Arnold Schwarzenegger
Governor

NATURAL GAS VARIABILITY IN CALIFORNIA: ENVIRONMENTAL IMPACTS AND DEVICE PERFORMANCE

EXPERIMENTAL EVALUATION OF POLLUTANT EMISSIONS FROM RESIDENTIAL APPLIANCES

APPENDIX D. SUMMARY REPORTS FOR COOKTOPS CT08–CT13

PIER INTERIM PROJECT REPORT

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Prepared By:
Lawrence Berkeley National Laboratory

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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

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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 v
1.0 Cooktop CT08 1
1.1. Experimental information for CT08 1
1.2. Results for CT08 6
2.0 Cooktop CT09 11
2.1. Experimental information for CT09 11
2.2. Results for CT09 16
3.0 Cooktop CT10 21
3.1. Experimental information for CT10 21
3.2. Results for CT10 25
4.0 Cooktop CT11 30
4.1. Experimental information for CT11 30
4.2. Results for CT11 34
5.0 Cooktop CT12 39
5.1. Experimental information for CT12 39
5.2. Results for CT12 43
6.0 Cooktop CT13 48
6.1. Experimental information for CT13 48
6.2. Results for CT13 52

List of Figures

Figure 1. Cooktop CT08. 2
Figure 2. Close-up of CT08 left rear burner. 2
Figure 3. Close-up of CT08 front burner flame with pot of water (PG&E line gas). 3
Figure 4. Analytical sampling configuration for CT08. 4
Figure 5. Installation of CT08. 4
Figure 6. Measured analyte concentrations for cooktop CT08 with PG&E line gas (L135). 8
Figure 7. Measured analyte concentrations for cooktop CT08 with fuel 3C (L136). 8
Figure 8. Measured analyte concentrations for cooktop CT08 with fuel 1C (L137). 9
Figure 9. Measured analyte concentrations for cooktop CT08 with PG&E line gas (L138). 9
Figure 10. Cooktop CT09. 12
Figure 11. Close-up of CT09 left front burner. 12
Figure 12. Close-up of CT09 front burner flame with pot of water. 13
Figure 13. CT09 left burner flames with pots of water (PG&E line gas). 13
Figure 14. Analytical sampling configuration for CT09. 14
Figure 15. Installation of CT09. 15
Figure 16. Measured analyte concentrations for cooktop CT09 with PG&E line gas (L143). 18
Figure 17. Measured analyte concentrations for cooktop CT09 with fuel 2C (L144). 19
Figure 18. Measured analyte concentrations for cooktop CT09 with fuel 3C (L145). 19
Figure 19. Measured analyte concentrations for cooktop CT09 with fuel 1C (L146). 20
Figure 20. Cooktop CT10. 22
Figure 21. Close-up of CT10 front burner flame with PG&E line gas. 22
Figure 22. Analytical sampling configuration for CT10. 23
Figure 23. Installation of CT10. 24
Figure 24. Measured analyte concentrations for cooktop CT10 with PG&E line gas (L151). 27
Figure 25. Measured analyte concentrations for cooktop CT10 with fuel 3C (L152). 27
Figure 26. Measured analyte concentrations for cooktop CT10 with fuel 1C (L153). 28
Figure 27. Measured analyte concentrations for cooktop CT10 with fuel 2C (L154). 28

Figure 28. Cooktop CT11. 31
Figure 29. Close-up of CT11 burners with/out grates. 32
Figure 30. CT11 front right burner flame with PG&E line gas. 32
Figure 31. Analytical sampling configuration for CT11. 33
Figure 32. Measured analyte concentrations for cooktop CT11 with fuel 2C (L160). 36
Figure 33. Measured analyte concentrations for cooktop CT11 with PG&E line gas (L161) 37
Figure 34. Measured analyte concentrations for cooktop CT11 with fuel 3C (L162). 37
Figure 35. Measured analyte concentrations for cooktop CT11 with fuel 1C (L163). 38
Figure 36. Cooktop CT12. –Need a better picture with grates. 39
Figure 37. Close-up of CT12 burners with/out grates. 40
Figure 38. CT12 front right burner flame with PG&E line gas. 40
Figure 39. Analytical sampling configuration for CT12. 41
Figure 40. Measured analyte concentrations for cooktop CT12 with fuel 2C (L168). 45
Figure 41. Measured analyte concentrations for cooktop CT12 with PG&E line gas (L169) 45
Figure 42. Measured analyte concentrations for cooktop CT12 with fuel 3C (L170). 46
Figure 43. Measured analyte concentrations for cooktop CT12 with fuel 1C (L171). 46
Figure 44. Cooktop CT13. 49
Figure 45. Close-up of CT13 burners with/out grates. 49
Figure 46. CT13 front right burner flame with PG&E line gas. 50
Figure 47. Analytical sampling configuration for CT13. 51
Figure 48. Measured analyte concentrations for cooktop CT13 with fuel 1C (L180). 54
Figure 49. Measured analyte concentrations for cooktop CT13 with fuel 3C (L181). 55
Figure 50. Measured analyte concentrations for cooktop CT13 with PG&E line gas (L182) 55
Figure 51. Measured analyte concentrations for cooktop CT13 with fuel 2C (L183). 56

List of Tables

Table 1. Appliance and burner information CT08. 1

Table 2. Interchangeability experiments for cooktop CT08. 3

Table 3. Fuel analysis for interchangeability experiments with CT08. 3

Table 4. Analyte ranges and calibration levels for experiments with CT08. 5

Table 5. Aerosol instrumentation used for CT08. 5

Table 6. Other measurements for experiments with CT08. 5

Table 7. Burner operating parameters for experiments with cooktop CT08. 6

Table 8. Environmental conditions[1] for experiments with CT08. 6

Table 9. Sampling location temperature (at hood exhaust) and dilution ratio for CT08 experiments. 7

Table 10. Measured RH of sample stream at room temperature. [1] 7

Table 11. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT08. 7

Table 12. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT08. 10

Table 13. Calculated emission rates over entirety of each burn, cooktop CT08. 10

Table 14. Appliance and burner information CT09. 11

Table 15. Interchangeability experiments for cooktop CT09. 14

Table 16. Fuel analysis for interchangeability experiments with CT09. 14

Table 17. Analyte ranges and calibration levels for experiments with CT09. 15

Table 18. Aerosol instrumentation used for CT09. 15

Table 19. Other measurements for experiments with CT09. 16

Table 20. Burner operating parameters for experiments with cooktop CT09. 17

Table 21. Environmental conditions[1] for experiments with CT09. 17

Table 22. Sampling location temperature (at hood exhaust) and dilution ratio for CT09 experiments. 17

Table 23. Measured RH of sample stream at room temperature. [1] 18

Table 24. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT09. 18

Table 25. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT09. 20

Table 26. Calculated emission rates over entirety of each burn, cooktop CT09. 20

Table 27. Appliance and burner information CT10. 21

Table 28. Interchangeability experiments for cooktop CT10. 23

Table 29. Fuel analysis for interchangeability experiments with CT10. 23

Table 30. Analyte ranges and calibration levels for experiments with CT10. 24

Table 31. Aerosol instrumentation used for CT10. 24

Table 32. Other measurements for experiments with CT10. 25

Table 33. Burner operating parameters for experiments with cooktop CT10. 25

Table 34. Environmental conditions[1] for experiments with CT10. 26

Table 35. Sampling location temperature (at hood exhaust) and dilution ratio for CT10 experiments. 26

Table 36. Measured RH of sample stream at room temperature.[1] 26

Table 37. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT10. 26

Table 38. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT10. 29

Table 39. Calculated emission rates over entirety of each burn, cooktop CT10. 29

Table 40. Appliance and burner information CT11. 31

Table 41. Interchangeability experiments for cooktop CT11. 32

Table 42. Fuel analysis for interchangeability experiments with CT11. 33

Table 43. Analyte ranges and calibration levels for experiments with CT11. 33

Table 44. Aerosol instrumentation used for CT11. 34

Table 45. Other measurements for experiments with CT11. 34

Table 46. Burner operating parameters for experiments with cooktop CT11. 35

Table 47. Environmental conditions[1] for experiments with CT11. 35

Table 48. Sampling location temperature (at hood exhaust) and dilution ratio for CT11 experiments. 35

Table 49. Measured RH of sample stream at room temperature.[1] 36

Table 50. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT11. 36

Table 51. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT11. 38

Table 52. Calculated emission rates over entirety of each burn, cooktop CT11. 38

Table 53. Appliance and burner information CT12. 39

Table 54. Interchangeability experiments for cooktop CT12. 41

Table 55. Fuel analysis for interchangeability experiments with CT12. 41

Table 56. Analyte ranges and calibration levels for experiments with CT12. 42

Table 57. Aerosol instrumentation used for CT12. 42

Table 58. Other measurements for experiments with CT12. 42

Table 59. Burner operating parameters for experiments with cooktop CT12. 43

Table 60. Environmental conditions[1] for experiments with CT12. 43

Table 61. Sampling location temperature (at hood exhaust) and dilution ratio for CT12 experiments. 44

Table 62. Measured RH of sample stream at room temperature. [1] 44

Table 63. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT12. 44

Table 64. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT12. 47

Table 65. Calculated emission rates over entirety of each burn, cooktop CT12. 47

Table 66. Appliance and burner information CT13. 48

Table 67. Interchangeability experiments for cooktop CT13. 50

Table 68. Fuel analysis for interchangeability experiments with CT13. 50

Table 69. Analyte ranges and calibration levels for experiments with CT13. 51

Table 70. Aerosol instrumentation used for CT13. 51

Table 71. Other measurements for experiments with CT13. 52

Table 72. Burner operating parameters for experiments with cooktop CT13. 53

Table 73. Environmental conditions[1] for experiments with CT13. 53

Table 74. Sampling location temperature (at hood exhaust) and dilution ratio for CT13 experiments. 53

Table 75. Measured RH of sample stream at room temperature. [1] 54

Table 76. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT13. 54

Table 77. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT13. 56

Table 78. Calculated emission rates over entirety of each burn, cooktop CT13. 56

1.0 Cooktop CT08

1.1. Experimental information for CT08

Four experiments (L135-L138) were conducted on the same day using, in order, PG&E line gas (WN=1334), mix 1C (WN=1390), mix 3C (WN=1419) and PG&E line gas. 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). To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 1. Appliance and burner information CT08.

Burner ID	CT08
Appliance manufacturer	General Electric
Model number	JGSP30GER1B7
Serial number	MG221447Q
Year of manufacture	1992
Burner technologies	Sealed burners; drilled ports in cast burner heads; burner head fixed in place with removable top disk
Burner ratings (Btu/h)	LF: 10,000; LR: 6000; RR: 6000; RF: 10,000; total = 32,000
Other information	Procured December 2008
Test location	Laboratory
History notes	Identified via Craig's List. Purchased from associate of owner with no knowledge of age or history of use. Owner provided assurance that all burners were in proper working order.

Figure 1. **Cooktop CT08.**

Figure 2. Close-up of CT08 left rear burner.

Figure 3. Close-up of CT08 front burner flame with pot of water (PG&E line gas).

Table 2. Interchangeability experiments for cooktop CT08.

Exp.	Fuel	Date	Burner operation
L135	PG&E	01/05/09	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L136	1C	01/05/09	
L137	3C	01/05/09	
L138	PG&E	01/05/09	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 3. Fuel analysis for interchangeability experiments with CT08.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L135, L138	PG&E	L135 [2]	95.4	2.48	0.30	0.10	0.98	0.77	1018	1334
L136	1C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L137	3C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390

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

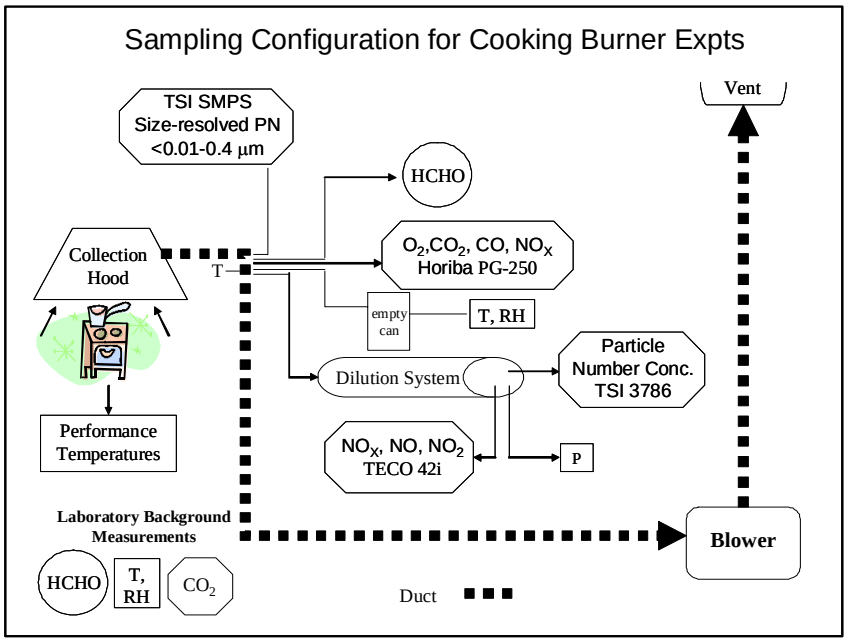

Figure 4. Analytical sampling configuration for CT08.

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.

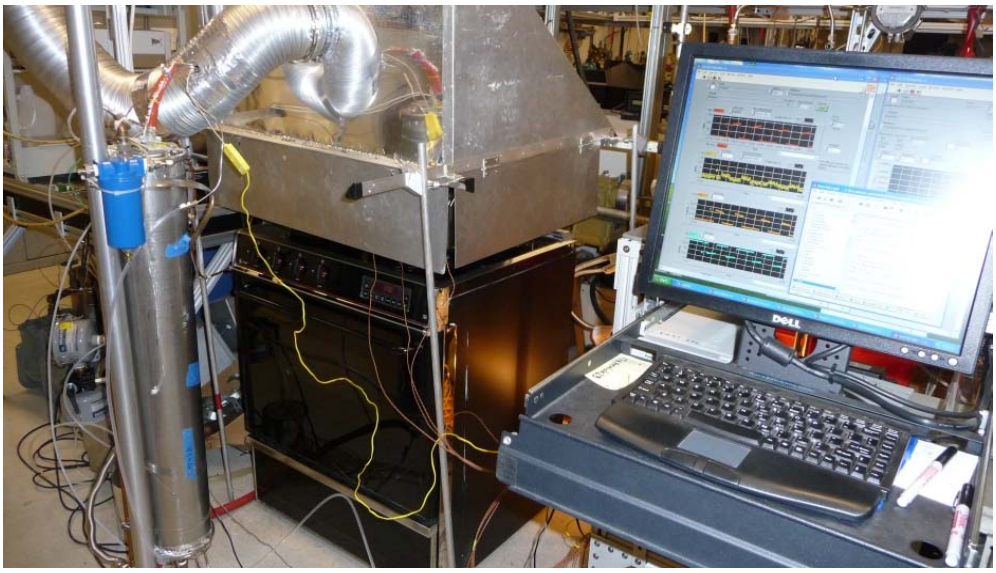

Figure 5. Installation of CT08.

Table 4. Analyte ranges and calibration levels for experiments with CT08.

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 5. Aerosol instrumentation used for CT08.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 6. Other measurements for experiments with CT08.

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, 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)

1.2. Results for CT08

Full burn emission rates were <10 ng/J for CO, 32-35 ng/J for NO_X, 6.3-7.3 ng/J for NO_2, 130-1600 x10^4 J^{-1} for PN and 0.08-0.11 ng/J for HCHO. These CO and formaldehyde emission rates are the lowest measured to date for cooktops. None of the pollutant emission rates varied with fuel Wobbe number. As in some past experimental series, particle number (PN) emissions were elevated in the first experiment of the day and much higher in this experiment with PG&E compared with the last experiment of the day. PN emissions decreased over the first three experiments (PG&E, 1C then 3C) then increased by roughly 80% between the 3rd and 4th experiments. The possibility of an experiment order effect is being investigated with the dataset of previous experiments.

Table 7. Burner operating parameters for experiments with cooktop CT08.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate, counter[2] (ft^3/h)	Firing rate, stopwatch[3] (kBtu/h)	Supply P (in. H_2O)[4]
L135	B1	09:17	09:32	31	31	7.5
(PG&E)	B2	09:52	10:07	29	29	7.5
L136	B1	10:40	10:55	30	31	7.7
(1C)	B2	11:15	11:30	30	28	7.7
L137	B1	12:50	13:05	32	30	7.7
(3C)	B2	13:25	13:40	31	30	7.7
L138	B1	14:10	14:24	n/a	32	7.5
PG&E	B2	14:45	15:00	n/a	29	7.5

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow (ft^3 h^{-1}) calculated over full burn using counter on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Fuel flow (ft^3 h^{-1}) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[4] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 8. Environmental conditions[1] for experiments with CT08.

Exp.	Fuel	T (°C)	RH (%)
L135	PG&E	22.1 ± 0.2	32 ± 1
L136	3C	22.5 ± 0.1	35 ± 1
L137	1C	21.7 ± 0.2	40 ± 1
L138	PG&E	21.7 ± 0.2	42 ± 0

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 9. Sampling location temperature (at hood exhaust) and dilution ratio for CT08 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L135	70 ± 1	71 ± 1	32	32
L136	73 ± 1	73 ± 1	31	32
L137	75 ± 1	73 ± 1	32	32
L138	70 ± 1	70 ± 1	32	32

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 10. Measured RH of sample stream at room temperature. [1]

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
L135	19.2 ± 0	19.2 ± 0	53 ± 1	54 ± 1
L136	19.3 ± 0	19.4 ± 0	56 ± 1	58 ± 1
L137	19.3 ± 0	19.2 ± 0	62 ± 1	63 ± 1
L138	19.2 ± 0	19.1 ± 0	63 ± 1	63 ± 1

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 11. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT08.

Exp(s)	Location	Date	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/μL)	Acet extract conc. (ng/μL)	HCHO air conc.[1] (μg/m^3)	Acet. air conc.[1] (μg/m^3)
Bkg	Lab air	01/05/09	9:12	15:02	0.96	337	0.282	0.186	2	1
L135a	Collection hood outlet	01/05/09	9:15	10:09	1.06	57	0.346	0.092	12	3
L135b			9:15	10:09	1.03	55	0.341	0.101	12	4
L136			10:38	11:32	0.98	53	0.290	0.061	11	2
L137			12:48	13:42	0.97	52	0.305	0.099	12	4
L138			14:08	15:02	0.98	53	0.261	0.065	10	2

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

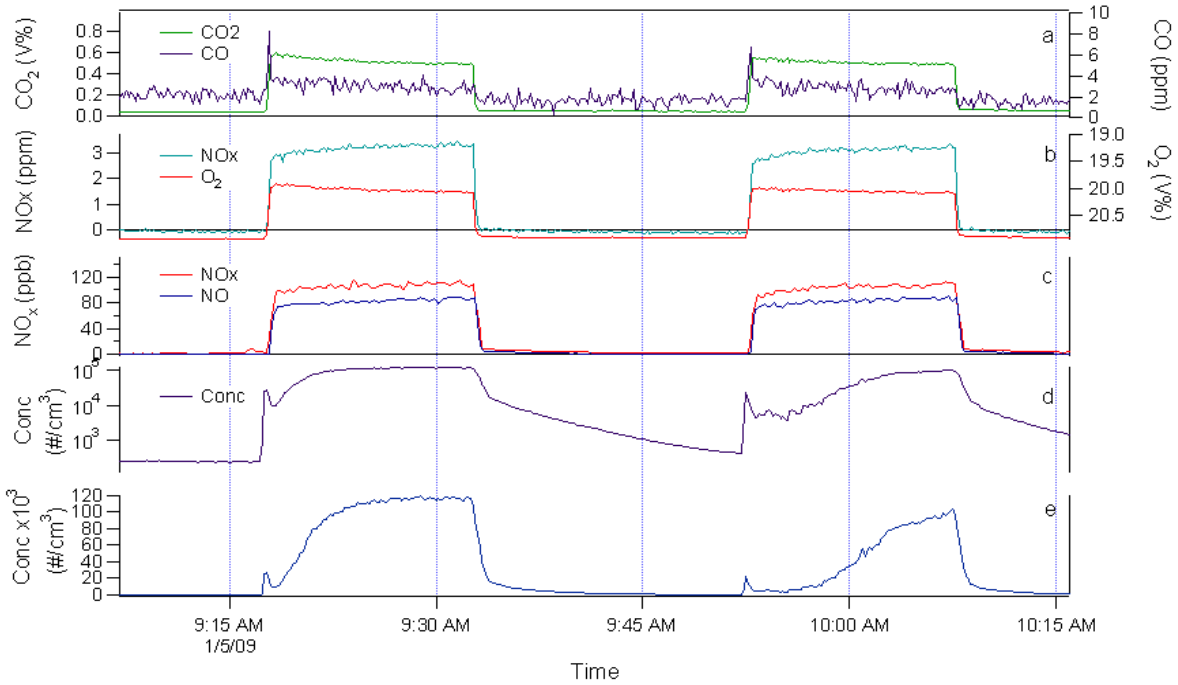

Figure 6. Measured analyte concentrations for cooktop CT08 with PG&E line gas (L135).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

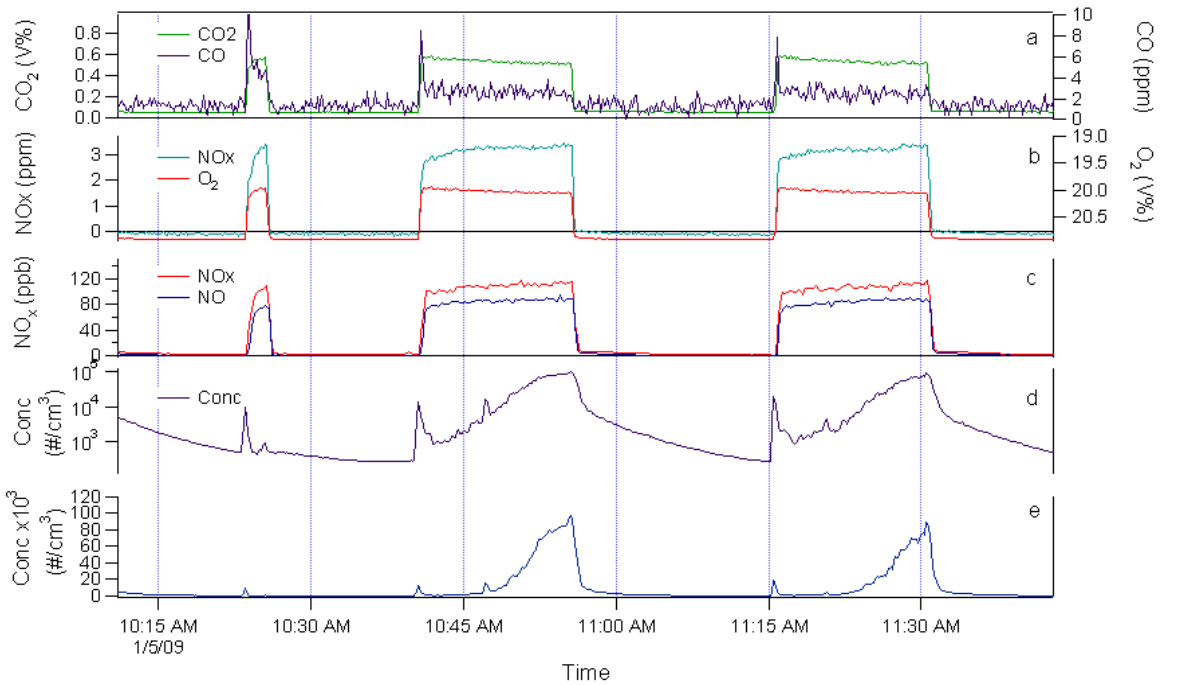

Figure 7. Measured analyte concentrations for cooktop CT08 with fuel 3C (L136).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

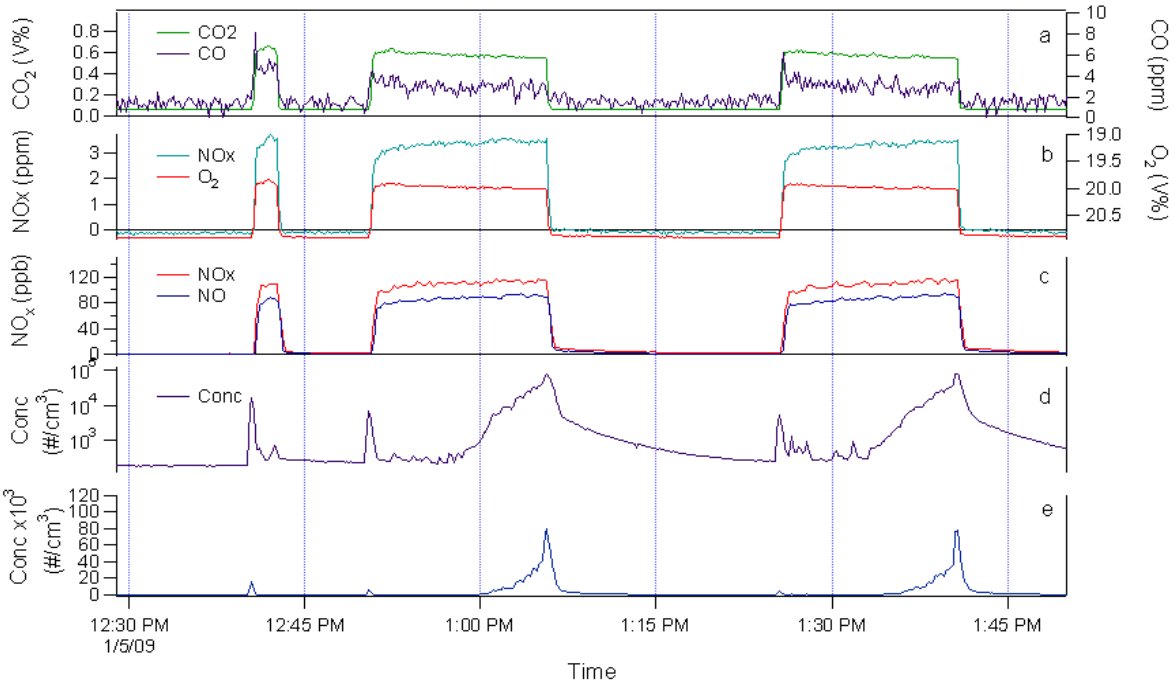

Figure 8. Measured analyte concentrations for cooktop CT08 with fuel 1C (L137).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

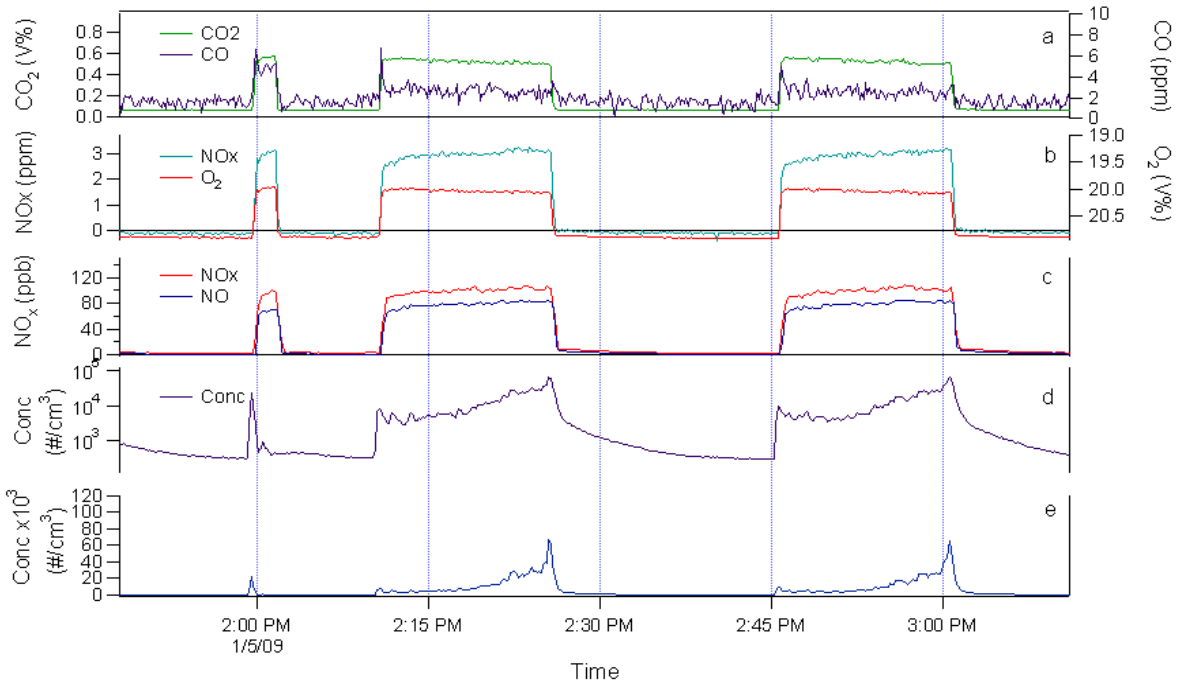

Figure 9. Measured analyte concentrations for cooktop CT08 with PG&E line gas (L138).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 12. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT08.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L135	PG&E	1334	26	23	88	86	70	71	17.5	15.1	950	680
L136	1C	1390	30	26	85	84	68	68	17.4	16.1	440	340
L137	3C	1419	32	30	83	82	67	66	16.0	15.8	86	81
L138	PG&E	1334	23	22	81	80	66	65	15.2	15.2	160	150

Table 13. Calculated emission rates over entirety of each burn, cooktop CT08.

Exp	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)		NO_X ($\mu g\ KJ^{-1}$)		NO ($\mu g\ KJ^{-1}$)		NO_2 ($\mu g\ KJ^{-1}$)		PN ($10^7\ KJ^{-1}$)		HCHO ($\mu g\ KJ^{-1}$)
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L135	PG&E	1334	9	7	35	35	27	28	7.3	6.5	1600	820	0.11, 0.11
L136	1C	1390	9	8	35	35	28	28	7.2	7.1	490	380	0.09
L137	3C	1419	9	10	34	34	27	27	6.9	6.7	140	130	0.09
L138	PG&E	1334	7	7	33	32	26	26	6.6	6.3	230	220	0.08

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2.0 Cooktop CT09

2.1. Experimental information for CT09

This range was procured from a landlord in late December 2008; the stated reason for sale was that the incoming tenant was bringing a stove. The range showed signs of aggressive cleaning, including scratches and a nameplate that was scrubbed to the point of being illegible. However, since the seller demonstrated that all burners were in proper working order and there was no indication of tampering with the burners or supplies lines, the unit was purchased for testing. Four experiments (L143-L146) were conducted on the same day using, in order, PG&E line gas (WN=1329), mix 2C (WN=1359), mix 1C (WN=1389) and mix 3C (WN=1419). 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. To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 14. Appliance and burner information CT09.

Burner ID	CT09
Appliance manufacturer	Kenmore
Model number	Illegible
Serial number	Illegible
Age	2 years[1]
Burner technologies	Sealed burners; removable cast aluminum burners with removable top discs. Burners of uniform size.
Burner ratings (Btu/h)	Front burners: 10,000; Rear burners: 6000; Total: 32,000
Other information	Procured December 2008
Test location	Laboratory
History notes	Identified via Craig's List. Purchased from landlord; stated reason for sale was that new tenant was bringing own stove. Frequency of use unknown. Evidence of aggressive cleaning including scratches to surface finish and rubbing away of product information label.

[1]Sellers reported this information with certainty (they had purchased unit). The date 2/17/07 was written on back of unit in permanent marker (purpose of this marking unknown).

Figure 10. Cooktop CT09.

Figure 11. Close-up of CT09 left front burner.

Figure 12. Close-up of CT09 front burner flame with pot of water.
Operation with PG&E line gas subsequent to experiment.

Figure 13. CT09 left burner flames with pots of water (PG&E line gas).
Operation with PG&E line gas subsequent to experiment.

Table 15. Interchangeability experiments for cooktop CT09.

Exp.	Fuel	Date	Burner operation
L143	PG&E	01/12/09	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L144	2C	01/12/09	
L145	3C	01/12/09	
L146	1C	01/12/09	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 16. Fuel analysis for interchangeability experiments with CT09.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L143	PG&E	PG&E [2]	95.3	2.41	0.27	0.11	1.02	0.91	1016	1329
L144	2C	Cylinder[3]	90.4	7.90	-	-	1.70	-	1053	1359
L145	3C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L146	1C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390

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

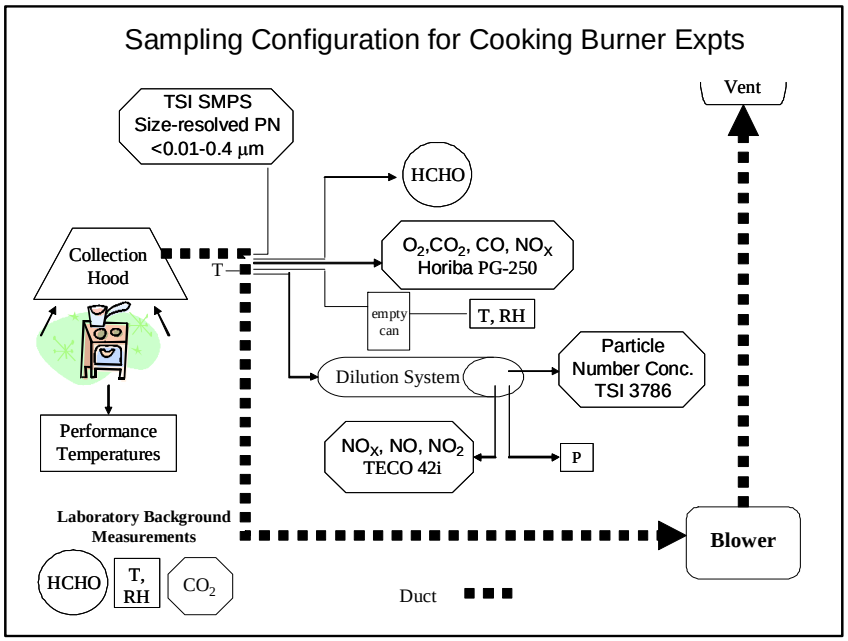

Figure 14. Analytical sampling configuration for CT09.

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 15. Installation of CT09.

Table 17. Analyte ranges and calibration levels for experiments with CT09.

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 18. Aerosol instrumentation used for CT09.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 19. Other measurements for experiments with CT09.

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 dry gas meter, 1- & ¼-ft dials (American Meter); 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, water	Inside pots, cooktop	Thermocouple (K), probe, Omega KQSS-18E-12

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

2.2. Results for CT09

Full burn emission rates were 830-910 ng/J for CO, 24-26 ng/J for NO_X, 17.3-18.5 ng/J for NO_2, 100-1100 x10^4 J^{-1} for PN and 4.4-4.7 ng/J for HCHO. This unit had the highest CO, HCHO and NO_2 emission rates, as well as the highest fraction of NO_X as NO_2 of any cooktop evaluated to date. These results indicate incomplete combustion. There was not, however, any substantial trend of emissions varying across the three fuels evaluated. As in some past experimental series, particle number (PN) emissions were elevated in the first experiment of the day and much higher in this experiment with PG&E compared with the last experiment of the day. PN emissions decreased from the first experiment with PG&E to fuel 1C, then increased with fuel 3C and decreased again with PG&E line gas. Replacement of the burner grates with a set having a higher profile (from a another cooktop) lead to substantially reduced, though still high levels of CO in the exhaust stream.

Table 20. Burner operating parameters for experiments with cooktop CT09.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate, stopwatch[2] (kBtu/h)	Supply P (in. H_2O)[3]
L143	B1	09:42	09:57	25	7.5
(PG&E)	B2	10:17	10:32	27	7.4
L144	B1	11:08	11:23	27	7.7
(2C)	B2	11:43	11:58	28	7.7
L145	B1	13:12	13:27	31	7.7
(3C)	B2	13:47	14:02	30	7.7
L146	B1	14:41	14:56	28	7.6
(1C)	B2	15:16	15:31	27	7.6

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow ($ft^3\ h^{-1}$) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 21. Environmental conditions[1] for experiments with CT09.

Exp.	Fuel	T (°C)	RH (%)
L143	PG&E	21.5 ± 0.3	36 ± 0
L144	2C	21.9 ± 0.3	36 ± 0
L145	3C	22.8 ± 0.2	36 ± 0
L146	1C	22.8 ± 0.2	37 ± 0

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 22. Sampling location temperature (at hood exhaust) and dilution ratio for CT09 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L143	68 ± 1	69 ± 1	30	27
L144	72 ± 1	72 ± 1	27	27
L145	77 ± 1	78 ± 1	27	28
L146	76 ± 1	77 ± 1	27	27

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 23. Measured RH of sample stream at room temperature. [1]

Exp.	Sample Manifold T (°C)[1]						Sample Manifold RH (%)[1]					
	Burn 1			Burn 2			Burn 1			Burn 2		
L143	19.9	±	0	20.2	±	0	60	±	0	58	±	0
L144	20.4	±	0	20.6	±	0	58	±	0	59	±	0
L145	21	±	0	21.2	±	0	59	±	1	59	±	0
L146	21.5	±	0	21.6	±	0	58	±	1	58	±	1

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 24. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT09.

Exp(s)	Location	Date	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/µL)	Acet extract conc. (ng/µL)	HCHO air conc.[1] (µg/m^3)	Acet. air conc.[1] (µg/m^3)
Bkg	Lab air	01/12/09	9:33	15:33	0.99	357	1.73	0.35	10	2
L143a	Collection hood outlet	01/12/09	9:40	10:34	1.08	58	16.14	1.19	556	41
L143b			9:40	10:34	1.18	64	17.31	1.28	542	40
L144			11:06	12:00	1.09	59	15.70	1.23	535	42
L145			13:10	14:04	1.06	57	17.66	1.56	616	54
L146			14:39	15:33	1.06	57	16.64	1.23	579	43

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

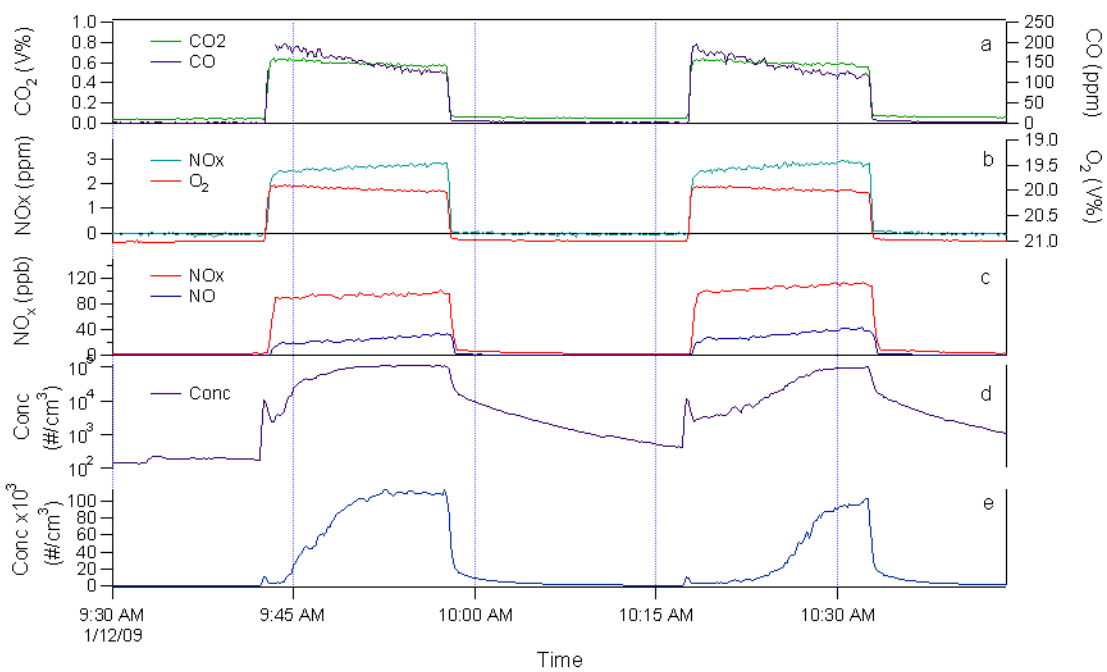

Figure 16. Measured analyte concentrations for cooktop CT09 with PG&E line gas (L143). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

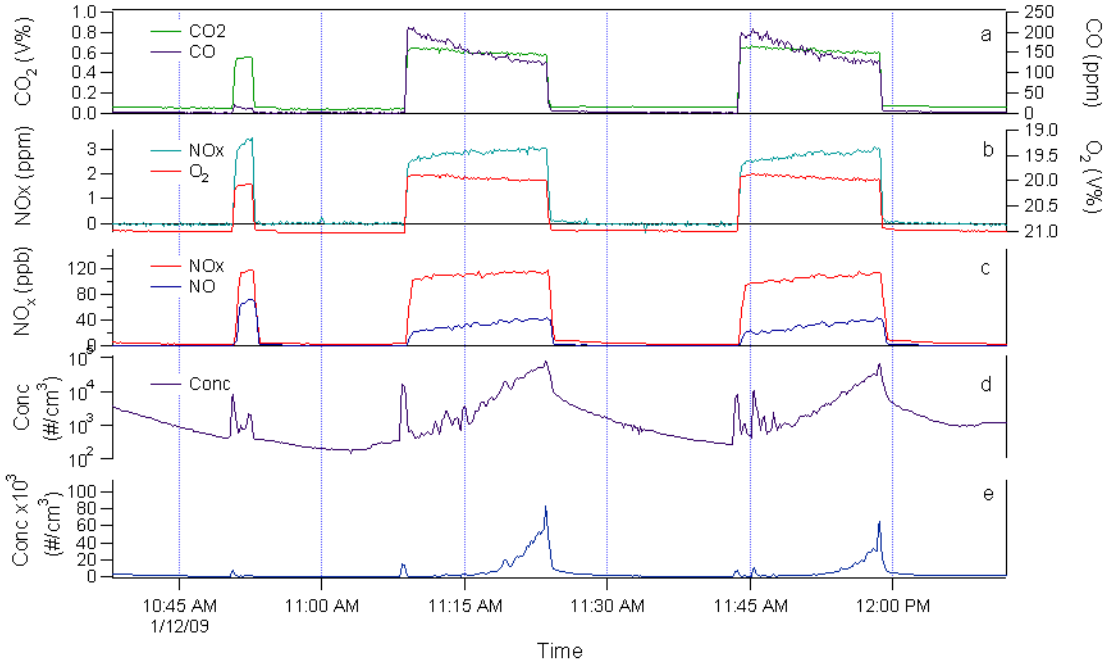

Figure 17. Measured analyte concentrations for cooktop CT09 with fuel 2C (L144).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

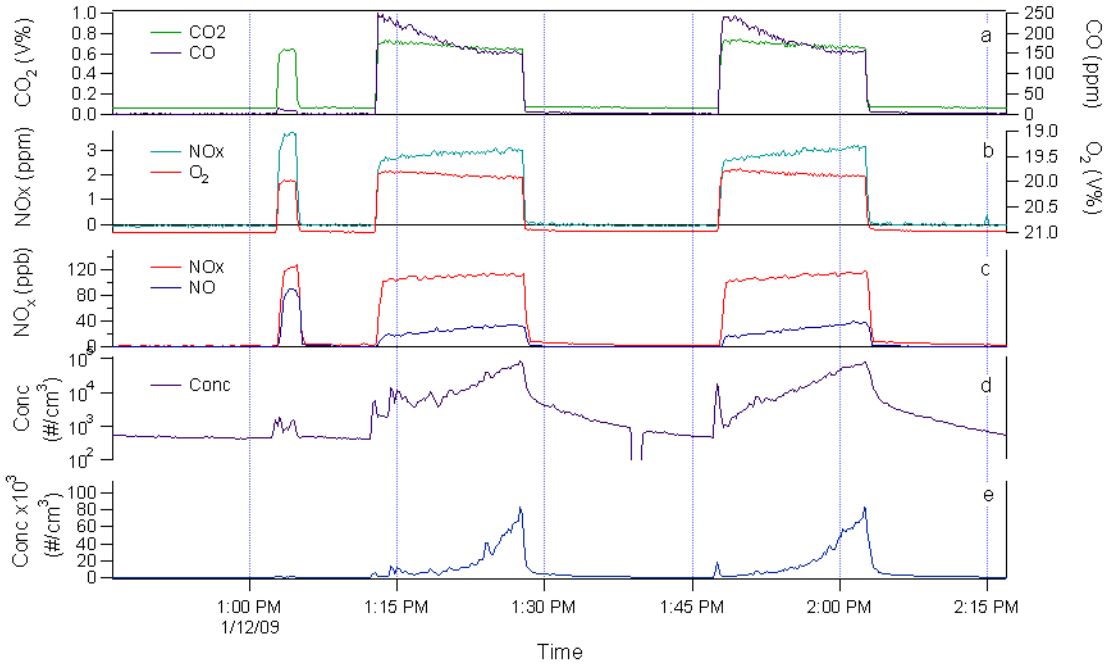

Figure 18. Measured analyte concentrations for cooktop CT09 with fuel 3C (L145).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

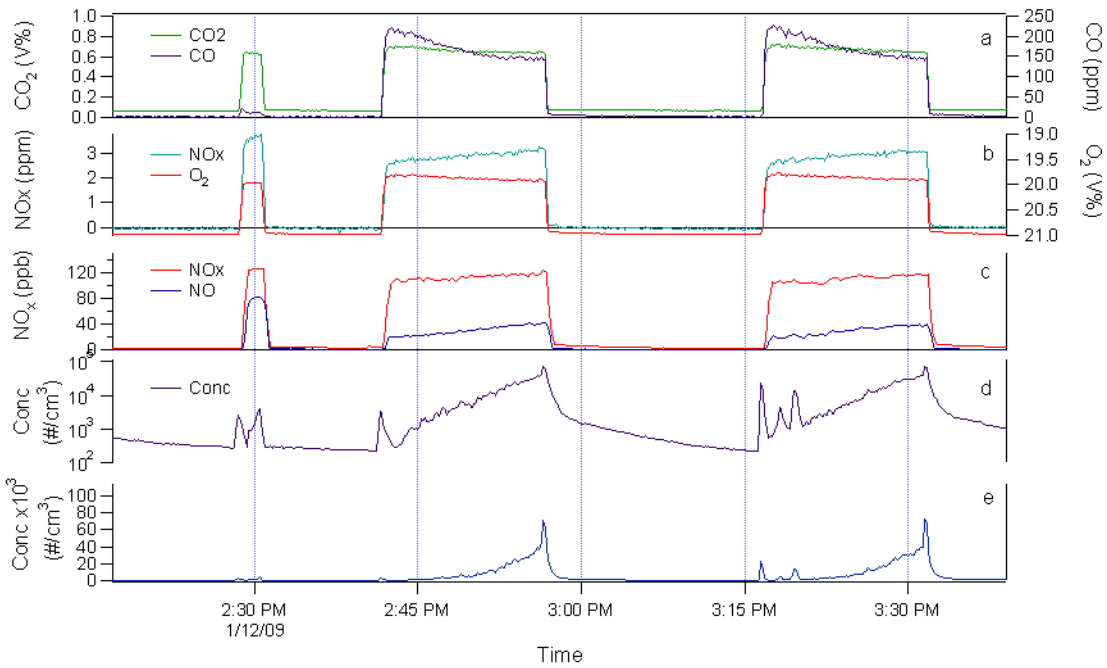

Figure 19. Measured analyte concentrations for cooktop CT09 with fuel 1C (L146).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 25. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT09.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L143	PG&E	1329	2900	2650	62	63	20	23	43	41	730	480
L144	1C	1359	2800	2750	66	61	23	21	43	41	130	70
L145	3C	1419	3000	3000	60	60	17	18	43	42	180	210
L146	PG&E	1390	2900	2900	62	60	20	19	42	41	100	110

Table 26. Calculated emission rates over entirety of each burn, cooktop CT09.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		NO_X (μg KJ^{-1})		NO (μg KJ^{-1})		NO_2 (μg KJ^{-1})		PN (10^7 KJ^{-1})		HCHO (μg KJ^{-1})
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L143	PG&E	1329	850	790	25	25	6.7	7.8	18.1	17.3	1100	510	4.73, 4.61
L144	1C	1359	850	830	26	25	7.9	7.2	18.5	17.5	170	100	4.41
L145	3C	1419	910	910	24	24	5.8	5.9	18.4	18.1	230	260	4.65
L146	PG&E	1390	870	870	25	24	6.7	6.6	18.2	17.8	140	150	4.43

3.0 Cooktop CT10

3.1. Experimental information for CT10

Four experiments (L151-L154) were conducted on the same day using, in order, PG&E line gas (WN=1332), mix 3C (WN=1419), mix 1C (WN=1389) and mix 2C (WN=1359). 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. To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 27. Appliance and burner information CT10.

Burner ID	CT10
Appliance manufacturer	General Electric
Model number	JGB520BEW2WH (XL44)
Serial number	DS121180R
Manufacture year	1997
Burner technologies	Open, stamped aluminum burner, slotted ports
Burner ratings (Btu/h)	Each burner = 9,000 ; total = 36,000
Other information	Procured January 2009
Test location	Laboratory
History notes	Identified via Craig's List. Seller was selling on behalf of family member. Frequency of use unknown.

Figure 20. Cooktop CT10.

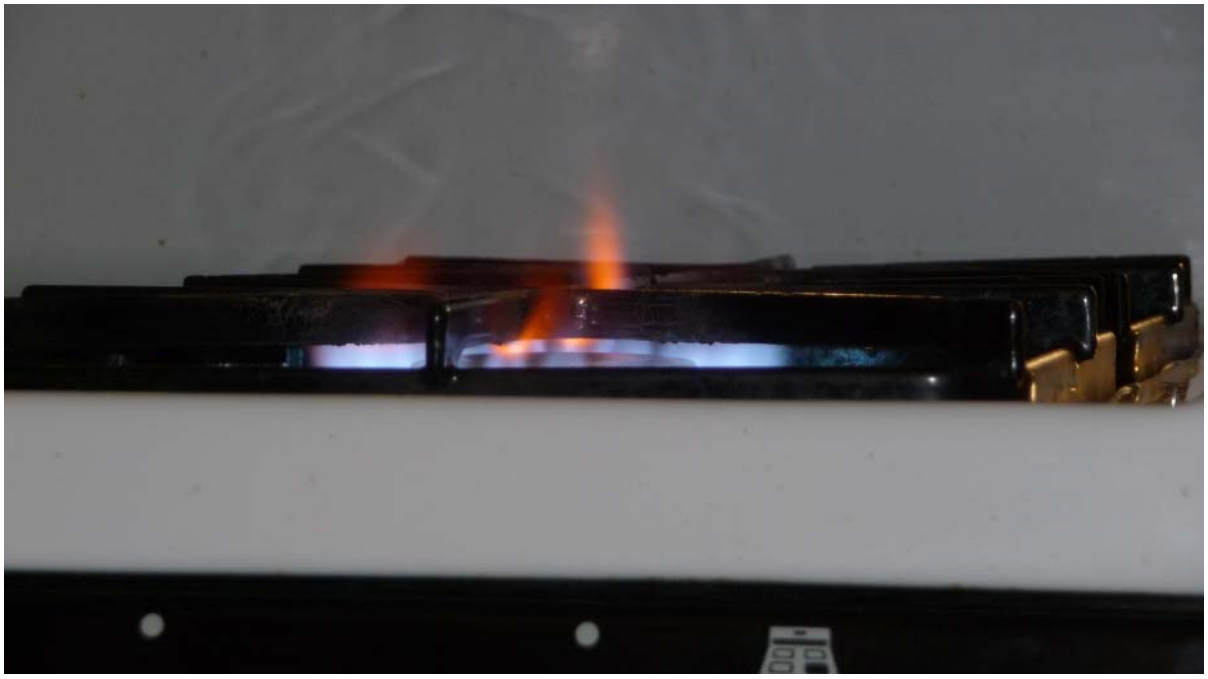

Figure 21. Close-up of CT10 front burner flame with PG&E line gas.
Photo taken subsequent to experiment; burner operating without pot of water used during experiments.

Table 28. Interchangeability experiments for cooktop CT10.

Exp.	Fuel	Date	Burner operation
L151	PG&E	01/20/09	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L152	3C	01/20/09	
L153	1C	01/20/09	
L154	2C	01/20/09	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 29. Fuel analysis for interchangeability experiments with CT10.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L151	PG&E	PG&E [2]	95.3	2.38	0.31	0.12	0.96	0.87	1017	1332
L152	3C	Cylinder[3]	86.4	12.0	1.60	-	-	-	1125	1419
L153	1C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390
L154	2C	Cylinder[3]	90.4	7.90	-	-	1.70	-	1053	1359

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

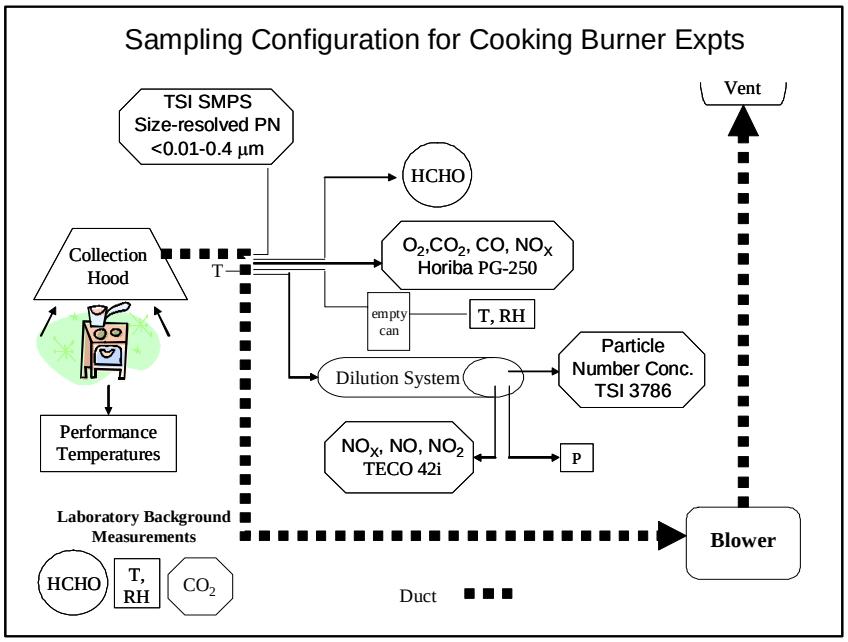

Figure 22. Analytical sampling configuration for CT10.

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 23. Installation of CT10.

Table 30. Analyte ranges and calibration levels for experiments with CT10.

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 31. Aerosol instrumentation used for CT10.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 32. Other measurements for experiments with CT10.

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 dry gas meter, 1- & ¼-ft dials (American Meter); 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, water	Inside pots, cooktop	Thermocouple (K), probe, Omega KQSS-18E-12

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

3.2. Results for CT10

Full burn emission rates were 54-85 ng/J for CO, 34-38 ng/J for NO_X, 7.9-11.3 ng/J for NO_2, 8-180 x10^4 J^{-1} for PN and 0.6-1.2 ng/J for HCHO. These levels reflect moderate emissions for CO and NO_2 and low PN emissions relative to other cooktops. CO appeared to increase monotonically with fuel Wobbe number but the other indicators of incomplete combustion – formaldehyde and nitrogen dioxide were lower for the two higher Wobbe fuels (1C and 3C) relative to the lower Wobbe fuels (PG&E and 2C). PN decreased through the series of experiments, as has been observed for other burners.

Table 33. Burner operating parameters for experiments with cooktop CT10.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate[2] (kBtu/h)	Supply P (in. H_2O)[3]
L151	B1	09:09	09:24	35	7.4
(PG&E)	B2	09:44	09:59	28	7.4
L152	B1	10:20	10:35	30	7.7
(3C)	B2	10:55	11:10	34	7.7
L153	B1	11:42	11:57	36	7.7
(1C)	B2	12:17	12:32	34	7.7
L154	B1	13:31	13:46	28	7.7
(2C)	B2	14:06	14:21	33	7.7

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow (ft^3 h^{-1}) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 34. Environmental conditions[1] for experiments with CT10.

Exp.	Fuel	T (°C)	RH (%)
L151	PG&E	22.0 ± 0.3	30 ± 1
L152	3C	22.2 ± 0.3	34 ± 1
L153	1C	22.3 ± 0.3	34 ± 1
L154	2C	22.3 ± 0.3	34 ± 0

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 35. Sampling location temperature (at hood exhaust) and dilution ratio for CT10 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L151	76 ± 1	77 ± 1	30	30
L152	79 ± 1	81 ± 1	30	30
L153	79 ± 1	79 ± 1	31	30
L154	79 ± 1	80 ± 1	31	31

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 36. Measured RH of sample stream at room temperature.[1]

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
L151	20.0 ± 0	20.3 ± 0	51 ± 0	48 ± 1
L152	20.7 ± 0	20.8 ± 0	53 ± 1	52 ± 1
L153	21.0 ± 0	21.1 ± 0	52 ± 1	52 ± 1
L154	21.3 ± 0	21.5 ± 0	51 ± 1	51 ± 1

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 37. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT10.

Exp(s)	Location	Date	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/μL)	Acet extract conc. (ng/μL)	HCHO air conc.[1] (μg/m^3)	Acet. air conc.[1] (μg/m^3)
Bkg	Lab air	01/20/09	9:06	14:23	1.04	330	0.712	0.324	4	2
L151a	Collection hood outlet	01/20/09	9:06	10:01	1.02	56	3.647	0.189	130	7
L151b			9:06	10:01	1.10	61	3.854	0.174	127	6
L152			10:18	11:12	1.05	57	2.503	0.289	88	10
L153			11:40	12:34	1.02	55	2.114	0.199	77	7
L154			13:29	14:23	1.04	56	3.996	0.295	142	10

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

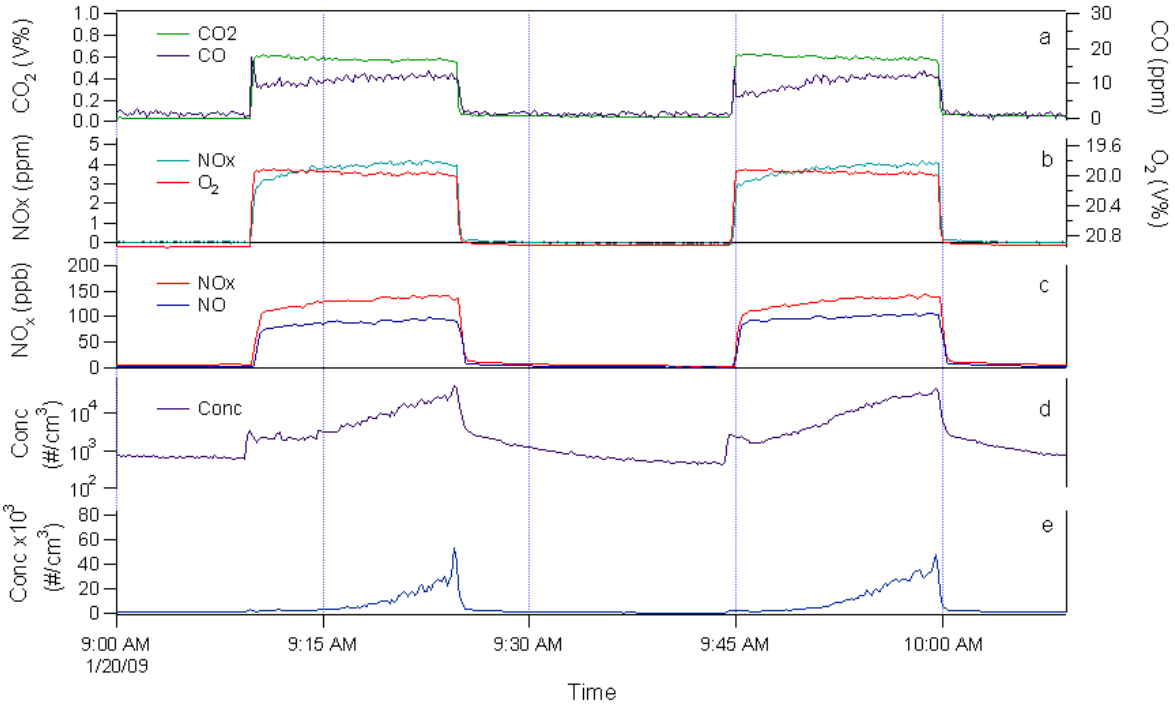

Figure 24. **Measured analyte concentrations for cooktop CT10 with PG&E line gas (L151).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

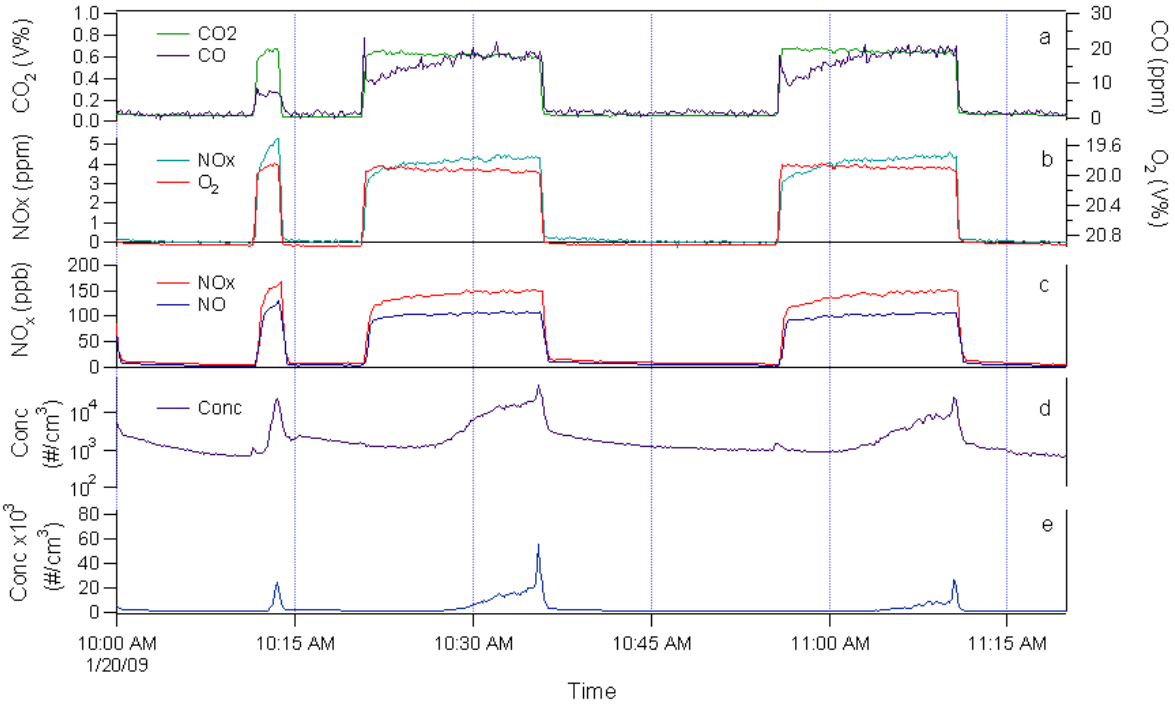

Figure 25. Measured analyte concentrations for cooktop CT10 with fuel 3C (L152). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

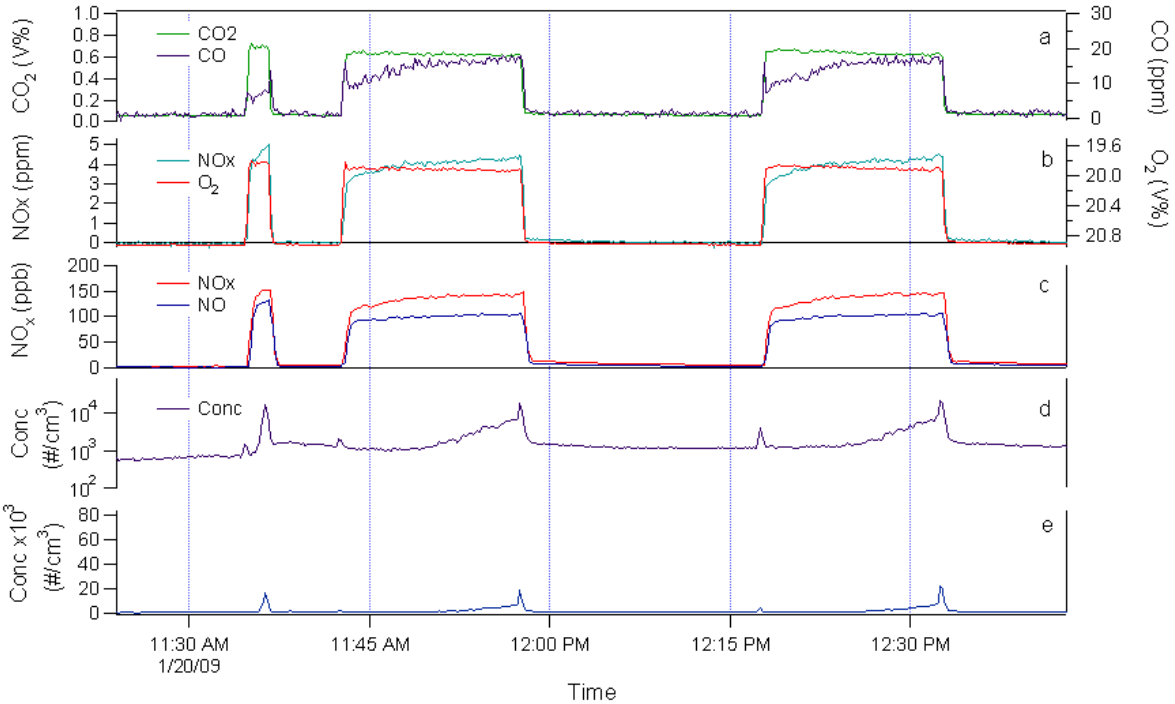

Figure 26. Measured analyte concentrations for cooktop CT10 with fuel 1C (L153).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

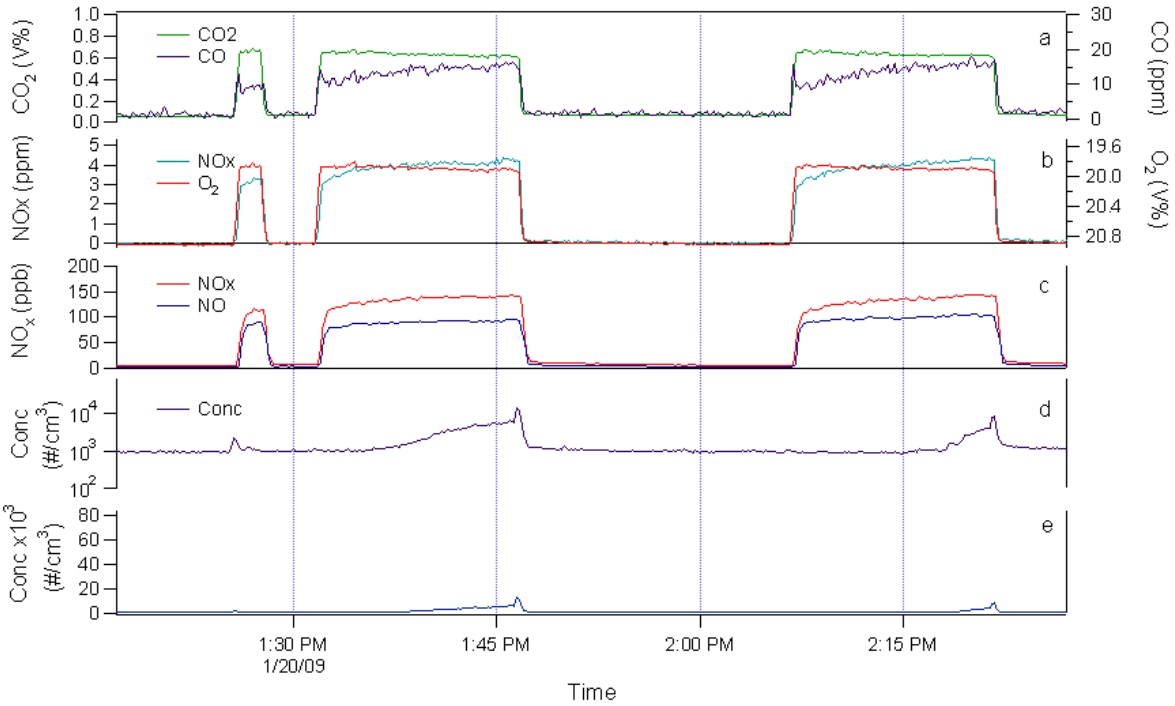

Figure 27. Measured analyte concentrations for cooktop CT10 with fuel 2C (L154).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 38. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT10.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L151	PG&E	1332	240	240	92	88	63	67	28	21	110	150
L152	3C	1419	360	370	92	87	67	63	25	25	77	29
L153	1C	1390	320	310	88	87	65	64	23	23	18	19
L154	2C	1359	280	290	85	86	57	64	28	22	22	5.1

Table 39. Calculated emission rates over entirety of each burn, cooktop CT10.

Exp	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)		NO_X ($\mu g\ KJ^{-1}$)		NO ($\mu g\ KJ^{-1}$)		NO_2 ($\mu g\ KJ^{-1}$)		PN ($10^7\ KJ^{-1}$)		HCHO ($\mu g\ KJ^{-1}$)
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L151	PG&E	1332	60	54	37	35	26	27	11.3	7.9	140	180	1.17, 1.14
L152	3C	1419	85	84	38	35	28	26	9.8	9.4	96	38	0.71
L153	1C	1390	74	71	36	35	27	26	9.1	8.9	26	30	0.60
L154	2C	1359	65	65	34	34	23	26	11.2	8.4	27	7.7	1.11

4.0 Cooktop CT11

4.1. Experimental information for CT11

This range was purchased from a used appliance retailer in San Jose, California. The store routinely advertises on craigslist.org. It was the only cooking appliance procured in this way; all others were purchased from private sellers. More than a dozen gas ranges were available in the store; this unit was selected as a newer model with sealed burners. The range appeared to be in good working order and came with a warranty. Four experiments (L160-L163) were conducted on the same day using, in order, mix 2C (WN=1359), PG&E line gas (WN=1333), mix 3C (WN=1419) and mix 1C (WN=1390). 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. To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 40. Appliance and burner information CT11.

Burner ID	CT11
Appliance manufacturer	General Electric
Model number	JGBP35BEA5BB (Spectra)
Serial number	DA245208P
Manufacture year	2001
Burner technologies	Sealed burners; removable cast aluminum burners with removable top discs. Burners of uniform size.
Burner ratings (Btu/h)	Right front = 12,000; Right rear=5,000; Others: 9,500 total = 36,000
Other information	Procured January 2009
Test location	Laboratory
History notes	Procured from used appliance dealer in San Jose, California. History unknown but seller provided 90-day warranty.

Figure 28. Cooktop CT11.

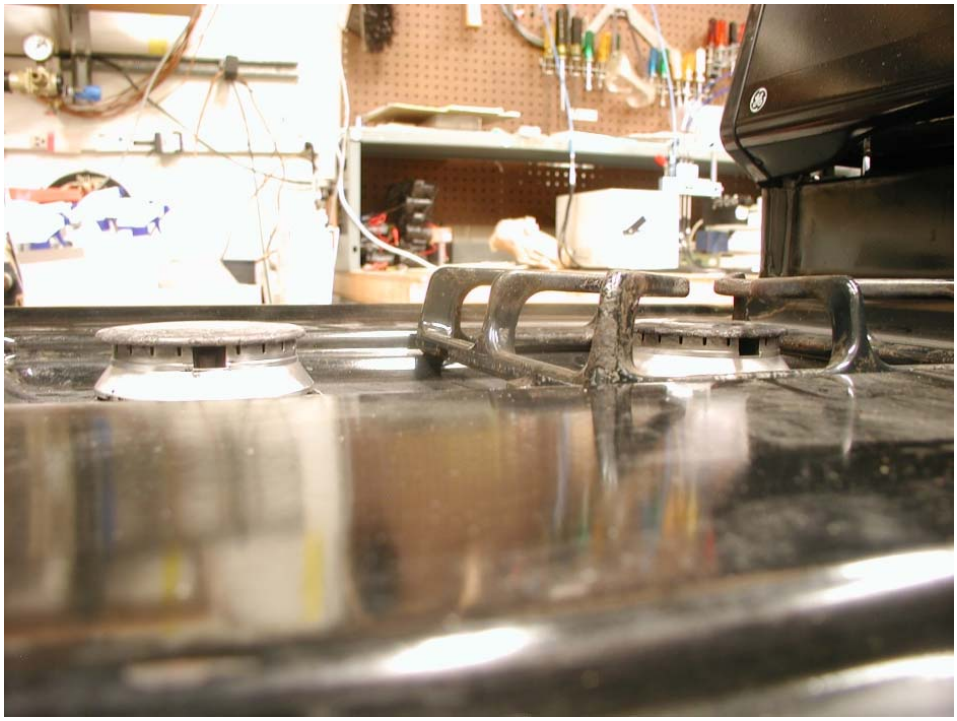

Figure 29. Close-up of CT11 burners with/out grates.

Figure 30. CT11 front right burner flame with PG&E line gas.

Table 41. Interchangeability experiments for cooktop CT11.

Exp.	Fuel	Date	Burner operation
L160	2C	01/26/09	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L161	PG&E	01/26/09	
L162	3C	01/26/09	
L163	1C	01/26/09	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 42. Fuel analysis for interchangeability experiments with CT11.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L160	2C	Cylinder[3]	90.4	7.90	-	-	1.70	-	1053	1359
L161	PG&E		95.6%	2.30%	0.30%	0.11%	0.82%	0.89%	1017	1333
L162	3C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L163	1C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390

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

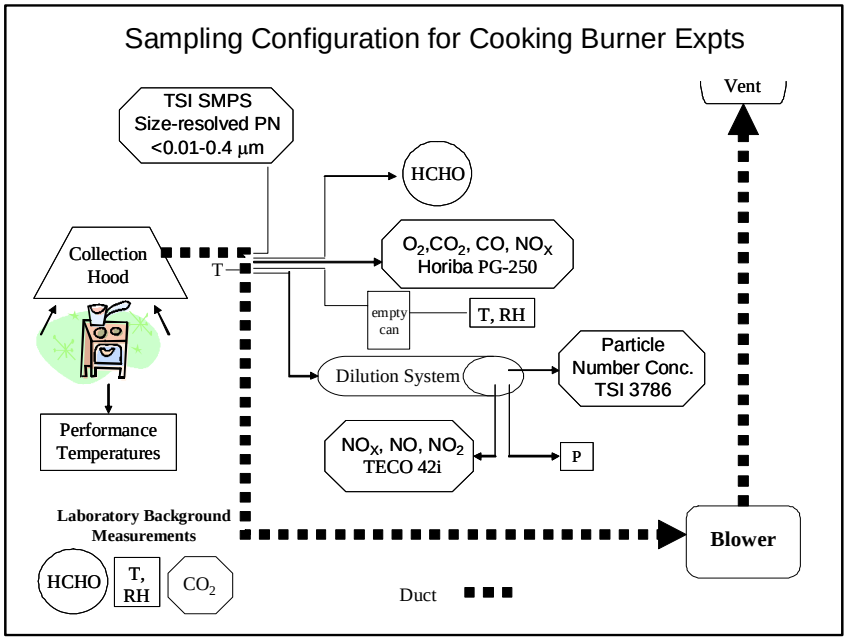

Figure 31. Analytical sampling configuration for CT11.

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.

Table 43. Analyte ranges and calibration levels for experiments with CT11.

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, 4.0 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 44. Aerosol instrumentation used for CT11.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 45. Other measurements for experiments with CT11.

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, 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 CT11

Full burn emission rates were 105-149 ng/J for CO, 29-32 ng/J for NO_X, 7.5-8.8 ng/J for NO_2, 70-1100 x10^4 J^{-1} for PN and 0.21-0.31 ng/J for HCHO. CO emissions were highest with fuel 3C (at about 150 ng/J), followed by 1C, with PG&E and 2C having similar CO emission levels of about 105 ng/J. Formaldehyde emissions were highest for the line gas and mix 2C relative to 1C and 3C. PN emissions decreased through the course of experiments with an effect that was larger than any effect of fuel properties.

Table 46. Burner operating parameters for experiments with cooktop CT11.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate[2] (kBtu/h)	Supply P (in. H_2O)[3]
L160	B1	08:30	08:45	37	7.6
(2C)	B2	09:05	09:22	31	7.6
L161	B1	09:56	10:11	35	7.4
(PG&E)	B2	10:31	10:46	31	7.4
L162	B1	11:12	11:27	37	7.7
(3C)	B2	11:47	12:02	36	7.7
L163	B1	13:12	13:27	37	7.6
(1C)	B2	13:47	14:02	34	7.7

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow ($ft^3\ h^{-1}$) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 47. Environmental conditions[1] for experiments with CT11.

Exp.	Fuel	T (°C)	RH (%)
L160	PG&E	21.9 ± 0.3	33 ± 0
L161	3C	21.7 ± 0.4	34 ± 0
L162	1C	20.9 ± 0.2	35 ± 1
L163	2C	22.4 ± 0.1	31 ± 0

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 48. Sampling location temperature (at hood exhaust) and dilution ratio for CT11 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L160	88 ± 1	89 ± 1	30	29
L161	85 ± 1	85 ± 1	28	28
L162	93 ± 1	92 ± 1	29	29
L163	89 ± 2	87 ± 1	29	29

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 49. Measured RH of sample stream at room temperature. [1]

Exp.	Sample Manifold T (°C)[1]						Sample Manifold RH (%)[1]					
	Burn 1			Burn 2			Burn 1			Burn 2		
L160	18.9	±	0	19	±	0	61	±	1	61	±	0
L161	19	±	0	19	±	0	61	±	1	61	±	1
L162	19.3	±	0	19.5	±	0	62	±	0	60	±	1
L163	20.1	±	0	20.3	±	0	54	±	1	52	±	1

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 50. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT11.

Exp(s)	Location	Date	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/µL)	Acet extract conc. (ng/µL)	HCHO air conc.[1] (µg/m^3)	Acet. air conc.[1] (µg/m^3)
Bkg	Lab air	01/20/09	8:28	14:04	1.07	359	0.414	0.194	2	1
L160a	Collection hood outlet	01/20/09	8:28	9:24	1.05	59	1.145	0.272	39	9
L160b			8:28	9:24	1.15	64	1.250	0.309	39	10
L161			9:54	10:48	1.04	56	1.036	0.155	37	6
L162			11:10	12:04	1.05	57	0.970	0.174	34	6
L163			13:10	14:04	1.06	57	0.733	0.127	26	4

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

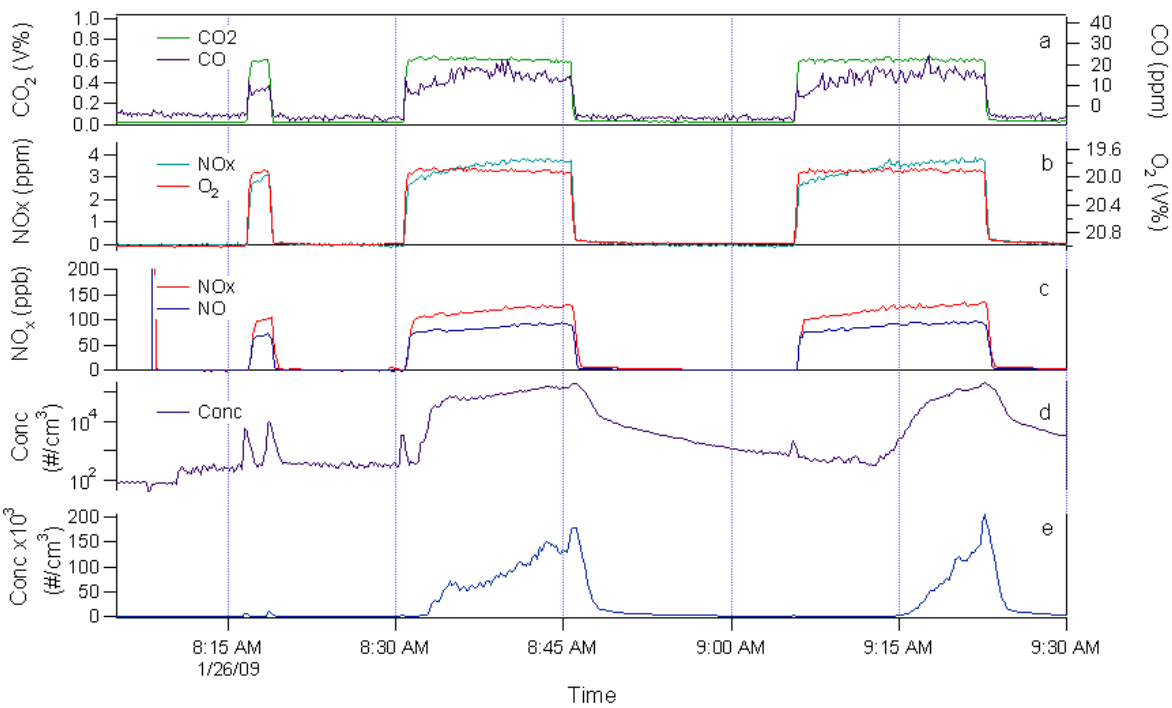

Figure 32. Measured analyte concentrations for cooktop CT11 with fuel 2C (L160).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

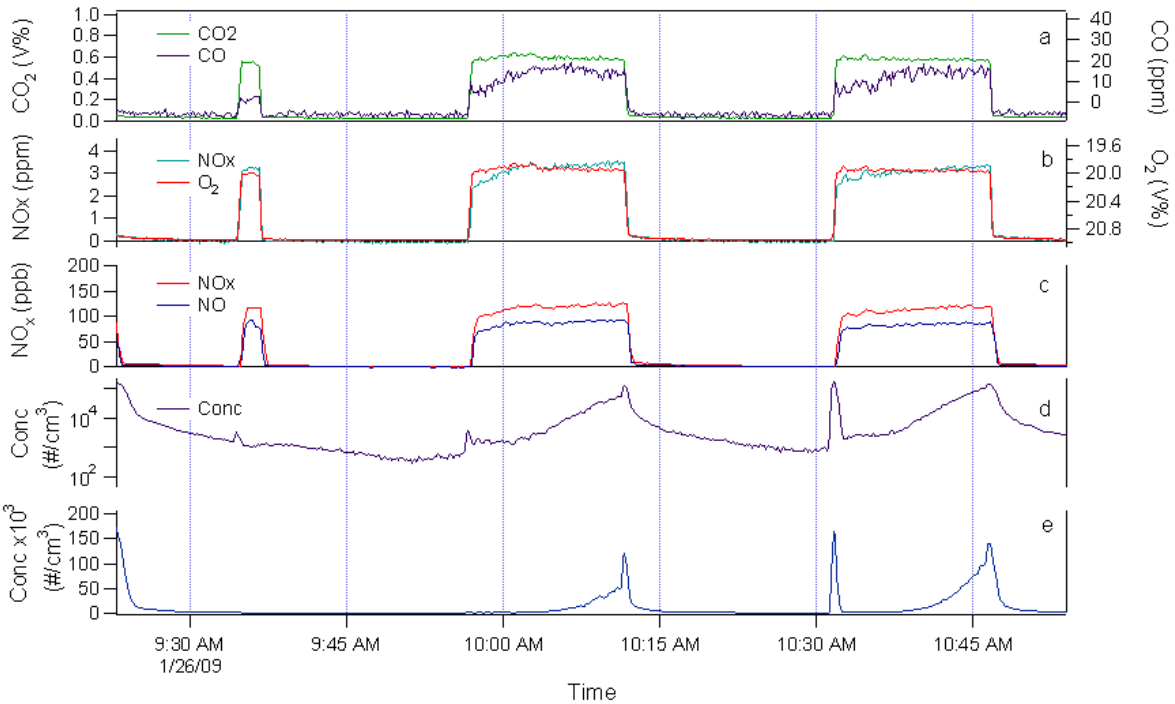

Figure 33. Measured analyte concentrations for cooktop CT11 with PG&E line gas (L161).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

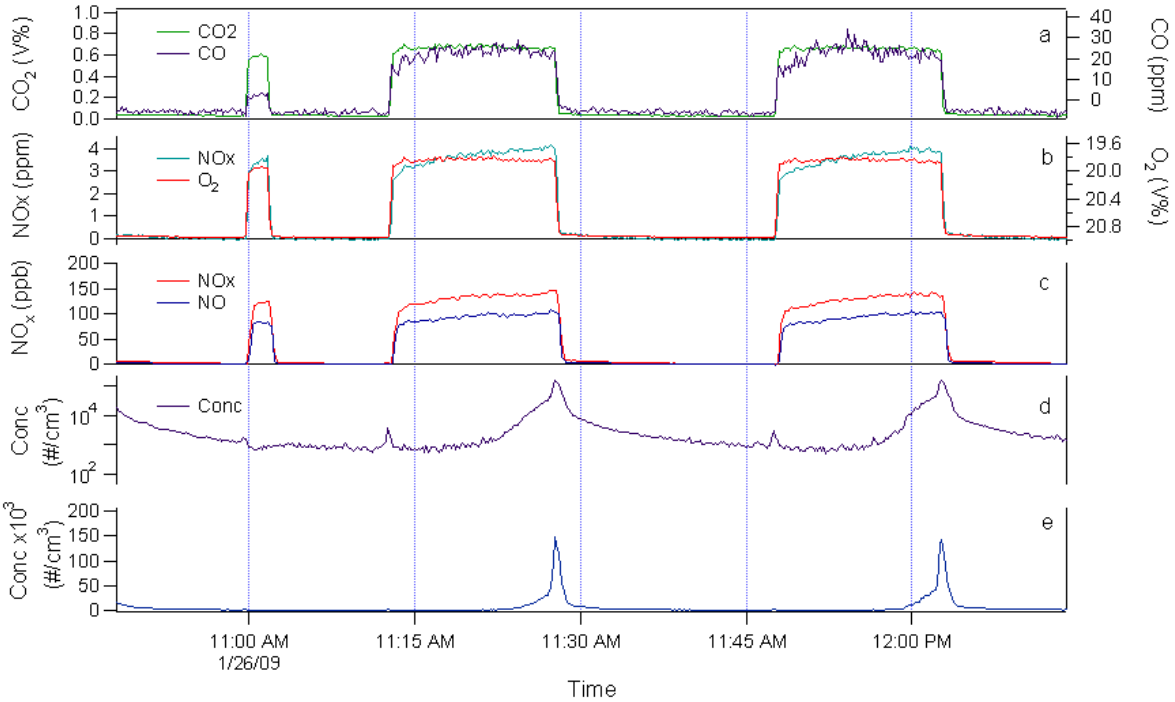

Figure 34. Measured analyte concentrations for cooktop CT11 with fuel 3C (L162).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

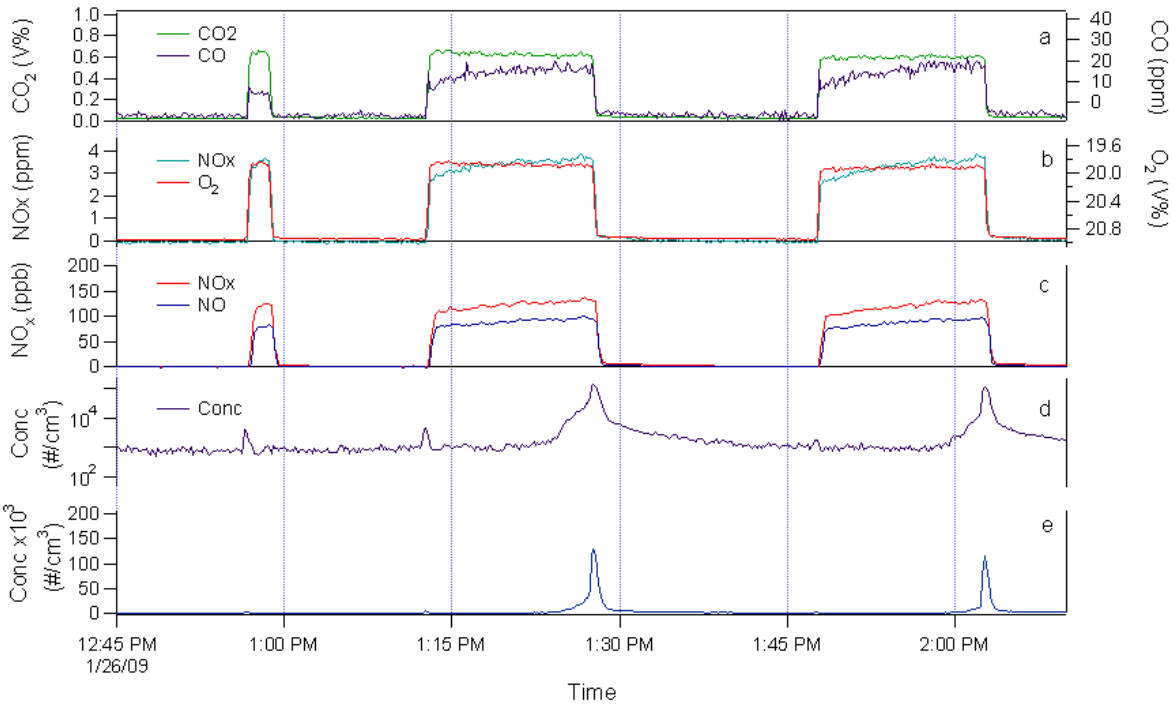

Figure 35. Measured analyte concentrations for cooktop CT11 with fuel 1C (L163).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 51. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT11.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L160	2C	1359	402	443	79	77	58	57	21.1	20.5	750	490
L161	PG&E	1333	450	455	74	73	56	53	18.2	19.1	150	280
L162	3C	1419	585	551	77	77	55	57	21.2	20.2	47	60
L163	1C	1390	463	510	75	77	56	57	19.4	20	32	10

Table 52. Calculated emission rates over entirety of each burn, cooktop CT11.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		NO_X (μg KJ^{-1})		NO (μg KJ^{-1})		NO_2 (μg KJ^{-1})		PN (10^7 KJ^{-1})		HCHO (μg KJ^{-1})
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L160	2C	1359	105	105	31	31	23	23	8.8	8.2	1100	500	0.31, 0.31
L161	PG&E	1333	109	106	30	29	22	22	7.5	7.6	200	430	0.31
L162	3C	1419	149	149	31	31	23	23	8.6	8.2	120	130	0.26
L163	1C	1390	113	122	31	32	23	24	8.1	8.1	110	68	0.21

5.0 Cooktop CT12

5.1. Experimental information for CT12

Four experiments (L168-L171) were conducted on the same day using, in order, mix 2C (WN=1359), PG&E line gas (WN=1330), mix 3C (WN=1419), and mix 1C (WN=1389). 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. To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 53. Appliance and burner information CT12.

Burner ID	CT12
Appliance manufacturer	Maytag
Model number	CRG860A
Serial number	100551FK
Manufacture year	1992
Burner technologies	sealed; cast-drilled ports, burner head & cover fixed in place (same burner heads as CT03)
Burner ratings (Btu/h)	Both front = 12,000; Both rear=9,200; Total = 42,400
Other information	Procured January 2009
Test location	Laboratory
History notes	Identified via craigslist.org. Reported reason for sale was kitchen remodel.

Figure 36. Cooktop CT12. –Need a better picture with grates.

Figure 37. Close-up of CT12 burners with/out grates.

Figure 38. CT12 front right burner flame with PG&E line gas.

Table 54. Interchangeability experiments for cooktop CT12.

Exp.	Fuel	Date	Burner operation
L168	2C	02/02/09	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L169	PG&E	02/02/09	
L170	3C	02/02/09	
L171	1C	02/02/09	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 55. Fuel analysis for interchangeability experiments with CT12.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L168	2C	Cylinder[3]	90.4	7.90	-	-	1.70	-	1053	1359
L169	PG&E		95.9	1.92	0.30	0.14	0.70	1.03	1015	1330
L170	3C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L171	1C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390

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

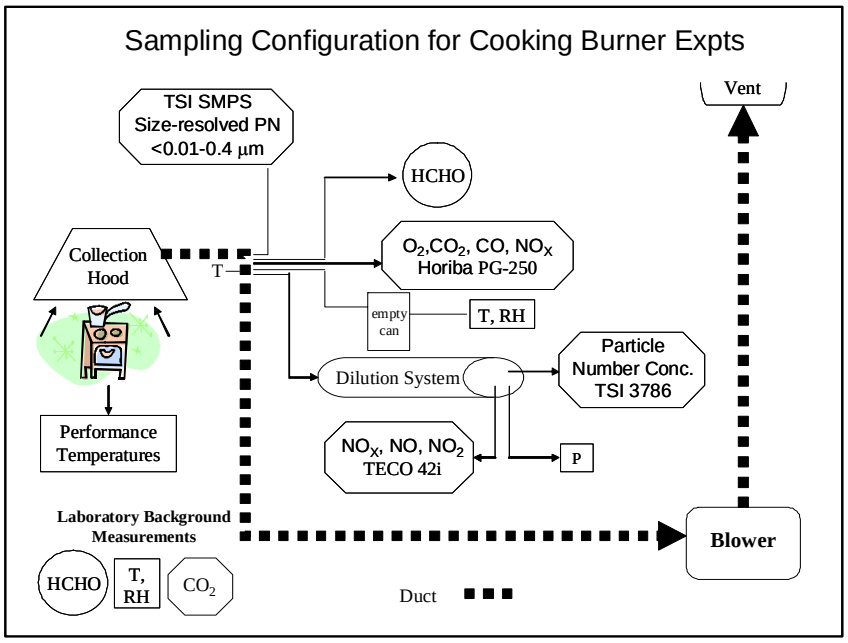

Figure 39. Analytical sampling configuration for CT12.

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.

Table 56. Analyte ranges and calibration levels for experiments with CT12.

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, 4.0 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 57. Aerosol instrumentation used for CT12.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 58. Other measurements for experiments with CT12.

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, comb. 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)

5.2. Results for CT12

Full burn emission rates were 119-229 ng/J for CO, 33-36 ng/J for NO_X, 9.9-12.6 ng/J for NO_2, 1100-5400 x10^4 J^{-1} for PN and 0.81-0.95 ng/J for HCHO. Formaldehyde and CO emissions were substantially higher with fuel 3C relative to PG&E line gas; but with both pollutants emissions with fuel 2C (WN=1359) were higher than with fuel 1C (WN=1390). Formaldehyde increased from 0.81 ng/J with PG&E line gas to 0.97 ng/J with fuel 3C. CO full-burn emissions were 210-230 with fuel 3C and roughly 120-130 with PG&E line gas. Values with fuels 1C and 2C were in between. A similar trend was observed for NO_2 emissions, going from an average of 10.2 ng/J with PG&E to 11.9 with 1C and 12.6 with fuel 3C. The two burns with fuel 2C had NO_2 emissions of 11.5 and 13.0 ng/J. There was not a clear fuel-related trend of emissions for total NO_X. As in many past experimental series, the highest particle number (PN) emission rates were observed in the first experiment of the day and emission rates with each of the first three experiments. The possibility of an experiment order effect is being investigated with the dataset of previous experiments.

Table 59. Burner operating parameters for experiments with cooktop CT12.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate[2] (kBtu/h)	Supply P (in. H_2O)[3]
L168	B1	08:45	09:00	43	7.6
(2C)	B2	09:20	09:35	43	7.6
L169	B1	10:06	10:21	34	7.3
(PG&E)	B2	10:41	10:56	48	7.3
L170	B1	12:01	12:16	36	7.7
(3C)	B2	12:36	12:51	34	7.7
L171	B1	13:19	13:34	37	7.7
(1C)	B2	13:54	14:09	43	7.7

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow (ft^3 h^{-1}) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 60. Environmental conditions[1] for experiments with CT12.

Exp.	Fuel	T (°C)	RH (%)
L168	2C	22.4 ± 0.2	35 ± 1
L169	PG&E	23 ± 0.2	38 ± 1
L170	3C	23.1 ± 0.3	42 ± 1
L171	1C	23.4 ± 0.2	42 ± 1

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 61. Sampling location temperature (at hood exhaust) and dilution ratio for CT12 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L168	88 ± 1	88 ± 2	32	31
L169	87 ± 2	89 ± 1	31	31
L170	94 ± 2	95 ± 1	32	32
L171	92 ± 2	92 ± 1	32	33

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 62. Measured RH of sample stream at room temperature. [1]

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
L168	20 ± 0.1	20.2 ± 0	57 ± 0	56 ± 0
L169	20.5 ± 0	20.7 ± 0	57 ± 1	57 ± 1
L170	21 ± 0	21.2 ± 0	60 ± 1	60 ± 1
L171	21.4 ± 0	21.5 ± 0	60 ± 1	59 ± 0

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 63. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT12.

Exp(s)	Location	Date	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/μL)	Acet extract conc. (ng/μL)	HCHO air conc.[1] (μg/m^3)	Acet. air conc.[1] (μg/m^3)
Bkg	Lab air	02/02/09	8:43	14:11	1.085	356	1.127	0.691	6	4
L168a	Collection hood outlet	02/02/09	8:43	9:37	1.042	56	2.971	0.514	106	18
L168b			8:43	9:37	1.159	63	3.281	0.571	105	18
L169			10:02	10:58	1.052	59	2.567	0.413	87	14
L170			11:59	12:53	1.055	57	3.315	0.533	116	19
L171			13:17	14:11	1.064	57	2.986	0.397	104	14

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

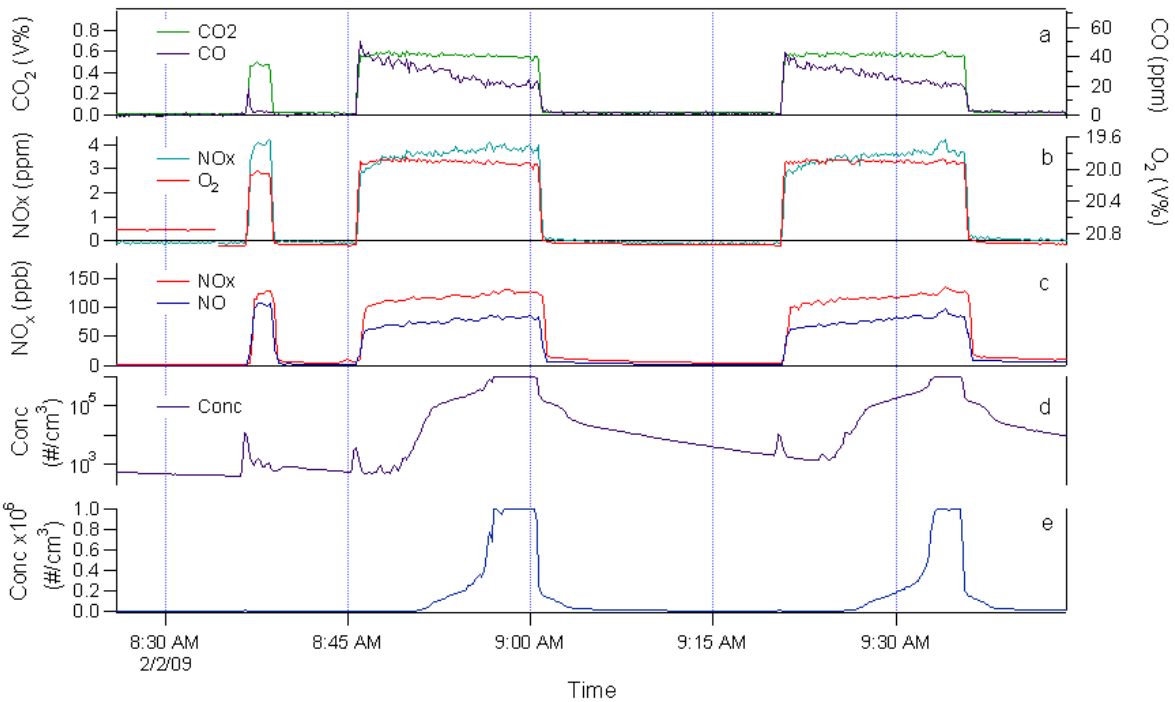

Figure 40. Measured analyte concentrations for cooktop CT12 with fuel 2C (L168).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

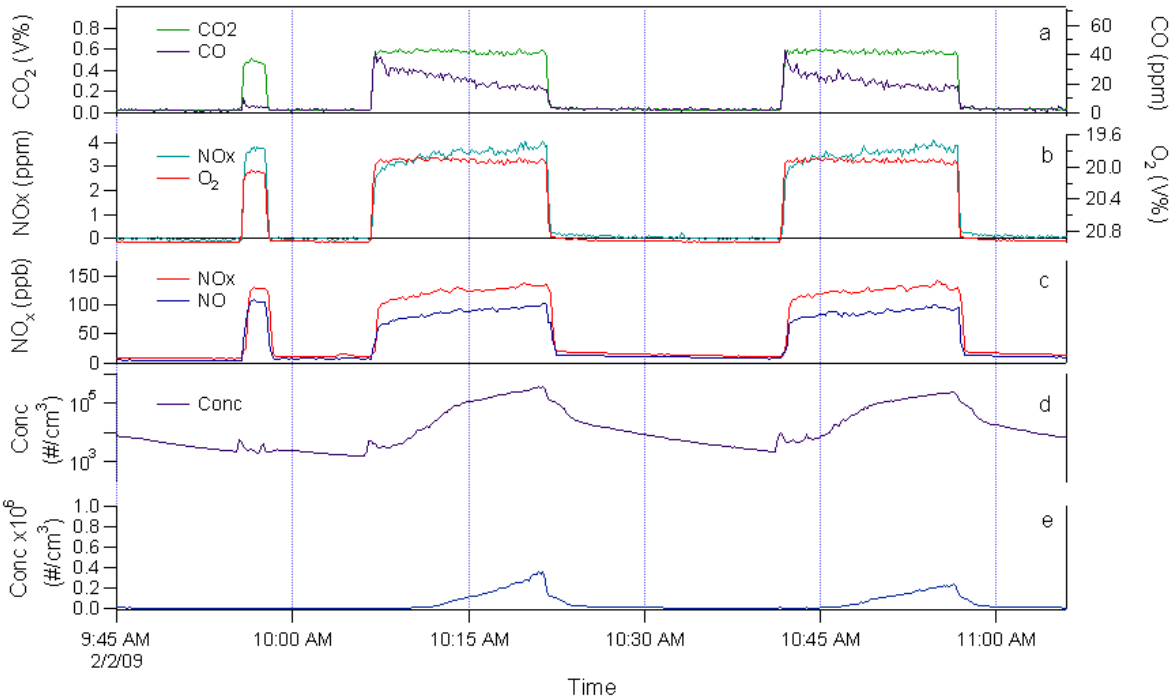

Figure 41. Measured analyte concentrations for cooktop CT12 with PG&E line gas (L169).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

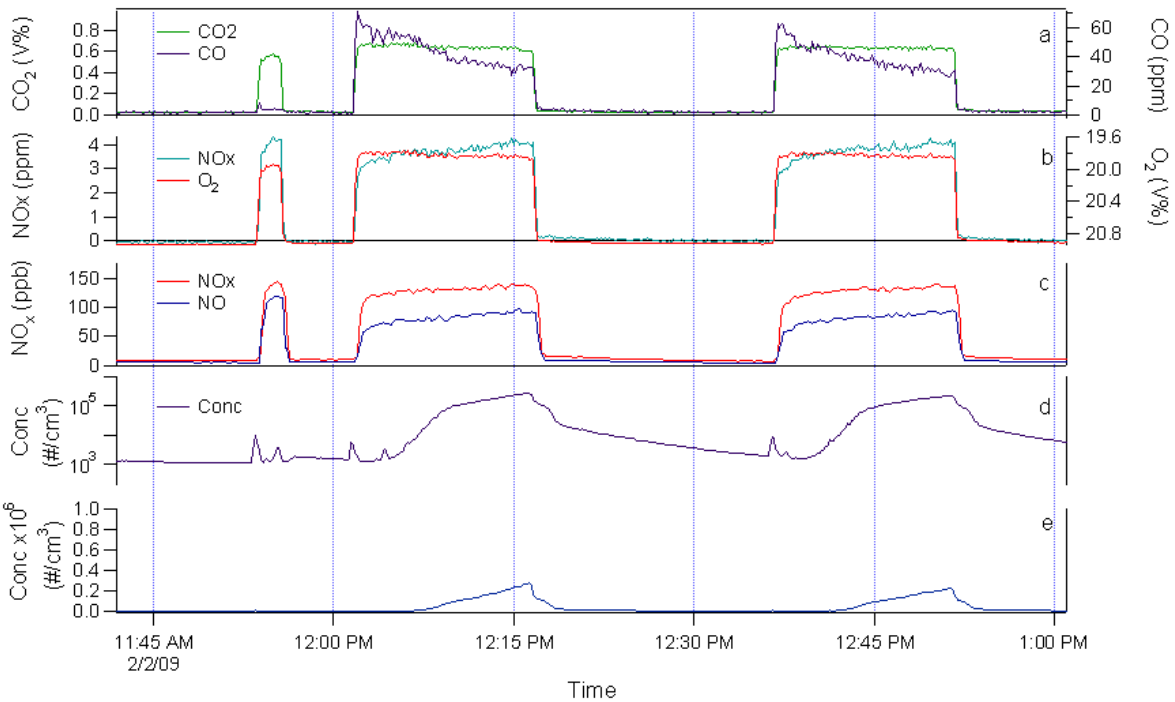

Figure 42. Measured analyte concentrations for cooktop CT12 with fuel 3C (L170).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

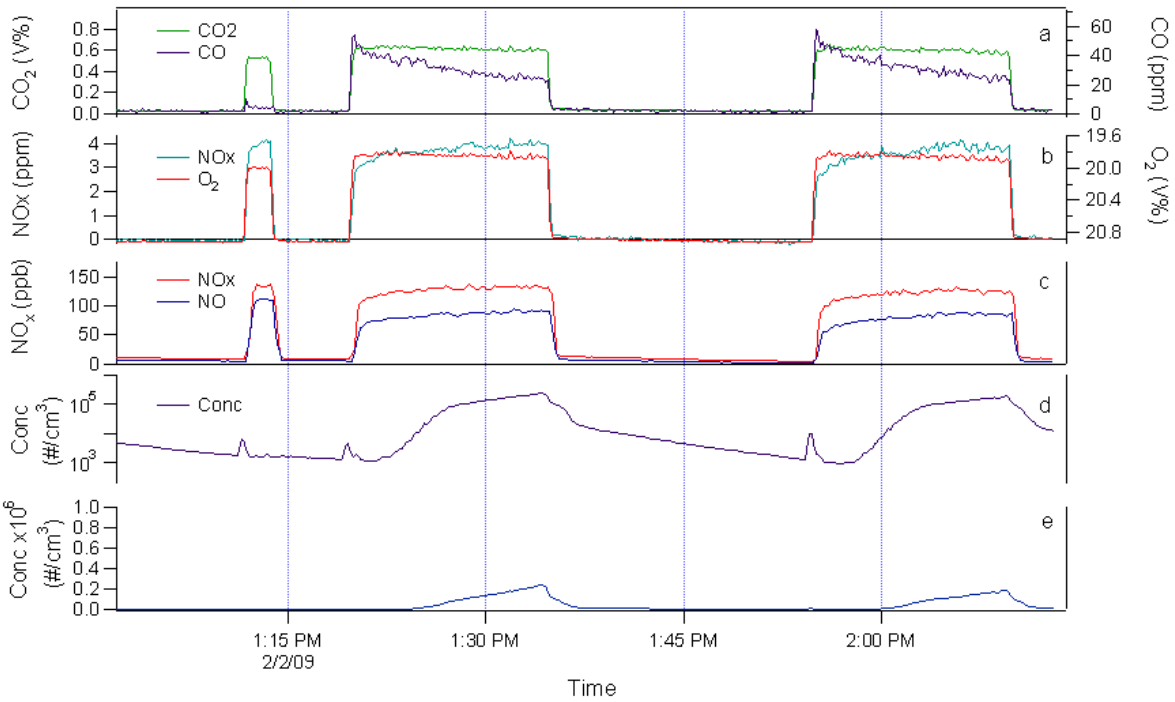

Figure 43. Measured analyte concentrations for cooktop CT12 with fuel 1C (L171).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 64. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT12.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L168	2C	1359	488	483	90	85	60	60	30	25.5	5500	4000
L169	PG&E	1330	369	357	85	86	62	61	22.7	24.5	1600	1200
L170	3C	1419	658	612	82	82	55	55	27.6	27.6	1200	1100
L171	1C	1390	504	535	83	85	57	58	26.7	26.6	1100	950

Table 65. Calculated emission rates over entirety of each burn, cooktop CT12.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		NO_X (μg KJ^{-1})		NO (μg KJ^{-1})		NO_2 (μg KJ^{-1})		PN (10^7 KJ^{-1})		HCHO (μg KJ^{-1})
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L168	2C	1359	172	162	36	35	24	23	13.0	11.5	5400	4100	0.95, 0.95
L169	PG&E	1330	128	119	34	35	24	24	9.9	10.5	1800	1400	0.81
L170	3C	1419	229	207	33	34	21	22	12.5	12.6	1300	1200	0.97
L171	1C	1390	169	180	34	34	22	22	11.8	11.9	1300	1100	0.90

6.0 Cooktop CT13

6.1. Experimental information for CT13

Four experiments (L180-L183) were conducted on the same day using, in order, mix 1C (WN=1389), mix 3C (WN=1419), PG&E line gas (WN=1333), and mix 2C (WN=1359). The dilution tube (through which particle concentrations were measured) was disconnected during the first burn of L180; an extra burn was added to provide two burns with valid data for all pollutants. 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. To assess the potential for condensation in gas sampling lines, RH was measured in an air sampling stream allowed to come to room temperature by pulling a sample stream through a using a 1-gal vessel; this sample was drawn parallel to the sampling stream of the PG-250 gas analyzer.

Table 66. Appliance and burner information CT13.

Burner ID	CT13
Appliance manufacturer	Frigidaire (Electrolux)
Model number	FGFL66ASD
Serial number	VF31132385
Manufacture year	2003
Burner technologies	Sealed burners; cast-slots, head & cover separate & removable
Burner ratings (Btu/h)	RF = 12000; Others 9,500; Total = 40,500
Other information	Procured February 2009
Test location	Laboratory
History notes	Identified via craigslist.org. Seller reported use 3-5x per week for 1 year, 1-4x per month over past 2 years. Reason for sale was upgrade.

Figure 44. Cooktop CT13.

Figure 45. Close-up of CT13 burners with/out grates.

Figure 46. CT13 front right burner flame with PG&E line gas.

Table 67. Interchangeability experiments for cooktop CT13.

Exp.	Fuel	Date	Burner operation
L180	1C	02/18/2009	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. A single purge burn occurred for each fuel change.[1]
L181	3C	02/18/2009	
L182	PG&E	02/18/2009	
L183	2C	02/18/2009	

[1] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots).

Table 68. Fuel analysis for interchangeability experiments with CT13.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L180	1C	Cylinder[3]	92.0	8.00	-	-	-	-	1071	1390
L181	3C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L182	PG&E		95.2	2.48	0.37	0.14	1.01	0.81	1019	1333
L183	2C	Cylinder[3]	90.4	7.90	-	-	1.70	-	1053	1359

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

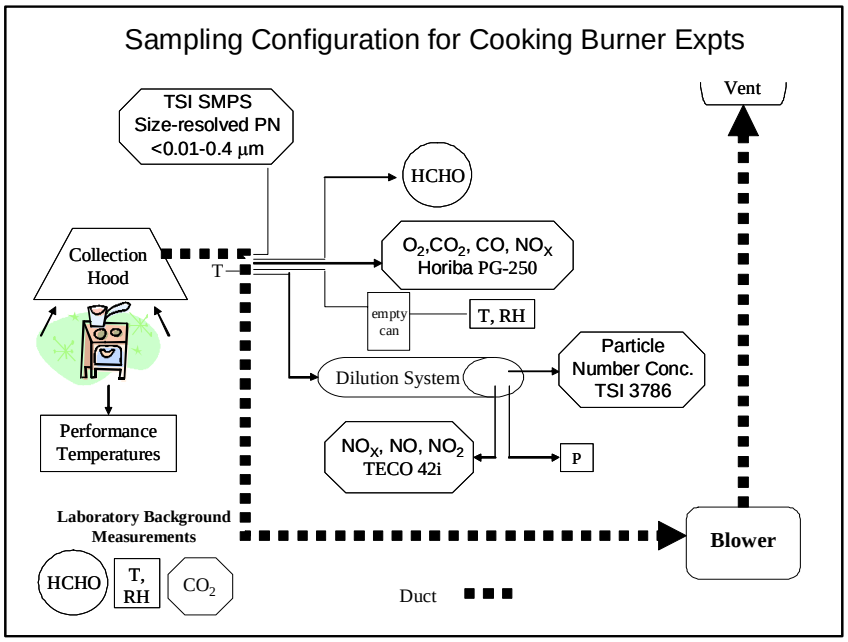

Figure 47. Analytical sampling configuration for CT13.

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.

Table 69. Analyte ranges and calibration levels for experiments with CT13.

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, 4.0 ppm
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-5 ppm	0, 2.0 ppm
Carbon dioxide (CO_2)	laboratory air	Fuji ZFP9-AB21	3000 ppm	0, 470 ppm

[1] Horiba Environmental and Process Instruments (environ.hii.horiba.com); Thermo Fisher Scientific (thermo.com); PP Systems (ppsystems.com).

Table 70. Aerosol instrumentation used for CT13.

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 part. mode	±12%
PN resolved by aerodynamic diameter	TSI 3071A classifier, TSI 3025A 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 71. Other measurements for experiments with CT13.

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, 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).

6.2. Results for CT13

Full burn emission rates were 44-98 ng/J for CO, 35-36 ng/J for NO_X, 6.9-9.5 ng/J for NO_2, 43-1200 x10^4 J^{-1} for PN and 0.10-0.20 ng/J for HCHO. These HCHO emission rates are among the lowest measured for cooktops. CO full-burn and end-of-burn emissions increased monotonically with fuel Wobbe number; full-burn emissions increased from 44-53 ng/J with PG&E line gas to 63-64 ng/J with fuel 2C to 78-83 with fuel 1C and 88-98 with fuel 3C. NO_2 full-burn emission rates exhibited a similar trend. There was not a clear relationship between fuel Wobbe number and emissions of HCHO, NO_X, or NO. As observed in many experimental series, particle number (PN) emissions were highest in the first experiment of the day. The possibility of an experiment order effect is being investigated with the dataset of previous experiments.

Table 72. Burner operating parameters for experiments with cooktop CT13.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate[2] (kBtu/h)	Supply P (in. H_2O)[3]
L180	B1	08:11	08:26	36	7.6
(1C)	B2	08:46	09:01	36	7.6
L181	B1	10:37	10:52	36	7.7
(3C)	B2	10:02	10:17	36	7.7
L182	B1	11:47	12:02	35	7.4
(PG&E)	B2	12:22	12:37	35	7.4
L183	B1	13:06	13:20	35	7.7
(2C)	B2	13:41	13:56	35	7.7

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] Fuel flow ($ft^3\ h^{-1}$) calculated from stopwatch timing of 1/4-foot dial on gas meter; firing rate calculated from fuel flow rate and higher heating value from fuel composition.
[3] Pressure in fuel supply line during burn. Pressure at outlet of appliance regulator was not readily accessible without dismantling the fuel transfer lines within the appliance, and was therefore not measured.

Table 73. Environmental conditions[1] for experiments with CT13.

Exp.	Fuel	T (°C)	RH (%)
L180	1C	20.5 ± 0.2	45 ± 0
L181	3C	20.9 ± 0.1	45 ± 0
L182	PG&E	20.8 ± 0.1	47 ± 1
L183	2C	20.9 ± 0.2	48 ± 1

[1] Mean ± standard deviation measured over period of formaldehyde sample.

Table 74. Sampling location temperature (at hood exhaust) and dilution ratio for CT13 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L180	101 ± 1	101 ± 1	27	27
L181	105 ± 1	104 ± 1	29	29
L182	98 ± 2	95 ± 2	29	29
L183	97 ± 1	101 ± 1	29	32

[1] Mean ± standard deviation measured during each burn.
[2] Calculated by comparing NO_x measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 75. Measured RH of sample stream at room temperature. [1]

Exp.	Sample Manifold T (°C)[1]						Sample Manifold RH (%)[1]					
	Burn 1			Burn 2			Burn 1			Burn 2		
L180	18.6	±	0	18.8	±	0	78	±	1	79	±	2
L181	19.2	±	0	19	±	0	80	±	1	80	±	1
L182	19.1	±	0	19.3	±	0	79	±	2	80	±	1
L183	19.6	±	0	19.8	±	0	79	±	1	78	±	1

[1] Measured in 1-gal vessel in parallel sample stream from hood outlet; measured to confirm that hood dilution is sufficient to avoid condensation in sampling stream for PG-250.

Table 76. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT13.

Exp(s)	Location	Sample start/end time		Flow (L/min)	Air vol. (L)	HCHO extract conc. (ng/µL)	Acet extract conc. (ng/µL)	HCHO air conc.[1] (µg/m^3)	Acet. air conc.[1] (µg/m^3)
Bkg	Lab air	8:09	13:58	1.06	369	0.463	0.217	3	1
L180a	Collection hood outlet	8:09	9:03	1.04	56	0.858	0.289	30	10
L180b		8:09	9:03	1.15	62	0.904	0.305	29	10
L181		9:25	10:54	1.06	94	0.838	0.240	18	5
L182		11:45	12:39	1.05	57	0.464	0.113	16	4
L183		13:04	13:58	1.05	57	0.510	0.114	18	4

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

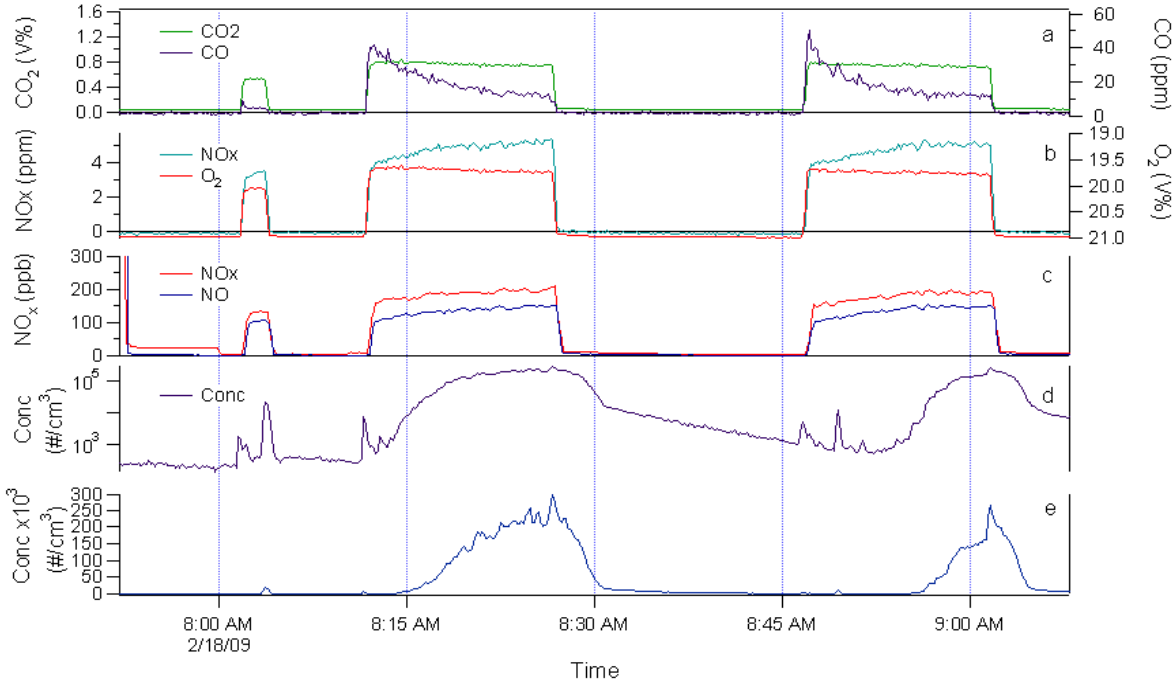

Figure 48. Measured analyte concentrations for cooktop CT13 with fuel 1C (L180).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

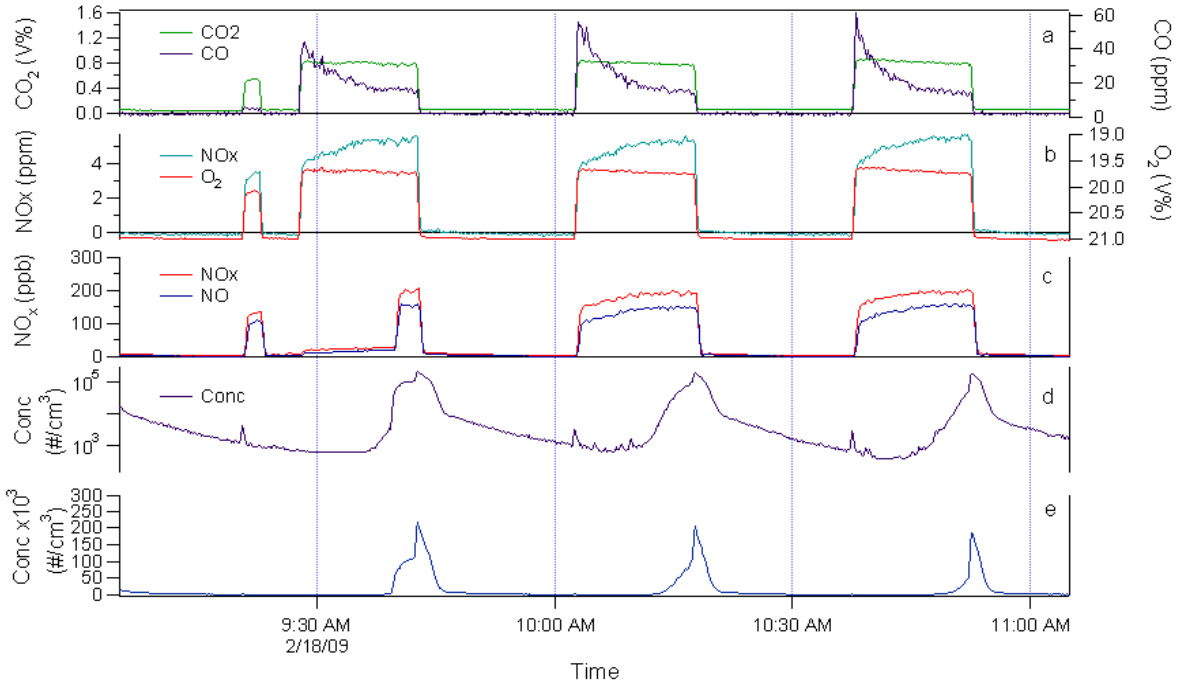

Figure 49. **Measured analyte concentrations for cooktop CT13 with fuel 3C (L181).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

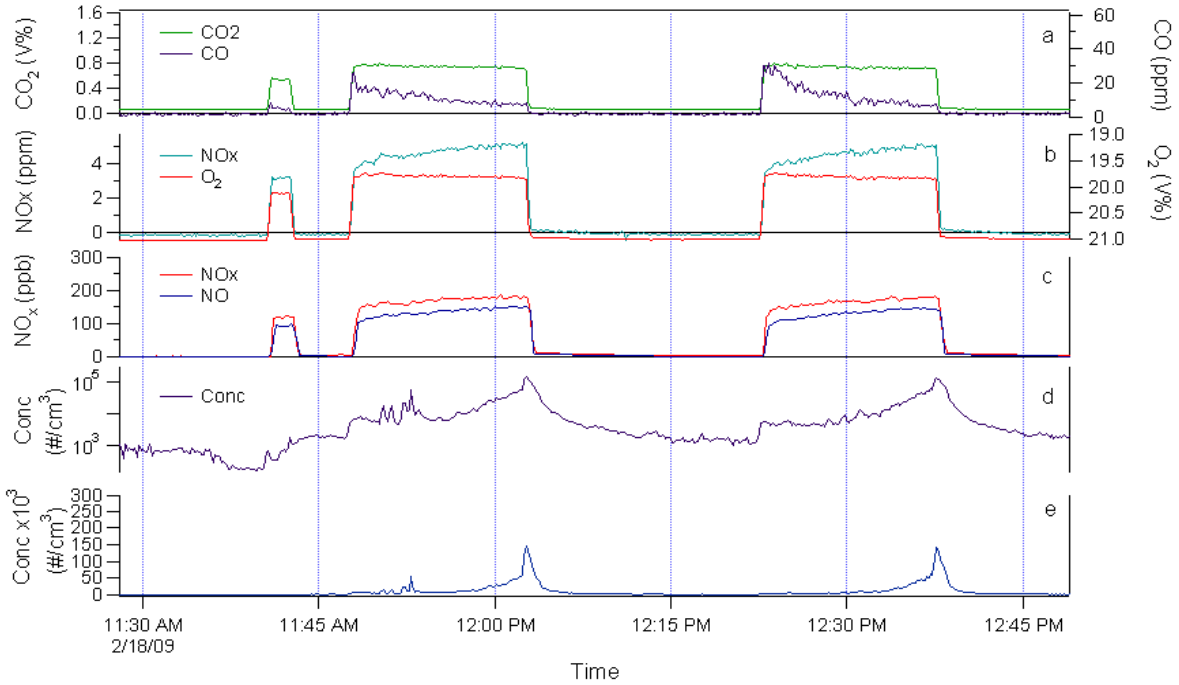

Figure 50. **Measured analyte concentrations for cooktop CT13 with PG&E line gas (L182).** Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

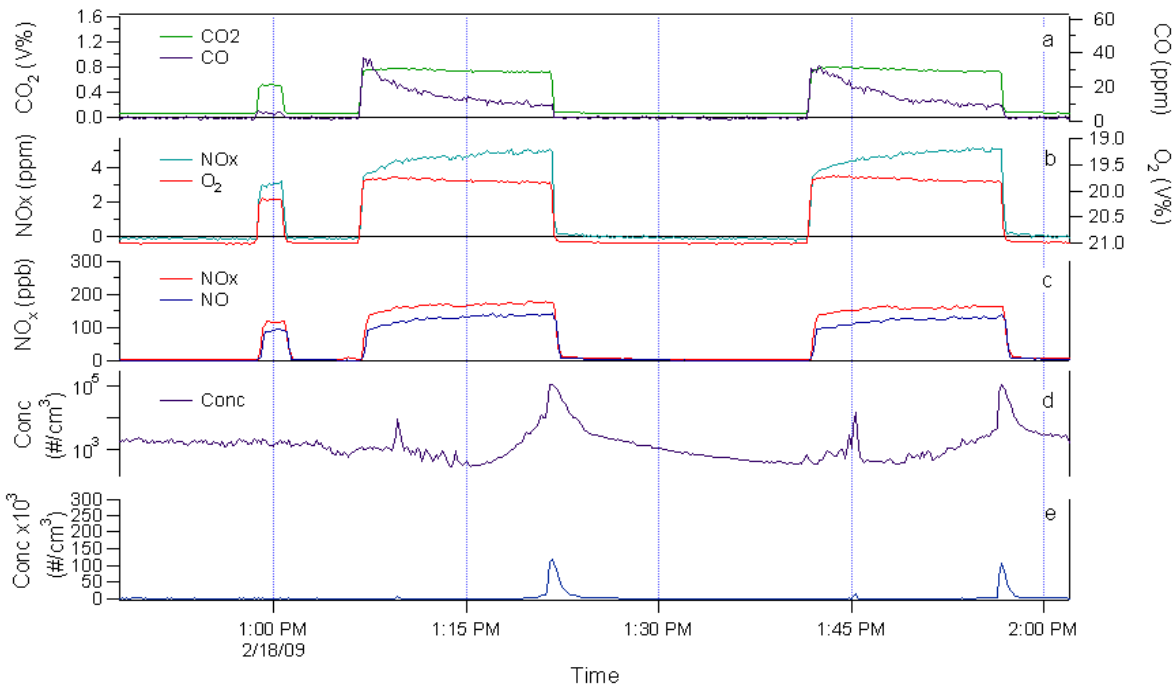

Figure 51. Measured analyte concentrations for cooktop CT13 with fuel 2C (L183).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 77. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT13.

Exp	Fuel	Wobbe	CO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L180	1C	1390	195	185	88	89	67	70	21.4	19.5	930	390
L181	3C	1419	214	233	90	89	73	70	17.8	19.2	44	130
L182	PG&E	1333	112	112	89	88	73	72	15.5	15.7	110	110
L183	2C	1359	157	146	88	88	70	71	17.5	17.6	2.5	1.6

Table 78. Calculated emission rates over entirety of each burn, cooktop CT13.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		NO_X (μg KJ^{-1})		NO (μg KJ^{-1})		NO_2 (μg KJ^{-1})		PN (10^7 KJ^{-1})		HCHO (μg KJ^{-1})
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	
L180	1C	1390	83	78	36	36	36	36	26	28	9.5	8.3	0.20, 0.19
L181	3C	1419	88	98	36	35	36	35	28	27	8.2	8.4	0.11
L182	PG&E	1333	44	53	35	35	35	35	28	27	6.9	7.3	0.10
L183	2C	1359	64	63	35	35	35	35	27	27	7.9	7.8	0.11