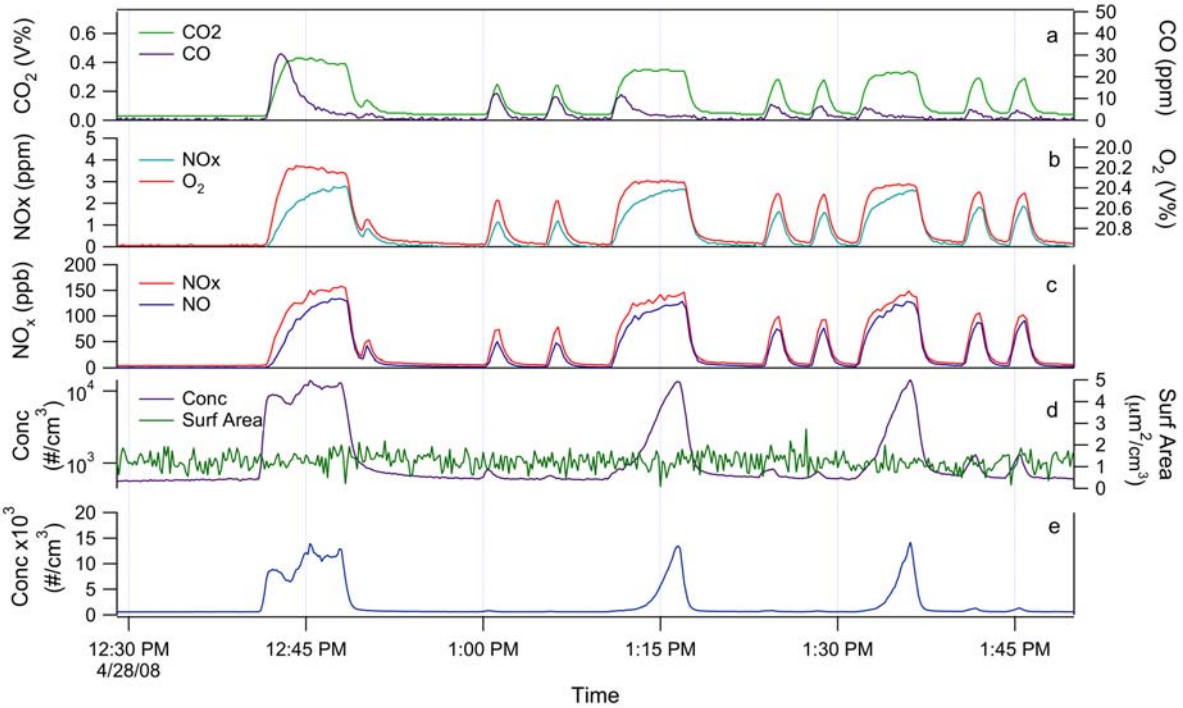

Figure 41. **Measured analyte concentrations for oven OV03 with PG&E line gas (L089).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

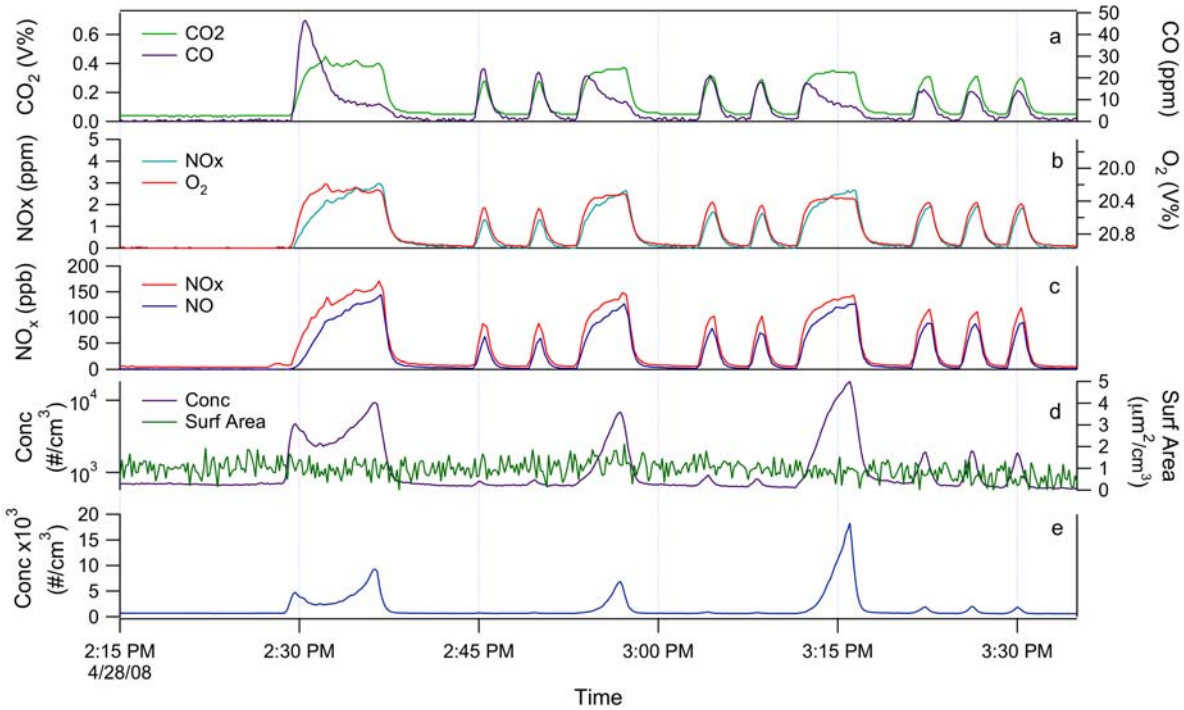

Figure 42. **Measured analyte concentrations for oven OV03 with fuel 3C (L090).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

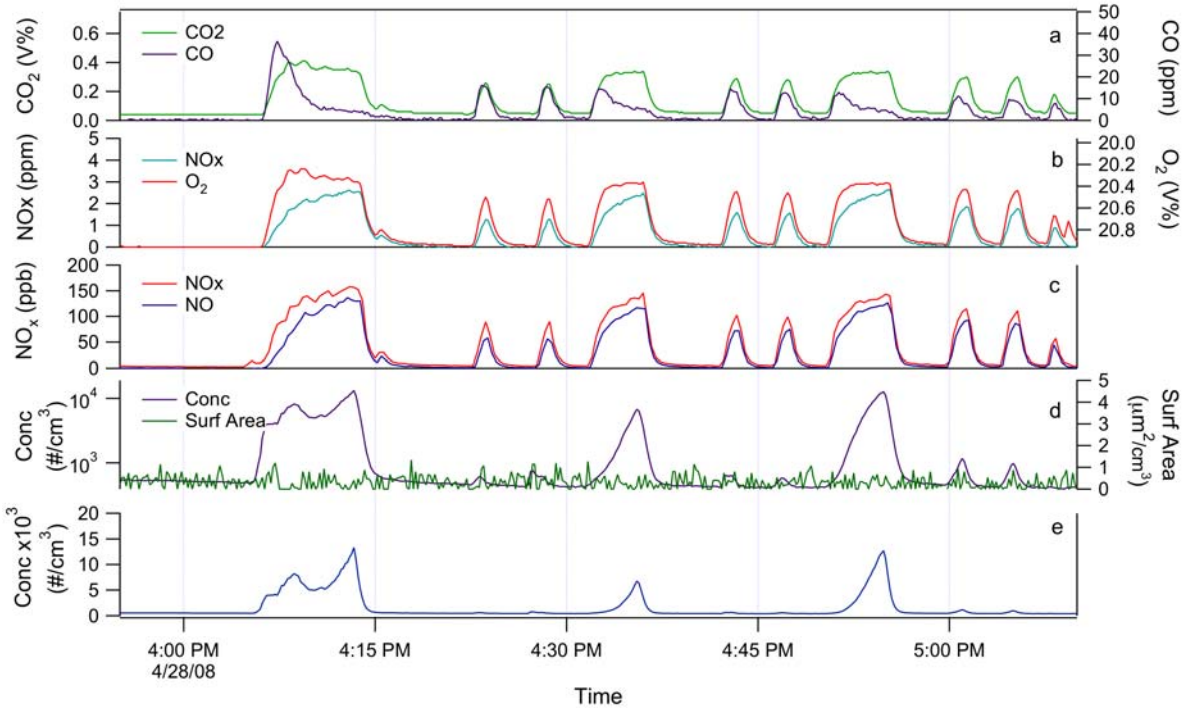

Figure 43. **Measured analyte concentrations for oven OV03 with fuel 1C (L091).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

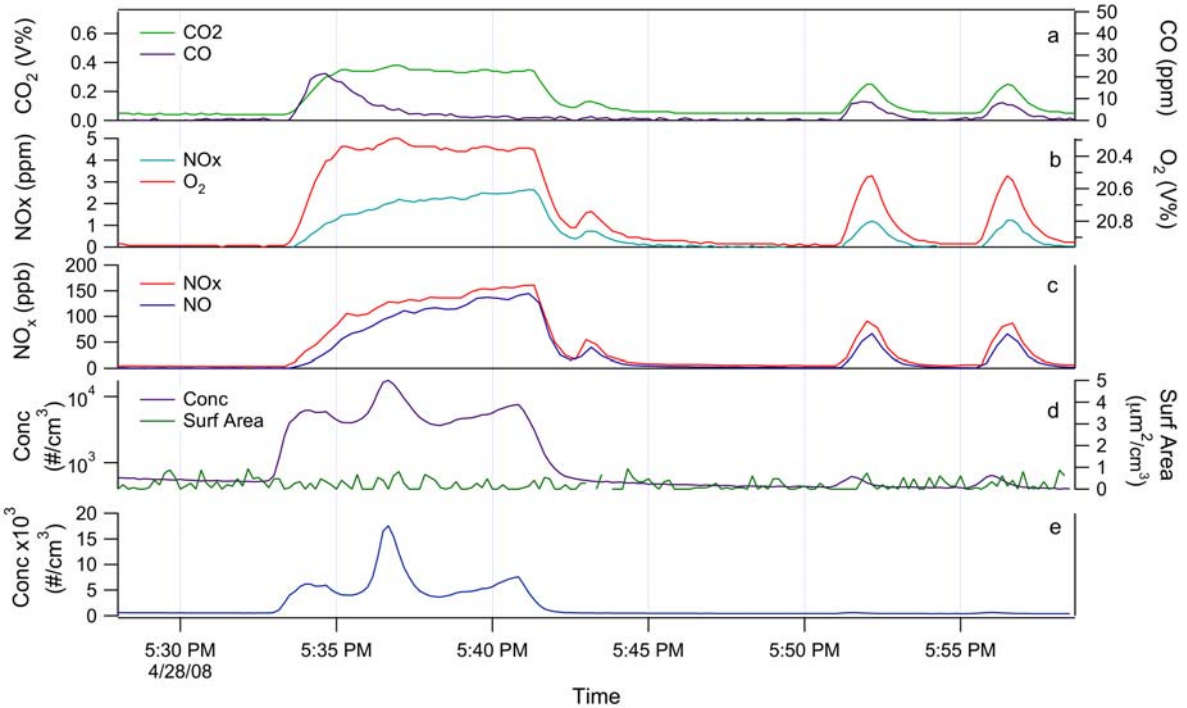

Figure 44. **Measured analyte concentrations for oven OV03 with PG&E line gas (L092).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

Table 53. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO_X and PN.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 $NO_{(X)}$ (ppm)[1]			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L008	PG&E	1329	65	70	48	89	82	92	240	34	58
L015	PG&E	1332	80	93	65	109	89	101	9.9	2.5	11
L016	3A	1417	337	363	311	86	80	90	11	7.4	17
L017	3A+N2	1385	179	164	146	85	82	93	13	7.5	15
L089[2]	PG&E	1328	94	61	56	95	107	108	73	86	84
L090	3C	1419	250	340	270	101	96	108	46	33	110
L091	1C	1390	160	230	190	104	99	106	71	31	80
L092	PG&E	1317	45	-	-	105	-	-	41	-	-

[1] PG250 measured NO during L008-L017, NO_X during L089-L092.
[2] For B1, oven set to 300 F not 350 F.

Table 54. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L008	PG&E	1329	97	90	98	89	82	92	7.9	8.6	6.6
L015	PG&E	1332	94	78	87	87	70	77	6.1	8.3	9.5
L016	3A	1417	78	73	93	69	63	81	9.8	9.9	12.3
L017	3A+N2	1385	84	84	93	78	74	85	6	10.2	8.5
L089[1]	PG&E	1328	95	107	108	86	100	101	9.1	6.9	7.1
L090	3C	1419	101	96	108	89	85	99	12.2	11.1	9.4
L091	1C	1390	104	99	106	92	86	98	12.5	12.8	8.8
L092	PG&E	1317	105	-	-	94	-	-	10.9	-	-

[1] For B1, oven set to 300 F not 350 F.

Table 55. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN.

Exp.	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)			PG250 $NO_{(X)}$ ($\mu g\ KJ^{-1}$) [1]			PN ($10^7\ KJ^{-1}$)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L008	PG&E	1329	87	50	37	28	31	35	530	56	77
L015	PG&E	1332	78	54	37	34	34	37	34	2.7	11
L016	3A	1417	238	182	157	25	30	33	19	9.6	21
L017	3A+N2	1385	171	111	82	24	30	34	18	8.8	18
L089[2]	PG&E	1328	109	46	29	34	41	43	140	75	92
L090	3C	1419	175	148	121	36	40	43	55	39	120
L091	1C	1390	135	105	84	37	40	43	97	37	88
L092	PG&E	1317	69	-	-	37	-	-	91	-	-

[1] PG250 measured NO during L008-L017, NO_X during L089-L092.
[2] For B1, oven set to 300 F not 350 F.

Table 56. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L008	PG&E	1329	33	36	39	28	31	35	5.4	4.9	4.3
L015	PG&E	1332	NA[2]	31	33	NA[2]	27	30	NA[2]	4.2	3.7
L016	3A	1417	27	30	37	20	24	31	6.7	6.2	6.2
L017	3A+N2	1385	29	33	37	22	27	31	6.9	6.1	5.4
L089[1]	PG&E	1328	34	41	43	28	36	40	6.1	4.3	3.0
L090	3C	1419	36	40	43	28	33	38	8.1	6.6	5.7
L091	1C	1390	37	40	43	29	34	38	8.1	6.6	5.3
L092	PG&E	1317	37	-	-	30	-	-	6.4	-	-

[1] For B1, oven set to 300 F not 350 F.
[2] The communications data for the Thermo 42i NO_X analyzer was disconnected for the first part of this run. See Figure with L015 data.

Table 57. Calculated formaldehyde emission rates over entire period of burner operation.

Exp.	Fuel	Wobbe	HCHO (μg KJ^{-1})
L089	PG&E	1328	0.46
L090	3C	1419	0.42
L091	1C	1390	0.39

4.0 Oven OV05

4.1. Experimental information for OV05

Experiments with PG&E line gas (WN = 1320), mix 1C (WN = 1389) and mix 3C (WN = 1419) were all conducted on the same day, and a replicate experiment was conducted for mix 1C. The heater for the dilution sampler inlet was set to automatic mode. The SMPS used to collect size-resolved particle number concentrations in the ultrafine mode (<100 nm particle diameter). Appliance manifold pressure was not measured because access was not possible without dismantling the internal fuel transfer lines.

Table 58. Appliance and burner information OV05.

Burner ID	OV05
Appliance manufacturer	Frigidaire (Electrolux)
Model number	F1F316BSA
Serial number	VF31227072
Design manifold P	4” H_2O (original factory setting based on label)
Age (years)	~4 years at time of testing
Burner technologies	Hot surface ignition; single tube-type oven burner below bottom plate
Burner ratings (Btu/h)	18,000
Other information	Procured December 2007
Test location	Laboratory
History notes	Purchased from original owner, advertised on Craig’s List. Owner reported regular daily use of cooktop; less frequent use of oven (exact frequency not specified). Purchased new in 2003.

Figure 45. **Oven bottom burner OV05.**

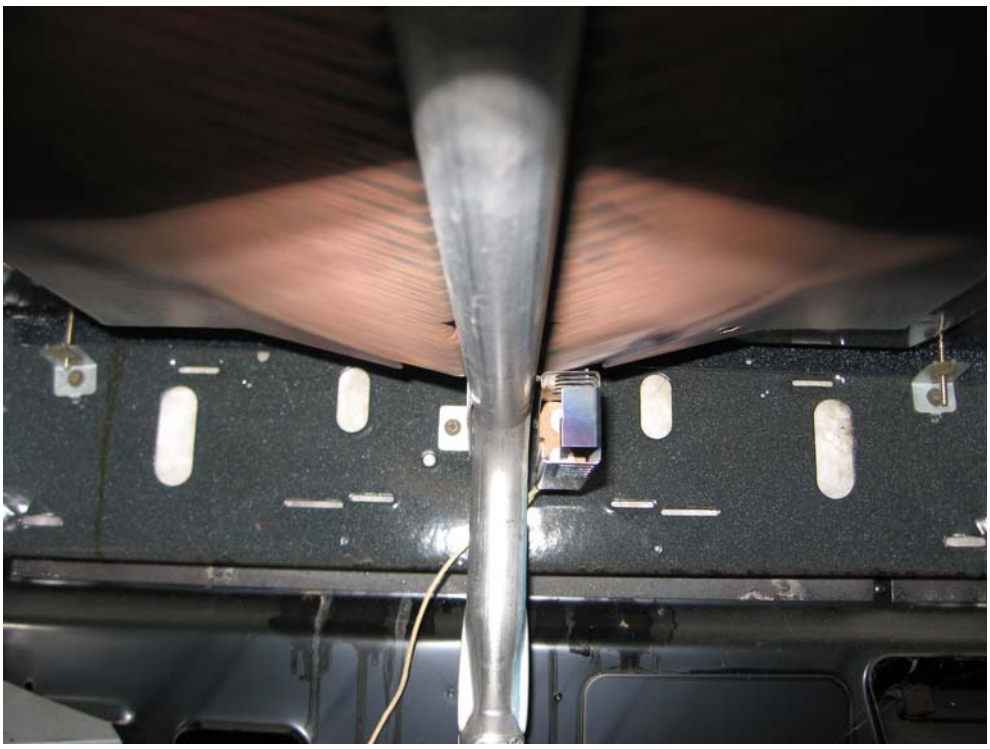

Figure 46. **Profile of spreader plate for oven bottom burner OV05.**

Table 59. Interchangeability experiments for oven bottom burner OV05.

Exp.	Fuel	Date	Burner operation
L073	PG&E	02/20/2008	Purge burn with each fuel change using cooktop burners. Operate oven through initial ramp plus 2 maintenance cycles at 350, 425 and 500F. Cool to touch between experiments.
L074	1C	02/20/2008	
L075	3C	02/20/2008	
L076	1C	02/20/2008	

Table 60. Fuel analysis for interchangeability experiments with OV05.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L073	PG&E	L073	94.5%	2.29%	0.39%	0.20%	1.85%	0.75%	1012	1320
L074	*Cont.*[3]								*1071*	*1389*
L075	3C	L075	86.4%	12.01%	1.56%	0.00%	0.00%	0.00%	1125	1419
L076	1C	L076	92.0%	7.97%	0.00%	0.00%	0.00%	0.00%	1071	1389

[1] Samples generally drawn from fuel supply line while burner is operating.
[2] Calculated using the American Gas Association interchangeability program.
[3] Sample contaminated; use results for L076 sample obtained from same cylinder.

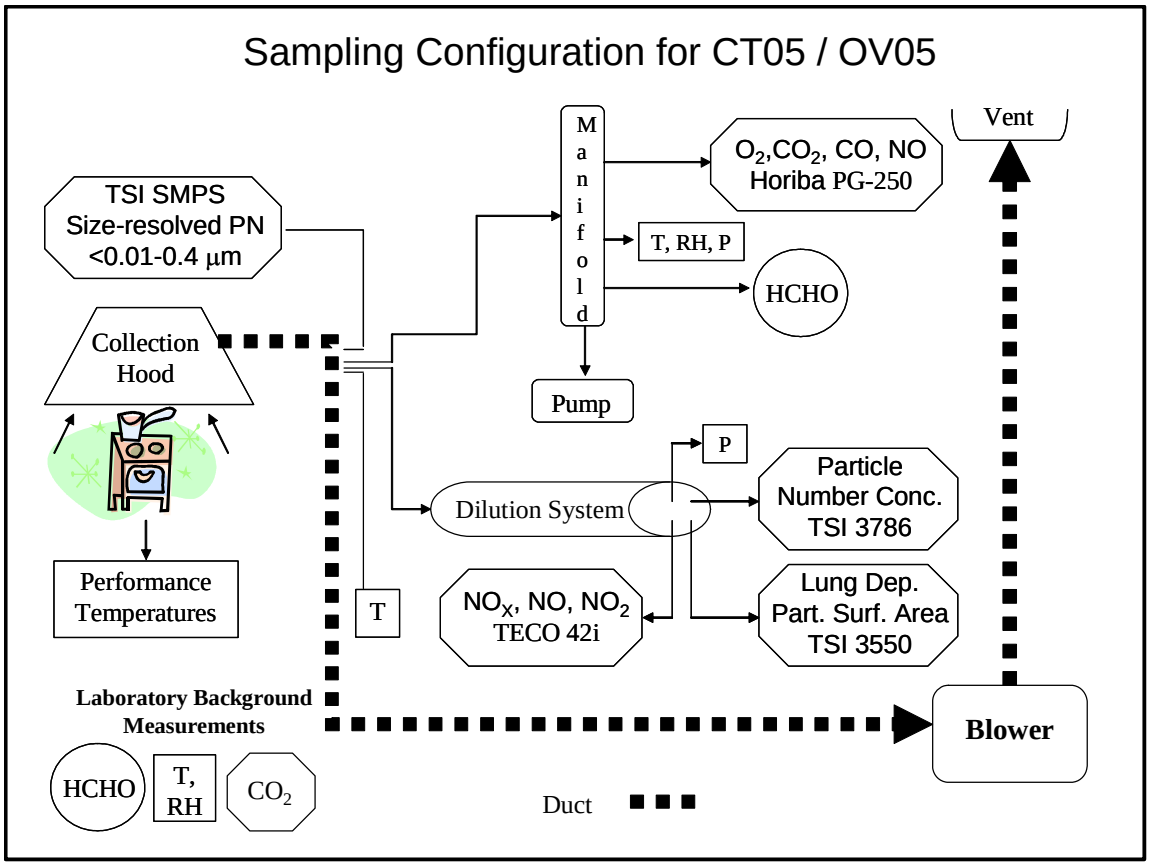

Figure 47. Analytical sampling configuration for CT05 / OV05.

Table 61. Analyte ranges and calibration levels for experiments with OV05.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-5%	0, 0.77%
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-200 ppm	0, 50 ppm
Nitrogen oxide (NO)	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 5.0 ppm[3]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 5.0 ppm[3]
Carbon dioxide (CO_2)	ambient air in laboratory	PPSystems EGM-4	5000 ppm	check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold. [2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com). [3] Calibrated from mixture of NO in N_2.

Table 62. Aerosol instrumentation used for CT05 / OV05.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
Surface area of particles (SA) depositing in lung alveolar region[4]	TSI 3550 nanoparticle surface area monitor	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	10 nm	10^5 um^2 cm^{-3}	±20% at 20-200 um^2 cm^{-3}
TSI SMPS[5]: 3071A classifier, 3025A ultrafine CPC	PN resolved by size (aerodynamic diameter)	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature.
[2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm.
[3] Product 3001788, purchased from TSI.
[4] Monitor has settings available for tracheobronchial (TB) or alveolar (A) regions; specifications are provided for the alveolar option which is being used in this study.
[5] SMPS used for experiments on Feb 8-12 (L064-L068).

Table 63. Other measurements for experiments with CT05 / OV05.

Measured Quantity	Location(s)	Device(s)[1]
Fuel pressure	Gas supply line Outlet of appliance regulator	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Fuel volume & flow	Just upstream of appliance in lab	Singer DTM-115 calibrated against AC-250-TC
Dilution sampler vacuum	Dilution tube	Setra Model 264 transducer
Temperature, combustion air	In vicinity of range	Precision NTC thermistor (APT)
Relative humidity, combustion air	In vicinity of range	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in hood	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, water	Inside pots, cooktop	Thermocouple (K), probe, Omega KQSS-18E-12

[1]APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com); American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com).

4.2. Results for OV05

CO concentrations and emissions were the highest during the initial burn – heating to 350 F – in each experiment, with a large peak occurring at ignition. For PG&E line gas, end of burn (last 1 min) air-free CO concentrations were 570, 470 and 390 ppm for burns at 350, 425 and 500 F, respectively. Both end of burn concentrations and full-burn emission rates increased with fuel Wobbe number; this increase occurred at each temperature setting. Full-burn CO emission rates increased by more than 50% between line gas and fuel 3C. Full-burn emission rates for NO_X were similar for all fuels. For each fuel, PN concentrations and emissions were highest during the 500 F burn. PN emissions were highest during the first experiment (with line gas) and decreased with successive experiments. During the first experiment only, substantial emissions were observed during the 350 and 425 F burns; in subsequent experiments, exhaust PN concentrations during these periods were below background levels. Full cycle formaldehyde emission rates increased with fuel Wobbe number in rough proportion to the observed CO increase. For all pollutants, very similar concentrations and emissions were observed in the replicate experiments with fuel 1C. Full burn emission rates were 210-350 ng/J for CO (350 F setting; highest for CO), 33-35 ng/J for NO_X (500 F setting; highest for NO_X), 83-210 x 10^4 J^{-1} for PN at 500 F setting, and 0.43-0.65 ng/J for HCHO.

Table 64. Burner operating parameters for experiments with oven OV05. Information provided for first burner firing at each temperature setting.

Experiment	Burn	Start Time	End Time	Fuel Flowrate ($ft^3\ h^{-1}$)	Firing Rate ($kBTU\ h^{-1}$)	Supply P (in. H_2O)	Appliance Manifold P (in. H_2O)[2]
L073	350F	10:58	11:06	18	18	7.5	NA
L073	425F	11:14	11:19	16	16	7.5	NA
L073	500F	11:30	11:38	17	17	7.5	NA
L074	350F	12:24	12:30	18	19	7.4	NA
L074	425F	12:38	12:43	16	17	7.4	NA
L074	500F	12:54	13:01	17	18	7.4	NA
L076	350F	15:13	15:20	18	19	7.3	NA
L076	425F	15:28	15:33	16	17	7.3	NA
L076	500F	15:43	15:51	17	18	7.3	NA
L075	350F	13:47	13:54	18	20	7.3	NA
L075	425F	14:02	14:06	16	18	7.4	NA
L075	500F	14:13	14:20	17	19	7.3	NA

[1] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over period of burner operation; firing rate calculated from fuel flow rate and higher heating value from fuel composition; calculation is for initial burn to reach 350 F.
[2] Appliance manifold pressure readings not taken.

Table 65. Environmental conditions[1] for experiments with OV05.

Exp.	Fuel	T (°C)	RH (%)
L073	PG&E	20.9 ± 0.2	49 ± 1
L074	1C	20.4 ± 0.1	48 ± 0
L076	1C	20.5 ± 0.1	47 ± 1
L075	3C	20.7 ± 0.4	47 ± 1

[1] Measured over period of formaldehyde sample.

Table 66. Sampling system conditions[1] for experiments with bottom oven burner OV05.

Exp.	Gas manifold T (°C)			Gas manifold RH (%)		
	350 F	425 F	500 F	350 F	425 F	500 F
L073	21.1 ± 0	21.4 ± 0	21.3 ± 0	87 ± 1	77 ± 0	75 ± 0
L074	20.8 ± 0	20.7 ± 0	20.7 ± 0	82 ± 0	78 ± 1	76 ± 0
L076	20.3 ± 0	20.5 ± 0	20.7 ± 0	84 ± 0	77 ± 0	73 ± 1
L075	20.8 ± 0	20.7 ± 0	20.8 ± 0	83 ± 1	77 ± 0	74 ± 1

[1] Measured in gas sampling manifold over last min of each burn to achieve new temperature setting. Mean ± standard deviation.

Table 67. Sample location temperatures and dilution ratios for each burn.

	Sample location T (°C)[1]			Dilution ratio[2]		
Exp.	350 F	425 F	500 F	350 F	425 F	500 F
L073	39 ± 1	47 ± 0	53 ± 0	26	30	32
L074	40 ± 1	46 ± 0	52 ± 0	28	28	29
L076	38 ± 1	46 ± 0	52 ± 0	27	28	30
L075	38 ± 1	46 ± 0	52 ± 0	26	29	28

[1] Measured in exhaust duct from collection hood alongside pollutant sampling inlets. Mean ± standard deviation measured over last min of each burn to achieve new temperature setting.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) over last min of each burn.

Table 68. Formaldehyde samples for experiments with oven OV05.

Exp(s)	Location	Date	Sample start time	Sample end time	Air vol. (L)	Extract conc. (ng/µL)	Air conc.[1] (µg/m^3)
Bkg	Lab air	2/20/2008	10:56	16:02	304	0.573	3.76
L073	Glass Manifold	2/20/2008	10:56	11:53	54	1.092	40.5
L074			12:20	13:12	49	1.049	42.4
L075			13:45	14:31	43	1.271	58.5
L076			15:10	16:02	52	1.173	45.5

[1] Average formaldehyde concentration in the air drawn through the sampler; the effect of gas quality on formaldehyde emissions is indicated in a subsequent table.

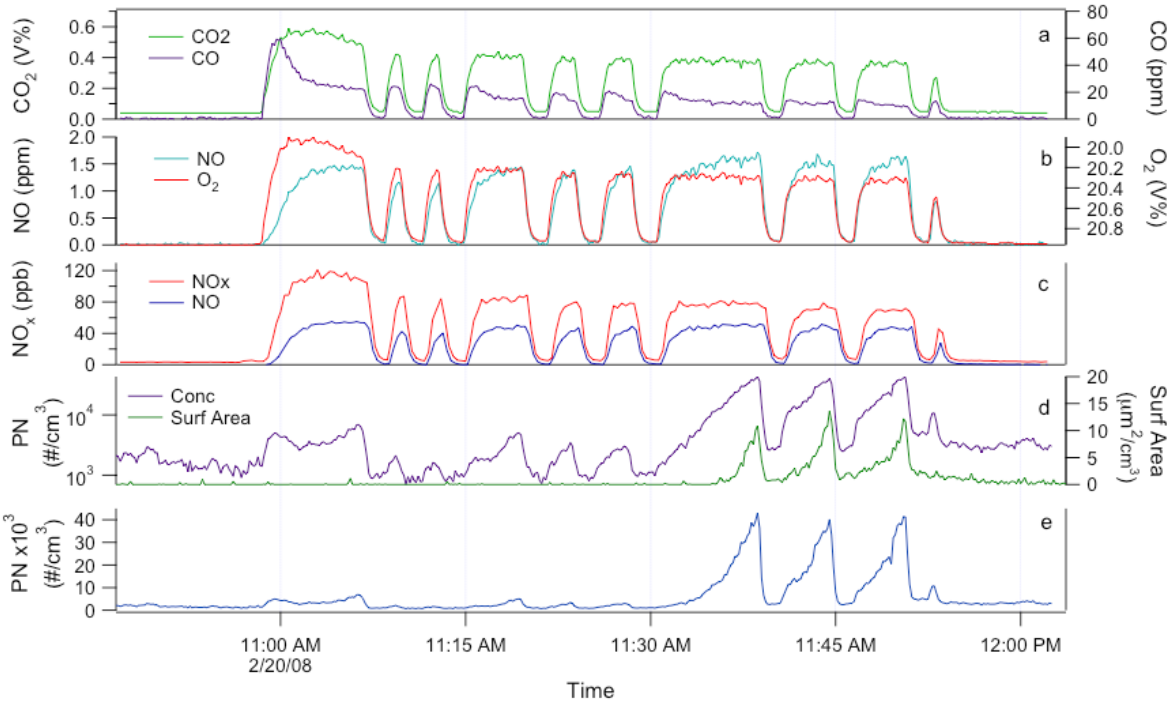

Figure 48. Measured analyte concentrations for oven OV05 with PG&E line gas (L073).

Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

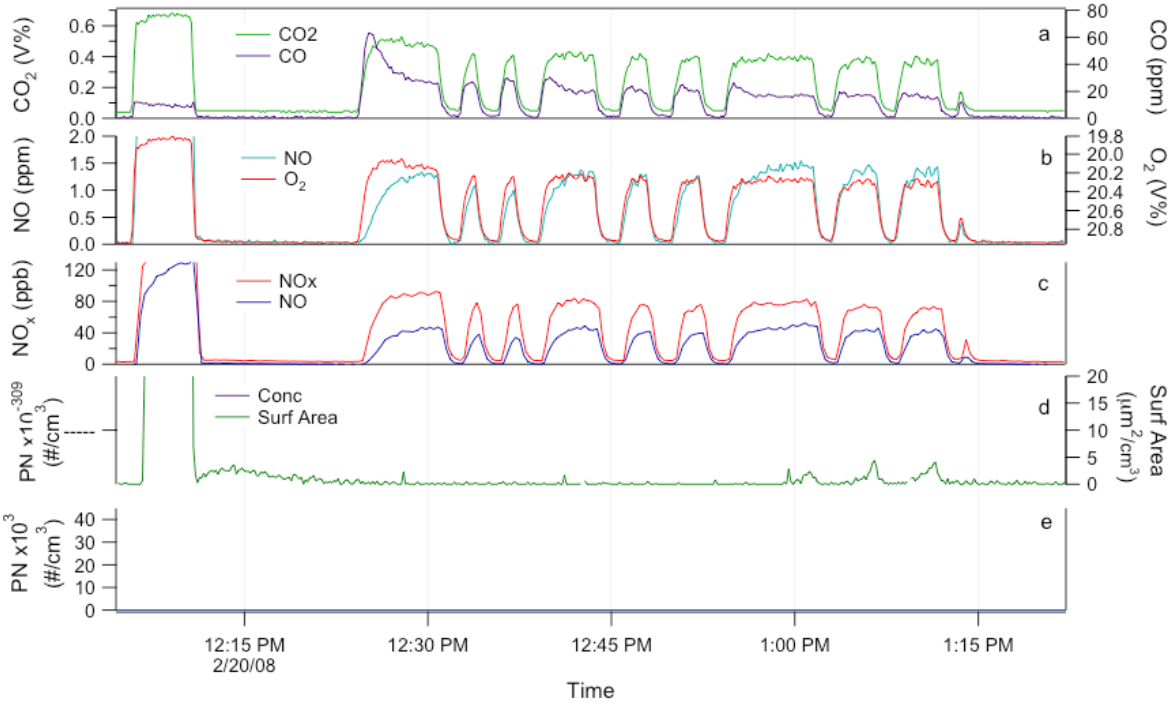

Figure 49. **Measured analyte concentrations for oven OV05 with fuel 1C (L074).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. The peak prior to Burn 1 is a purge burn. PN instrument failed during this experiment.

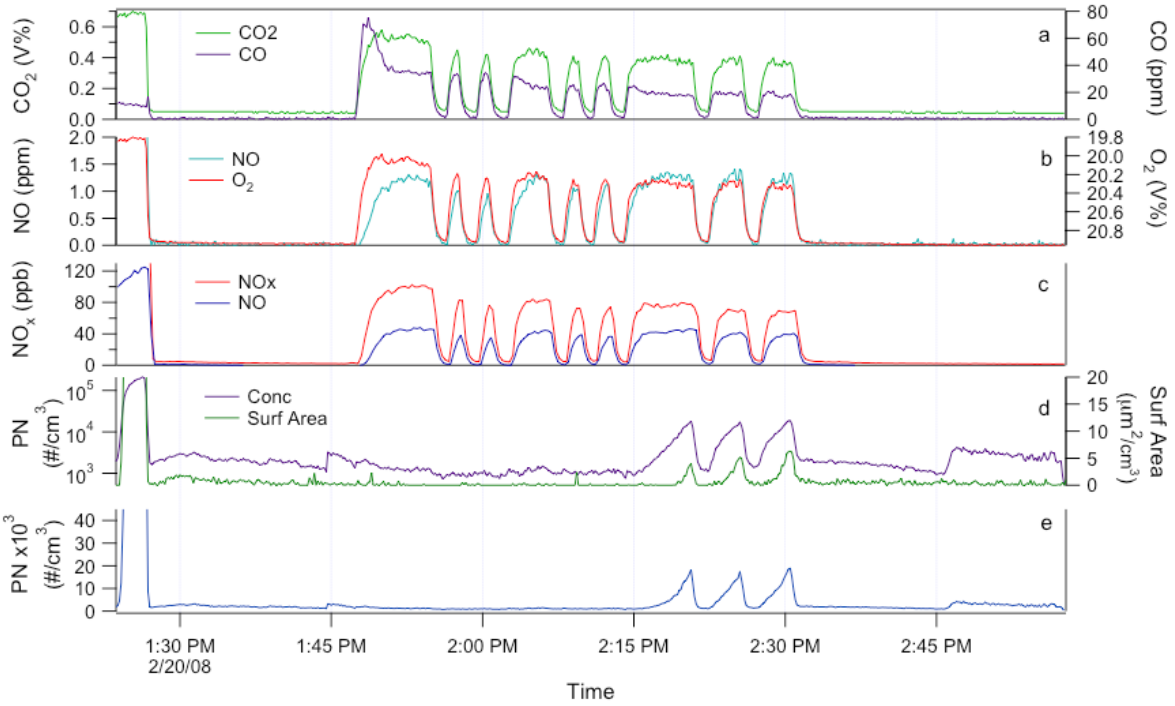

Figure 50. Measured analyte concentrations for oven OV05 with fuel 3C (L075).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. The peak prior to Burn 1 is a purge burn. The particle instruments sampled from ambient air after the last burn.

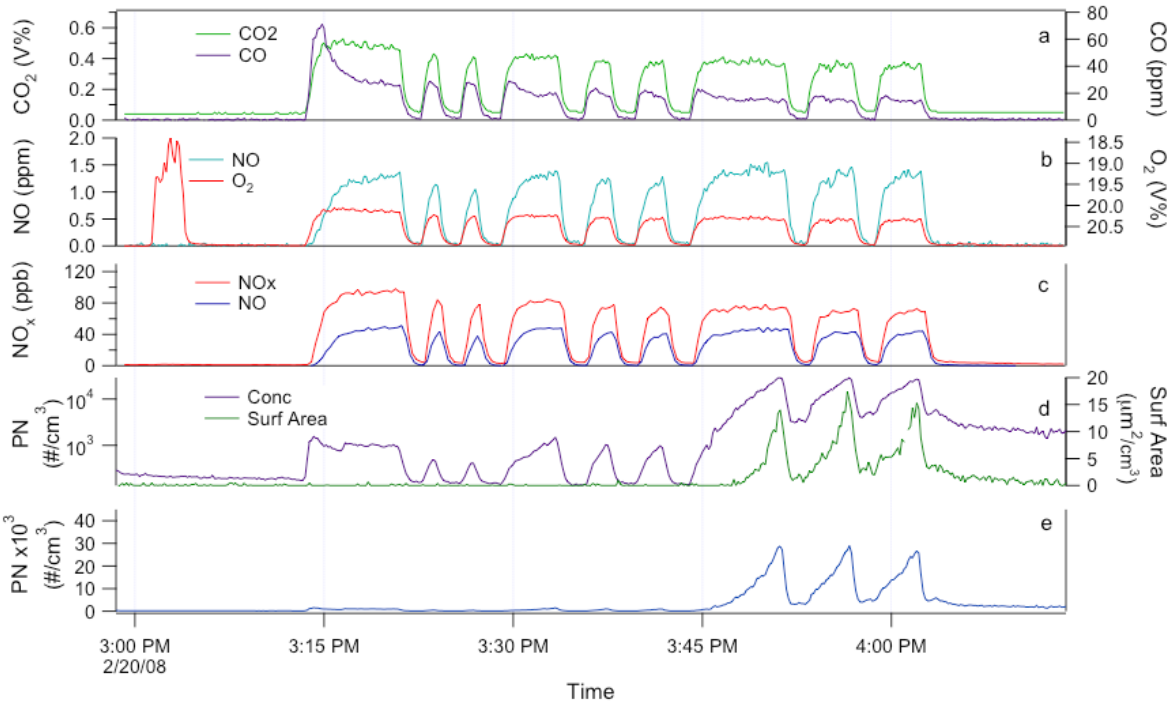

Figure 51. Measured analyte concentrations for oven OV05 with fuel 1C (L076).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

Table 69. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L073	PG&E	1320	570	470	390	37	46	59	20	14	370
L074	1C	1389	740	650	580	36	43	50	NA[1]	NA[1]	NA[1]
L076	1C	1389	720	610	530	36	43	51	-1	-1	240
L075	3C	1419	860	720	640	31	39	46	-3	-3	100

[1] Did not log PN data during L074 experiments. L076 is a duplicate experiment of L074.

Table 70. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L073	PG&E	1320	74	77	88	37	46	59	37	31	29
L074	1C	1389	68	74	78	36	44	51	32	30	27
L076	1C	1389	69	73	80	36	43	52	33	30	28
L075	3C	1419	67	72	79	32	39	47	35	33	33

Table 71. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)			PG250 NO ($\mu g\ KJ^{-1}$)			PN ($10^7\ KJ^{-1}$)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L073	PG&E	1320	210	150	130	12	18	22	25	2.6	290
L074	1C	1389	280	210	170	13	17	20	NA[1]	NA[1]	NA[1]
L076	1C	1389	280	190	160	13	17	21	-3	-11	210
L075	3C	1419	310	230	190	11	15	18	-4	-12	83

[1] Did not log PN data during L074 experiments. L076 is a duplicate experiment of L074.

Table 72. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X ($\mu g\ KJ^{-1}$)			NO ($\mu g\ KJ^{-1}$)			NO_2 ($\mu g\ KJ^{-1}$)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L073	PG&E	1320	28	32	35	13	18	22	16	14	12
L074	1C	1389	28	32	33	13	17	20	15	15	13
L076	1C	1389	28	31	35	13	17	21	15	14	14
L075	3C	1419	27	30	33	12	16	19	15	15	14

Table 73. Calculated formaldehyde emission rates over entire period of burner operation.

Exp.	Fuel	Wobbe	HCHO ($\mu g\ KJ^{-1}$)
L073	PG&E	1320	0.43
L074	1C	1389	0.50
L076	1C	1389	0.52
L075	3C	1419	0.65

5.0 Oven OV06

5.1. Experimental information for OV06

The oven compartment appeared clean at the time it was procured, presumably because it had been cleaned by the owner prior to sale. The owner reported using the cooktop a few times per week, but did not specify frequency of oven use. We preconditioned the oven prior to our experiments by operating for >3 hours on the self-clean setting then wiping down interior with wet then dry paper towels.

A set of 3 experiments – with PG&E line gas (WN = 1328), mix 1C (WN = 1390) and mix 3C (WN = 1419) – were conducted on the same day. It was subsequently recognized that the CPC was malfunctioning during at least one of the three experiments. An additional two experiments – with fuel 1C and PG&E line gas (WN = 1317) – were completed on the same day, approximately 1 week later. The heater for the dilution sampler inlet was set to automatic mode. The SMPS was used to sample size-resolved particle number concentrations in the ultrafine mode (<100 nm particle diameter). Appliance manifold pressure was not measured because access was not possible without dismantling the internal fuel transfer lines. The temperature and RH in the glass sampling manifold was also not recorded. RH was substantially lower for the first three experiments (28-31%) compared with the two later experiments (42-44%).

Table 74. Appliance and burner information OV06.

Burner ID	OV06
Appliance manufacturer	General Electric
Model number	JGSP33WEV3WW
Serial number	DS218239Q
Design manifold P	4” H_2O
Age (years)	~10 years at time of testing
Burner technologies	Hot surface ignition; Tube burner
Burner ratings (Btu/h)	16,000
Other information	Procured April 2008
Test location	Laboratory
History notes	Purchased from owner since 1999, advertised on Craig’s List. Owner cooktop use 3-4x per week; no specifics on oven use. Believed to be purchased new and installed during kitchen remodel in 1998.

Figure 52. Oven compartment of OV06.
Bottom burner located beneath raised bottom.

Figure 53. OV06 raised bottom plate lifted to reveal top of spreader.
Burner not accessible without dismantling further

Table 75. Interchangeability experiments for oven bottom burner OV06.

Exp.	Fuel	Date	Burner operation
L096	PG&E	5/1/2008	Purge burn with each fuel change using cooktop burners. Operate oven through initial ramp plus 2 maintenance cycles at 350, 425 and 500F. Cool to touch between experiments.
L097	1C	5/1/2008	
L098	3C	5/1/2008	
L104	1C	5/8/2008	
L105	PG&E	5/8/2008	

Table 76. Fuel analysis for interchangeability experiments with OV06.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L096	PG&E	95.9%	2.06%	0.19%	0.06%	95.9%	0.88%	0.95%	1012	1328
L097	1C	92.0%	8.00%	-	-	92.0%	-	-	1071	1390
L098	3C	86.4%	12.00%	1.60%	-	86.4%	-	-	1125	1419
L104	1C	92.0%	8.00%	-	-	92.0%	-	-	1071	1390
L105	PG&E	95.1%	1.83%	0.37%	0.15%	95.1%	1.52%	0.98%	1008	1317

[1] Samples generally drawn from fuel supply line while burner is operating.
[2] Calculated using the American Gas Association interchangeability program.
[3] Sample contaminated; use results for L076 sample obtained from same cylinder.

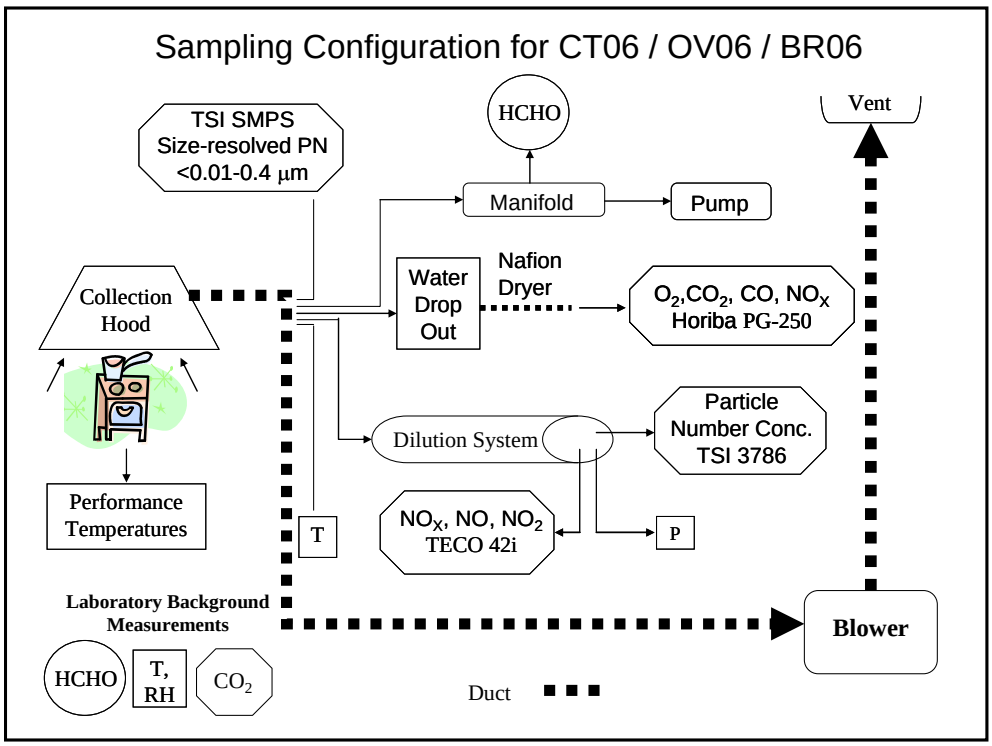

Figure 54. Analytical sampling configuration for OV06.

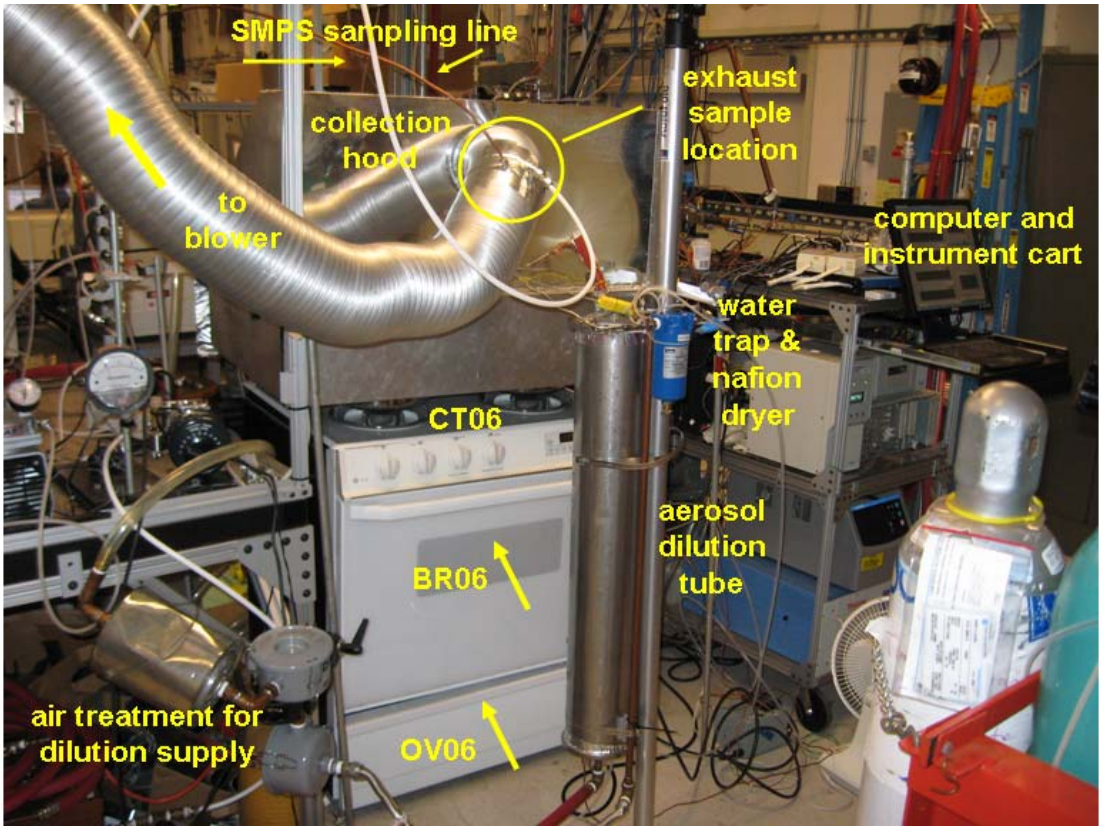

Figure 55. Installation of OV06.

Table 77. Analyte ranges and calibration levels for experiments with OV06.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-10%	0, 1%
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-200 ppm	0, 40 ppm
Nitrogen oxides (NO_X)	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 4.0 ppm[3]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 2.0 ppm[3]
Carbon dioxide (CO_2)	ambient air in laboratory	PPSystems EGM-4	5000 ppm	check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold. [2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com). [3] Calibrated from mixture of NO in N_2.

Table 78. Aerosol instrumentation used for CT06 / OV06.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
TSI SMPS[5]: 3071A classifier, 3025A ultrafine CPC	PN resolved by size (aerodynamic diameter)	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature.
[2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm.
[3] Product 3001788, purchased from TSI.
[4] Monitor has settings available for tracheobronchial (TB) or alveolar (A) regions; specifications are provided for the alveolar option which is being used in this study.
[5] SMPS used for experiments on Feb 8-12 (L064-L068).

Table 79. Other measurements for experiments with CT06 / OV06.

Measured Quantity	Location(s)	Device(s)[1]
Fuel pressure	Gas supply line	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Dilution sampler vacuum	Dilution tube	Setra Model 264 transducer
Temperature, combustion air	In vicinity of range	Precision NTC thermistor (APT)
Relative humidity, combustion air	In vicinity of range	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in hood	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, oven	Oven interior, shelf middle at lowest, highest positions	Thermocouple (K), screw-mount, Omega XCIB-K-4-2-3

[1]APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com); American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com).

5.2. Results for OV06

Full-burn CO emissions were the highest during the initial burn – heating to 350 F – in each experiment, with a large peak occurring at ignition. By contrast, end-of-burn CO emissions were highest at the 425 F burn in 4 of 5 experiments. End-of-burn NO_X concentrations and emissions were highest during the 500 F burn. PN concentrations and emissions were generally a bit higher during the 350 F and 500 F burns compared to the 425 F burn, but the increments were small for PN variations. PN emissions were much higher (54-140 x 10^4 J^{-1}) during the first experiment with PG&E line gas than during all subsequent experiments (3-35 x 10^4 J^{-1}), including a replicate experiment with PG&E fuel. CO full burn emission rates at 350 F suggest a possible small dependence on WN; however, the difference in CO emissions at 350 and 425 F between 1C replicate experiments is similar in magnitude to the differences observed as a function of WN. There were no other trends of emissions varying with fuel WN. Full burn emission rates were 190-260 ng/J for CO (350 F setting; highest for CO), 34-39 ng/J for NO_X (500 F setting; highest for NO_X), 3-140 x 10^4 J^{-1} for PN at 500 F setting (see above), and 1.3-1.7 ng/J for HCHO.

Table 80. Environmental conditions[1] for experiments with OV06.

Exp.	Fuel	T (°C)	RH (%)
L096	PG&E	22.7 ± 0.3	28 ± 1
L097	1C	23.4 ± 0.2	30 ± 1
L098	3C	22.7 ± 0.1	31 ± 1
L104	1C	22.5 ± 0.2	44 ± 1
L105	PG&E	23.2 ± 0.5	42 ± 2

[1] Measured over period of formaldehyde sample.

Table 81. Burner operating parameters for experiments with oven OV06. Information provided for first burner firing at each temperature setting.

Experiment	Burn	Start Time	End Time	Fuel Flowrate ($ft^3\ h^{-1}$)	Firing Rate ($kBTU\ h^{-1}$)	Supply P (in. H_2O)	Appliance Manifold P (in. H_2O)[2]
L096	350F	11:22	11:30	16	17	7.7	NA
L096	425F	11:49	11:52	15	15	7.8	NA
L096	500F	12:08	12:12	16	16	7.7	NA
L097	350F	13:21	13:28	16	17	7.9	NA
L097	425F	13:46	13:49	16	17	7.9	NA
L097	500F	14:05	14:08	16	17	7.9	NA
L098	350F	15:26	15:33	16	18	7.9	NA
L098	425F	15:50	15:53	14	16	7.9	NA
L098	500F	16:08	16:11	15	17	7.9	NA
L104	350F	13:47	13:54	17	18	7.9	NA
L104	425F	14:08	14:15	16	18	7.9	NA
L104	500F	14:54	14:58	13	14	7.9	NA
L105	350F	15:44	15:52	14	14	7.7	NA
L105	425F	16:09	16:14	13	13	7.8	NA
L105	500F	16:28	16:34	13	13	7.8	NA

[1] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over period of burner operation; firing rate calculated from fuel flow rate and higher heating value from fuel composition; calculation is for initial burn to reach 350 F.
[2] Appliance manifold pressure readings not taken.

Table 82. Sample location temperatures and dilution ratios for each burn.

	Sample location T (°C)[1]			Dilution ratio[2]		
Exp.	350 F	425 F	500 F	350 F	425 F	500 F
L096	34 ± 1	44 ± 0	50 ± 0	22	21	21
L097	35 ± 1	45 ± 0	51 ± 0	21	21	23
L098	35 ± 1	44 ± 0	49 ± 0	20	21	21
L104	33 ± 0	35 ± 1	50 ± 0	22	19	20
L105	37 ± 0	45 ± 0	50 ± 0	21	20	20

[1] Measured in exhaust duct from collection hood alongside pollutant sampling inlets. Mean ± standard deviation measured over last min of each burn to achieve new temperature setting.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) over last min of each burn.

Table 83. Formaldehyde samples for experiments with oven OV06.

Exp(s)	Location	Date	Sample start time	Sample end time	Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m^3)
Bkg	Lab air	5/1/2008	11:19	16:24	320	0.587	3.7
L096	Glass Manifold		11:19:40	12:25:00	61	2.637	85.9
L097			13:19:30	14:21:00	59	2.077	70.5
L098			15:24:00	16:24:30	57	2.179	75.9
Bkg	Lab air	5/8/2008	13:25	16:46	208	0.524	5.0
L104	Glass Manifold		14:07:00	15:09:20	60	2.117	70.0
L105			15:42:30	16:46:00	61	2.037	67.2

[1] Average formaldehyde concentration in the air drawn through the sampler; the effect of gas quality on formaldehyde emissions is indicated in a subsequent table.

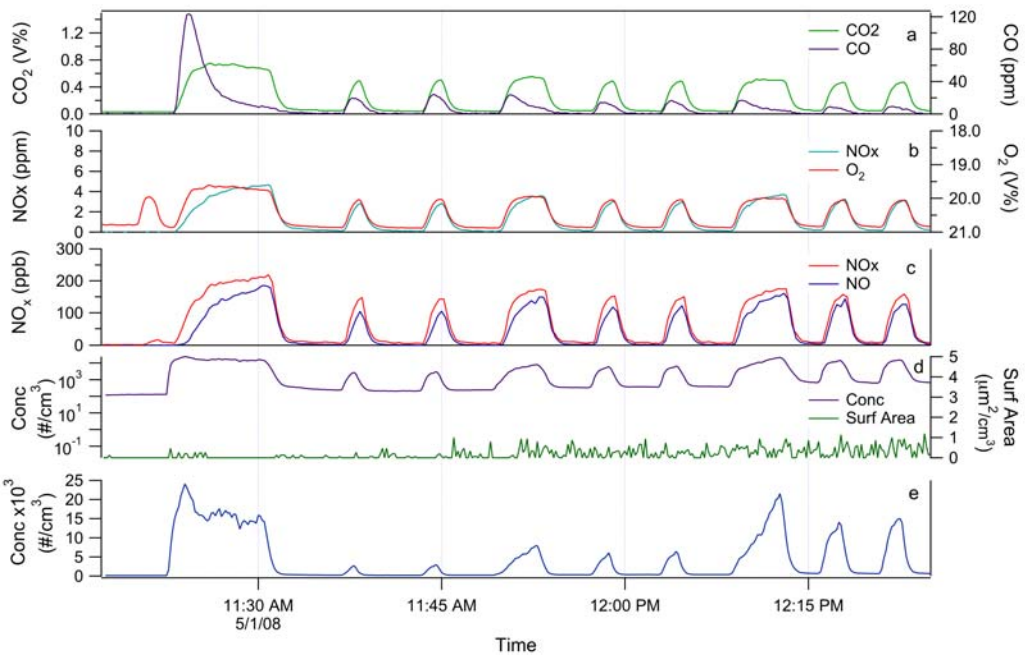

Figure 56. **Measured analyte concentrations for oven OV06 with PG&E line gas (L096).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

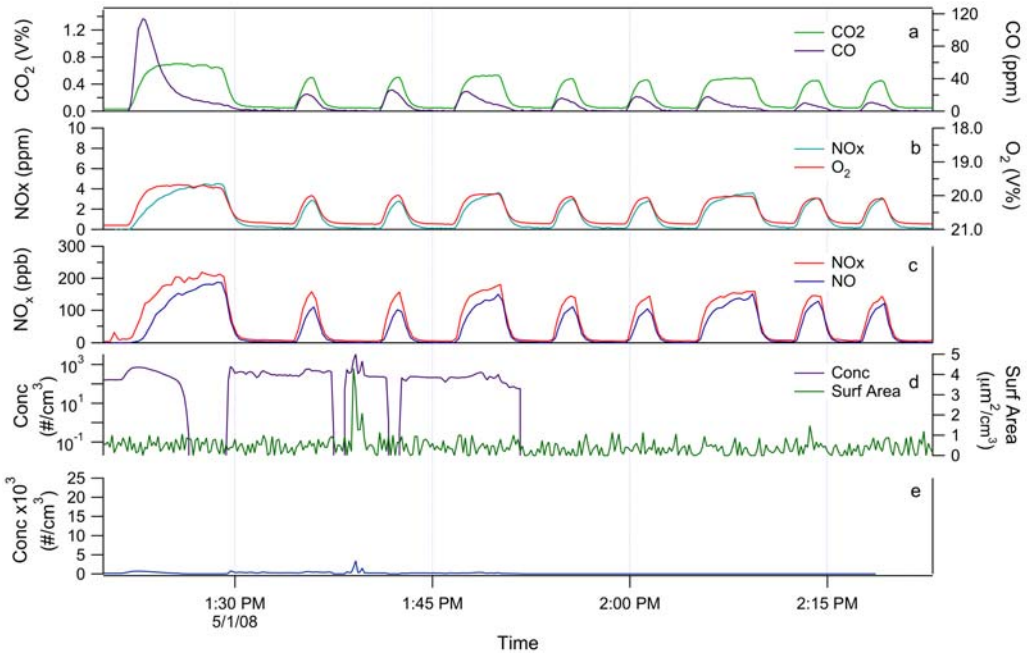

Figure 57. **Measured analyte concentrations for oven OV06 with fuel 1C (L097).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. PN data not valid.

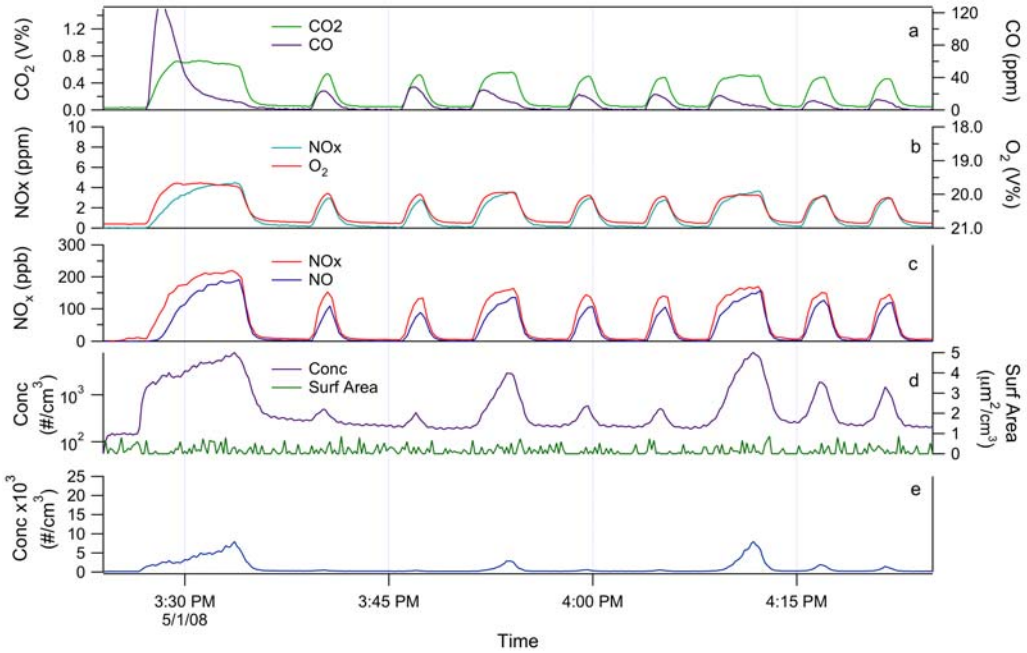

Figure 58. Measured analyte concentrations for oven OV06 with fuel 3C (L098).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. PN data may not be valid.

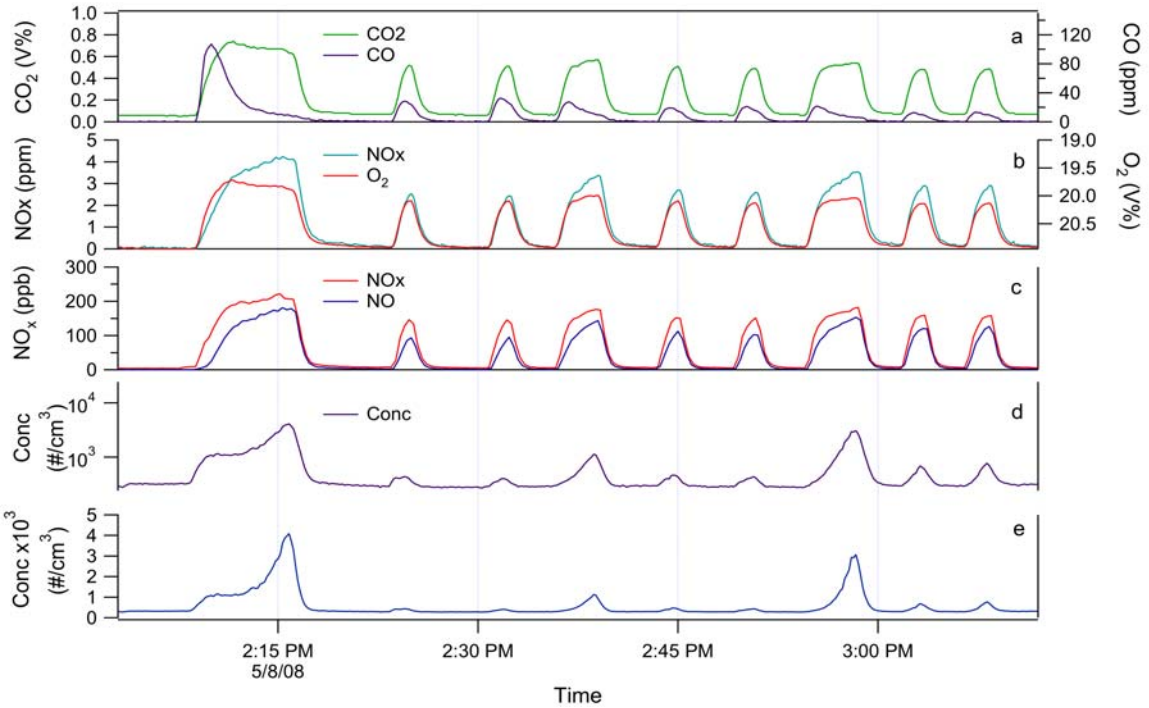

Figure 59. Measured analyte concentrations for oven OV06 with fuel 1C (L104).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

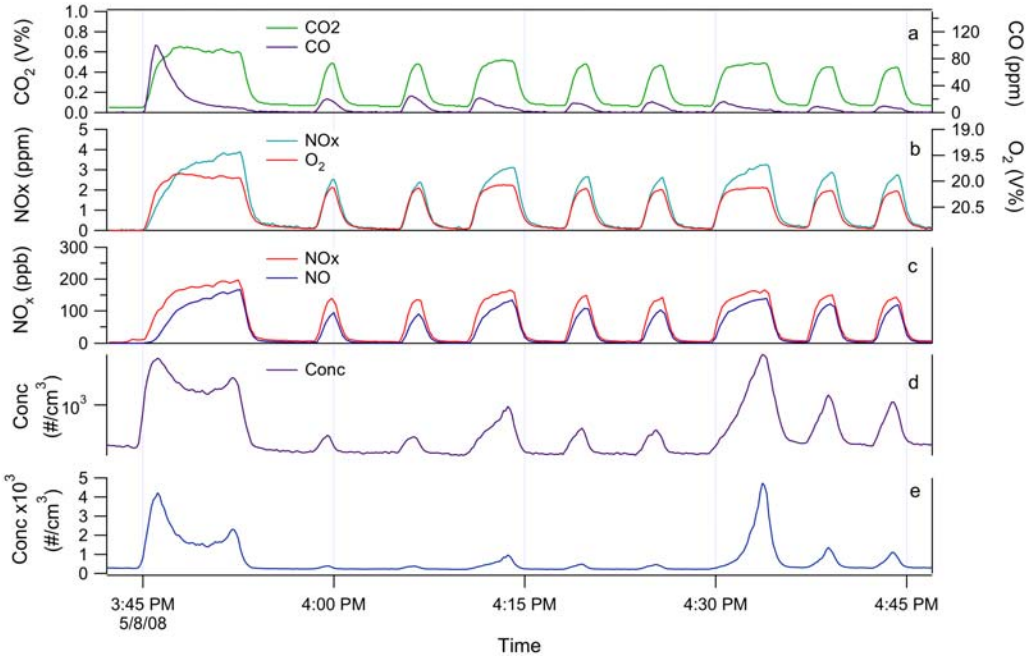

Figure 60. **Measured analyte concentrations for oven OV06 with PG&E line gas (L105).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 84. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for CO, PG250 NO_X and PN.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO_X (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L096	PG&E	1328	180	216	134	86	83	94	60	35	100
L097	1C	1390	213	237	141	86	85	96	NA[1]	NA[1]	NA[1]
L098	3C	1419	231	266	153	82	81	91	23	10	35
L104	1C	1390	191	272	161	80	74	83	11	2.7	9.9
L105	PG&E	1317	181	202	124	80	77	86	6.3	2.2	17

[1] CPC not functioning during this experiment; PN data invalid.

Table 85. Calculated air-free concentrations (using CO_2) over last 30 sec of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L096	PG&E	1328	86	83	94	75	68	85	10.7	14.9	9.3
L097	1C	1390	86	85	96	75	69	84	10.7	15.8	11.5
L098	3C	1419	82	81	91	70	66	82	12.0	15.0	8.9
L104	1C	1390	80	74	83	67	59	71	12.5	15.3	12.0
L105	PG&E	1317	80	77	86	67	62	74	13.2	14.9	11.7

Table 86. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO_X and PN.

Exp.	Fuel	Wobbe	CO (μg KJ^{-1})			PG250 NO_X (μg KJ^{-1})			PN (10^7 KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L096	PG&E	1328	205	102	72	30	34	38	140	54	140
L097	1C	1390	216	114	75	31	36	39	NA[1]	NA[1]	NA[1]
L098	3C	1419	252	120	79	29	34	37	35	15	42
L104	1C	1390	261	200	75	25	28	34	16	12	13
L105	PG&E	1317	187	100	70	29	31	34	17	2.7	19

[1] CPC not functioning during this experiment; PN data invalid.

Table 87. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L096	PG&E	1328	30	34	38	21	26	31	8.8	8.3	6.7
L097	1C	1390	31	36	39	23	27	32	8.2	8.4	6.8
L098	3C	1419	29	34	37	21	25	30	7.9	8.8	7.0
L104	1C	1390	25	28	34	16.3	20	26	8.7	8.4	7.5
L105	PG&E	1317	29	31	34	20	23	27	8.3	8.6	7.2

Table 88. Calculated formaldehyde emission rates over entire period of burner operation.

Exp.	Fuel	Wobbe	HCHO ($\mu g\ KJ^{-1}$)
L096	PG&E	1328	1.15
L097	1C	1390	0.95
L098	3C	1419	1.03
L104	1C	1390	0.86
L105	PG&E	1317	0.88

6.0 Oven OV07

6.1. Experimental information for OV07

Four experiments were conducted on the same day, in the following order: PG&E line gas (WN = 1328), mix 1C (WN = 1390) and mix 3C (WN = 1419), and a replicate experiment with PG&E line gas. The heater for the dilution sampler inlet was set to automatic mode. The SMPS used to collect size-resolved particle number concentrations in the ultrafine mode (<100 nm particle diameter). Appliance manifold pressure was not measured because access was not possible without dismantling the internal fuel transfer lines. The pulse counter on the gas meter malfunctioned during several of the experiments.

Table 89. Appliance and burner information OV07.

Burner ID	OV07
Appliance manufacturer	General Electric
Model number	JGB#20GEV4WH
Serial number	VM129300P
Design manifold P	4” H_2O
Age (years)	~8 years at time of testing
Burner technologies	Hot surface ignition; single tube-type oven burner (non self-cleaning)
Burner rating (Btu/h)	18,000
Other information	Procured May 2008
Test location	Laboratory
History notes	Identified via Craig’s List and purchased from landlord in May 2008. Landlord reported purchasing range new circa year 2000 for use in apartment with single tenant. Level of use unknown.

Figure 61. Oven compartment for OV07.

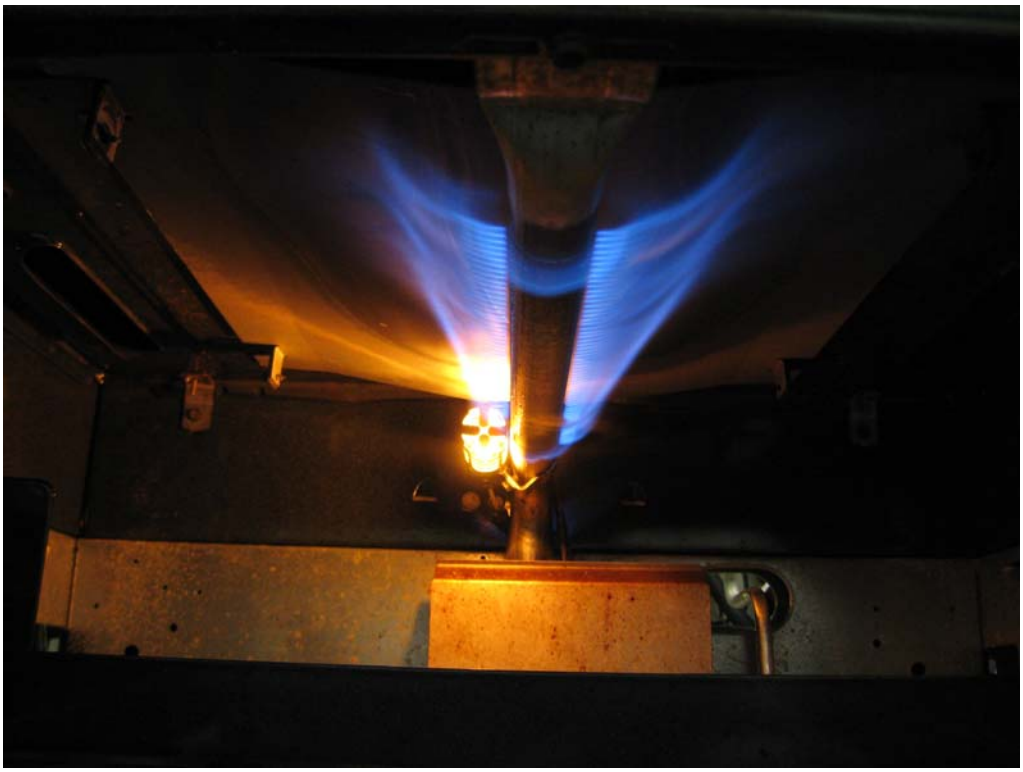

Figure 62. OV07 flame with PG&E line gas.

Table 90. Interchangeability experiments for oven bottom burner OV07.

Exp.	Fuel	Date	Burner operation
L116	PG&E	05/23/2008	Purge burn with each fuel change using cooktop burners. Operate oven through initial ramp plus 2 maintenance cycles at 350, 425 and 500F. Cool to touch between experiments.
L117	3C		
L118	1C		
L119	PG&E		

Table 91. Fuel analysis for interchangeability experiments with OV07.

Expt. ID	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L116	PG&E	L116	95.3%	2.10%	0.39%	0.16%	1.37%	0.72%	1015	1328
L117	3C	Cylinder	86.4%	12.00%	1.60%				1125	1419
L118	1C	Cylinder	92.0%	8.00%					1071	1390
L119	PG&E	L116	95.3%	2.10%	0.39%	0.16%	1.37%	0.72%	1015	1328

[1] Calculated using the American Gas Association interchangeability program.

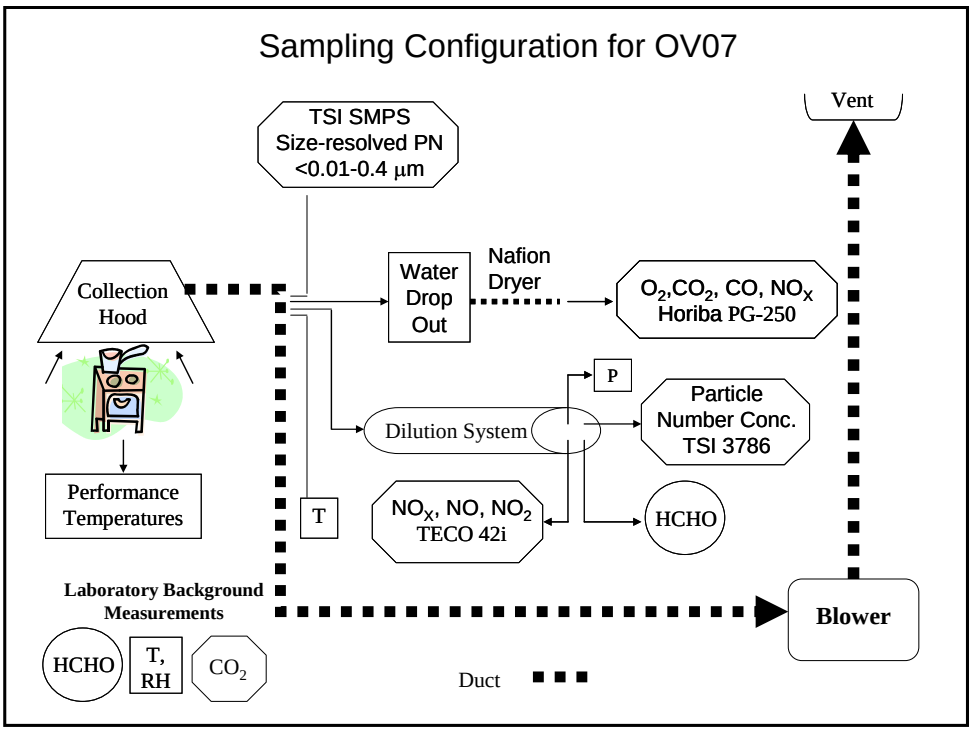

Figure 63. Analytical sampling configuration for OV07.

Table 92. Analyte ranges and calibration levels for experiments with OV07.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-10%	0, 1.0%
Oxygen (O_2)	outlet of collection hood	Horiba PG-250	0-25%	0, 20.95%
Carbon monoxide (CO)	outlet of collection hood	Horiba PG-250	0-200 ppm	0, 175 ppm
Nitrogen oxides (NO_X)	outlet of collection hood	Horiba PG-250	0-100 ppm	0, 4.0 ppm[3]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 2.0 ppm[3]
Carbon dioxide (CO_2)	ambient air in laboratory	PPSystems EGM-4	5000 ppm	check at 507 ppm

[1] Sample air drawn from duct connected to outlet of hood through 3/8" Teflon tubing to gas manifold; analyzers sampled most directly from gas manifold. [2] Horiba Environmental and Process Instruments, Irvine CA (environ.hii.horiba.com); Thermo Fisher Scientific, Waltham, MA (thermo.com); TSI Instruments, Shoreview, MN (tsi.com). [3] Calibrated from mixture of NO in N_2.

Table 93. Aerosol instrumentation used for OV07.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3786 ultrafine CPC	sample from dilution tube via 2.2 m × 0.48 cm ID conductive tubing[3]	2.5 nm	10^5 cm^{-3} single particle mode	±12%
TSI SMPS[4]: 3071A classifier, 3025A ultrafine CPC	PN resolved by size (aerodynamic diameter)	Sort using electrostatic classifier, count with CPC	3 nm	10^5 cm^{-3}	±10%

[1] TSI Instruments, Shoreview, MN (tsi.com). CPC = condensation particle counter. Detailed information provided in product literature.
[2] 50% detection. Ultrafine particles (UFP) are generally defined as having aerodynamic diameters <100 nm.
[3] Product 3001788, purchased from TSI.
[4] SMPS used for experiments on Feb 8-12 (L064-L068).

Table 94. Other measurements for experiments with OV07.

Measured Quantity	Location(s)	Device(s)[1]
Fuel pressure	Gas supply line	Model 264 transducer (Setra)
Fuel volume & flow	Fuel flow to appliance during burner operation	AC-250-TC T-compensating dry gas meter with 1- and ¼-ft dials (American Meter); flow rate timed by stopwatch
Fuel flow rate	Fuel flow to appliance during burner operation	Pulse counter for AC-250-TC, 10 counts per rev (Riotronics)
Dilution sampler vacuum	Dilution tube	Setra Model 264 transducer
Temperature, combustion air	In vicinity of range	Precision NTC thermistor (APT)
Relative humidity, combustion air	In vicinity of range	Thermostet polymer based capacitance RH sensor (APT)
Temperature, air sample location in hood	At point of air sampling in duct connected to hood	Thermocouple (K), probe, Omega KQSS-18E-12
Temperature, oven	Oven interior, shelf lower and upper halves of oven	Thermocouple (K), screw-mount, Omega XCIB-K-4-2-3

[1]APT: Automated Performance Testing System, Energy Conservatory, Minneapolis, MN (energyconservatory.com); Setra: Boxborough, MA (setra.com); Riotronics: Engelwood, CO (riotronics.com); American Meter (americanmeter.com); obtained via Miners & Pisani, San Leandro, CA; Omega Engineering, Stamford, CT (omega.com).

6.2. Results for OV07

CO concentrations and emissions were the highest during the initial burn – heating to 350 F – a resulting from the large peak that occurred at the start of burner firing. End of burn air-free CO concentrations were similar for burns at 350 and 425 F and somewhat lower at 500 F within each experiment; end-of-burn air-free CO was in the range of 370 to 510 ppm. Full-burn CO emission rates were on the order of 10-20% higher for fuel 3C relative to PG&E line gas. In 3 of 4 experiments, end of burn PN concentrations and full-burn emission rates were substantially higher during the 425 and 500 F burns relative to the 350 F burn; during the fuel 1C experiment, PN was higher only during the last burn. PN concentrations and emissions were remarkably similar during the replicate PG&E experiments, much more so than during replicate experiments for most other burners). Relative to PG&E experiments, PN concentrations and emissions were slightly lower with fuel 3C and substantially lower with fuel 1C. In each experiment NO_X concentrations and emissions were highest at the highest temperature burn, as expected. NO_X concentrations and emissions were a few percent lower for fuels 3C and 1C relative to PG&E. Formaldehyde emission rates were very similar in the first 3 experiments and substantially lower in the replicate with PG&E line gas. Full burn emission rates were 185-220 ng/J for CO (350 F setting; highest for CO), 33-35 ng/J for NO_X (500 F setting; highest for NO_X), 180-790 x 10^4 J^{-1} for PN at 500 F setting, and 0.48-0.66 ng/J for HCHO.

Table 95. Burner operating parameters for experiments with oven OV07. Information provided for first burner firing at each temperature setting.

Experiment	Burn	Start Time	End Time	Fuel Flowrate ($ft^3\ h^{-1}$)	Firing Rate ($kBTU\ h^{-1}$)	Supply P (in. H_2O)	Appliance Manifold P (in. H_2O)[2]
L116	350F	12:38	12:48	18	18	7.6	NA
L116	425F	12:55	13:00	-	-	7.7	NA
L116	500F	13:05	13:12	-	-	7.7	NA
L117	350F	13:53	14:02	17	19	7.8	NA
L117	425F	14:09	14:13	-	-	7.9	NA
L117	500F	14:18	14:24	-	-	7.8	NA
L118	350F	15:00	15:10	17	18	7.9	NA
L118	425F	15:16	15:21	-	-	7.9	NA
L118	500F	15:26	15:32	-	-	7.9	NA
L119	350F	16:03	16:13	17	17	7.6	NA
L119	425F	16:19	16:25	-	-	7.7	NA
L119	500F	16:30	16:36	-	-	7.7	NA

[1] Fuel flow rate $ft^3\ h^{-1}$ calculated from measured fuel use over period of burner operation using stopwatch and 1/4-foot dial of gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition; calculation is for initial burn to reach 350 F.
[2] Appliance manifold pressure readings not taken.

Table 96. Environmental conditions[1] for experiments with OV07.

Exp.	Fuel	T (°C)	RH (%)
L116	PG&E	24.1 ± 0.5	42 ± 1
L117	3C	24.5 ± 0.3	40 ± 1
L118	1C	24.8 ± 0.3	39 ± 1
L119	PG&E	25.0 ± 0.3	38 ± 1

[1] Measured over period of formaldehyde sample.

Table 97. Sample location temperatures and dilution ratios for each burn.

	Sample location T (°C)[1]			Dilution ratio[2]		
Exp.	350 F	425 F	500 F	350 F	425 F	500 F
L116	38 ± 1	47 ± 0	55 ± 1	18	19	20
L117	39 ± 1	49 ± 1	56 ± 0	17	18	18
L118	39 ± 1	47 ± 1	52 ± 0	17	17	18
L119	41 ± 1	51 ± 1	57 ± 1	17	17	18

[1] Measured in exhaust duct from collection hood alongside pollutant sampling inlets. Mean ± standard deviation measured over last min of each burn to achieve new temperature setting.
[2] Calculated by comparing NO_X measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) over last min of each burn.

Table 98. Formaldehyde samples for experiments with oven OV07.

Exp(s)	Location	Date	Sample start time	Sample end time	Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m^3)
Bkg	Lab air	5/23/2008	12:36	16:41	273	0.665	4.87
L116	Dilution system	5/23/2008	12:36:00	13:17:30	41.6	0.066	3.15
L117			13:51:00	14:28:50	38.7	0.063	3.23
L118			14:58:00	15:37:00	40.2	0.064	3.20
L119			16:01:30	16:41:20	40.9	0.050	2.42

[1] Average formaldehyde concentration in the air drawn through the sampler; the effect of gas quality on formaldehyde emissions is indicated in a subsequent table. Concentrations are lower in samples because dilution system inlet air is virtually free of formaldehyde.

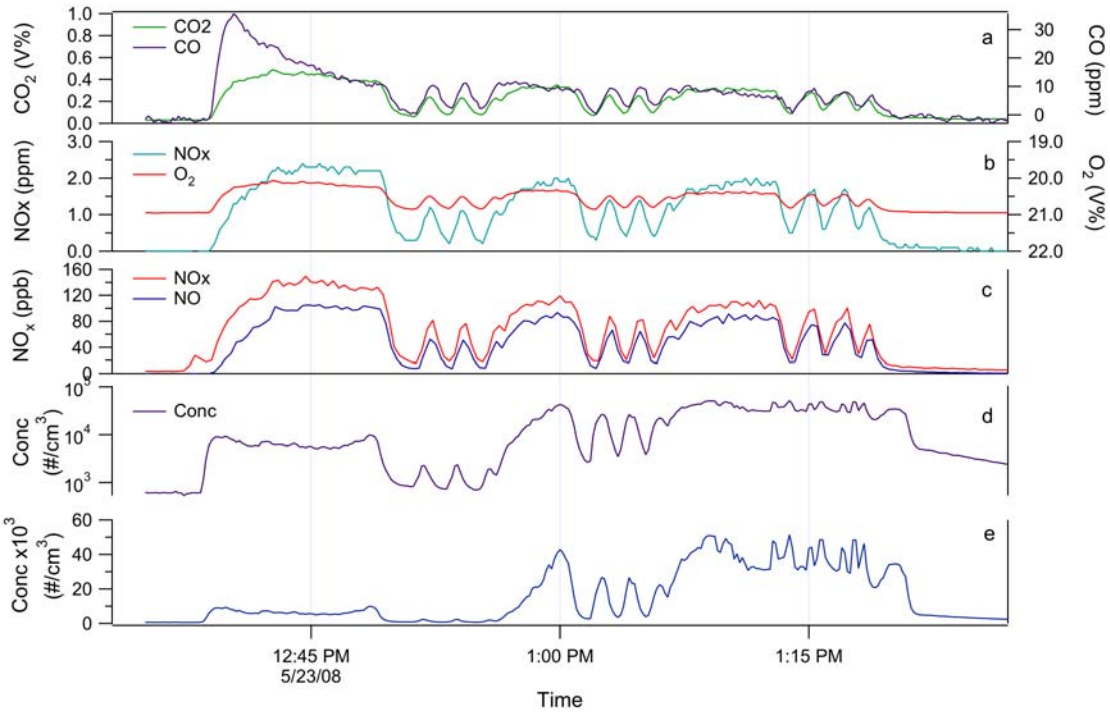

Figure 64. **Measured analyte concentrations for oven OV07 with PG&E line gas (L116).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

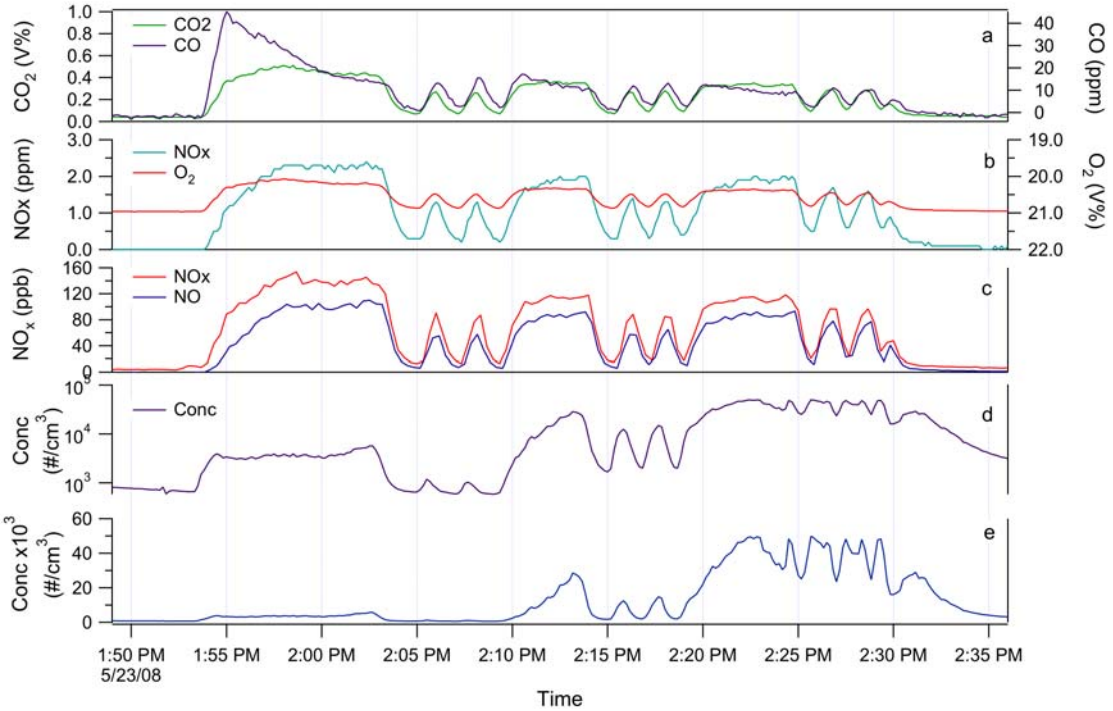

Figure 65. **Measured analyte concentrations for oven OV07 with fuel 3C (L117).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

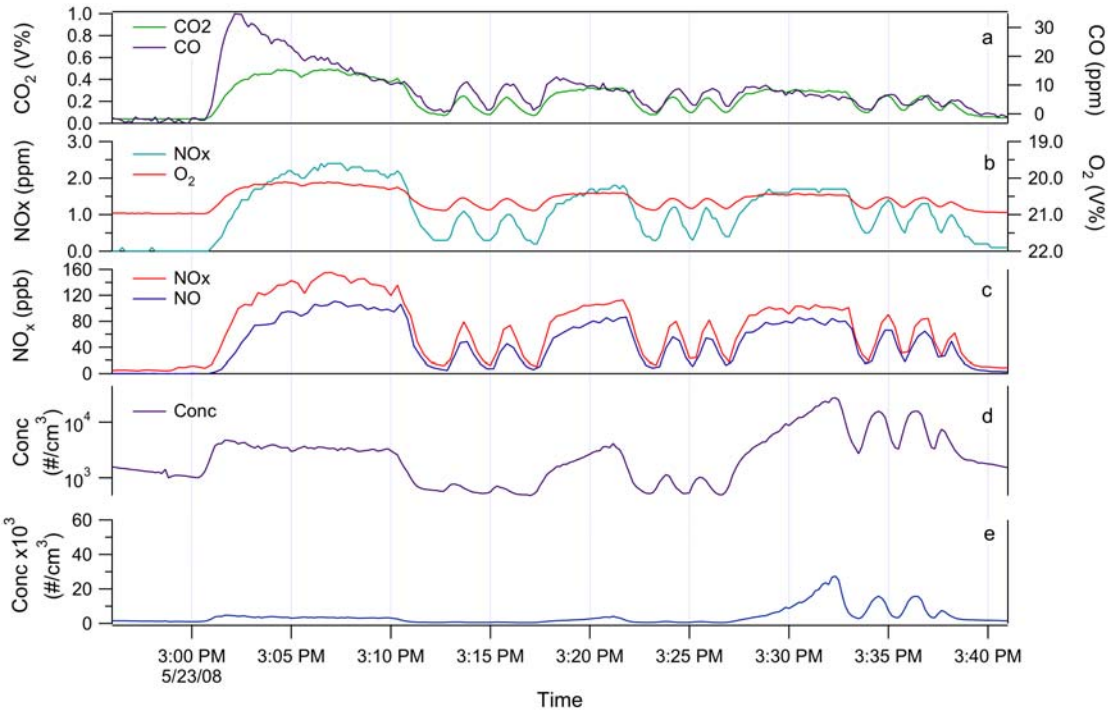

Figure 66. Measured analyte concentrations for oven OV07 with fuel 1C (L118).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

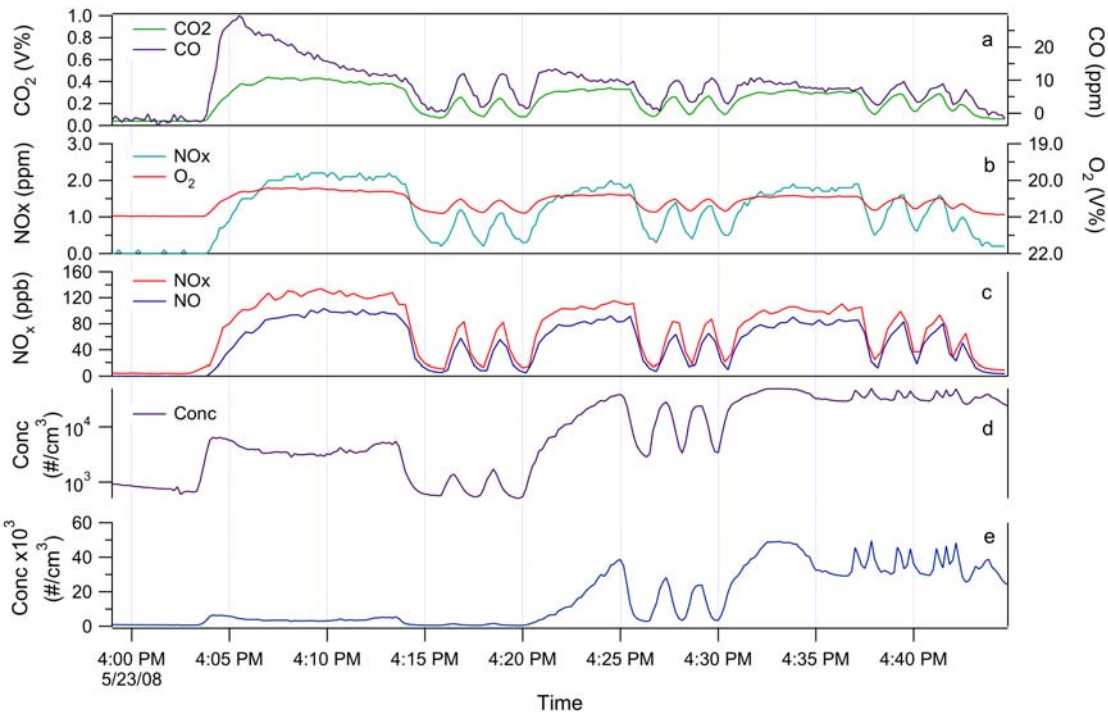

Figure 67. Measured analyte concentrations for oven OV07 with PG&E line gas (L119). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 99. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO (ppm)			PG250 NO_X (ppm)			PN (10^5 cm^{-3})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L116	PG&E	1328	427	435	367	75	76	85	47	250	270
L117	3C	1419	503	506	427	71	75	80	20	160	270
L118	1C	1390	443	464	380	70	74	81	11	15	190
L119	PG&E	1328	476	474	422	74	77	81	24	240	240

Table 100. Calculated air-free concentrations (using CO_2) over last 1 min of each burn; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (ppm)			NO (ppm)			NO_2 (ppm)		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L116	PG&E	1328	75	76	85	63	66	75	12.1	10.5	9.9
L117	3C	1419	71	75	80	54	61	64	16.2	14.6	15.6
L118	1C	1390	70	74	81	55	59	68	14.9	14.3	12.6
L119	PG&E	1328	74	77	81	59	62	69	14.4	15.1	12.3

Table 101. Calculated emission rates over entirety of first burn at each temperature setting; results for CO, PG250 NO and PN.

Exp.	Fuel	Wobbe	CO (μg KJ^{-1})			PG250 NO_X (μg KJ^{-1})			PN (10^7 KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F

L116	PG&E	1328	185	145	124	28	32	35	76	320	790
L117	3C	1419	223	166	139	27	31	33	34	190	620
L118	1C	1390	190	156	128	26	31	34	24	14	180
L119	PG&E	1328	189	156	134	29	32	35	44	280	770

Table 102. Calculated emission rates over entirety of first burn at each temperature setting; results for NO_X, NO, and NO_2 (NO_X-NO) measured with Thermo 42i.

Exp.	Fuel	Wobbe	NO_X (μg KJ^{-1})			NO (μg KJ^{-1})			NO_2 (μg KJ^{-1})		
			350F	425F	500F	350F	425F	500F	350F	425F	500F
L116	PG&E	1328	28	32	35	20	27	31	7.4	5.5	4.3
L117	3C	1419	27	31	33	18.6	25	27	8.1	6.8	6.4
L118	1C	1390	26	31	34	18.6	24	28	7.9	6.8	5.4
L119	PG&E	1328	29	32	35	21	26	29	7.2	6.6	5.8

Table 103. Calculated formaldehyde emission rates over entire period of burner operation.

Exp.	Fuel	Wobbe	HCHO (μg KJ^{-1})
L116	PG&E	1328	0.66
L117	3C	1419	0.63
L118	1C	1390	0.64
L119	PG&E	1328	0.48