Arnold Schwarzenegger
Governor

NATURAL GAS VARIABILITY IN CALIFORNIA: ENVIRONMENTAL IMPACTS AND DEVICE PERFORMANCE

EXPERIMENTAL EVALUATION OF POLLUTANT EMISSIONS FROM RESIDENTIAL APPLIANCES

APPENDIX C. SUMMARY REPORTS FOR COOKTOPS CT01–CT07

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

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

List of Figures

List of Tables

1.0 Cooktop CT01

1.1. Experimental information for CT01

A total of 10 experiments were conducted with CT01. These include 5 experiments with fuel 3A (WN = 1418), 2 experiments 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 = 1329-1334). Experiments for the three burners of this free-standing range – cooktop CT01, oven OV01 and waist-high broiler BR01 – were initially interwoven to minimize the number of purge burns required when switching fuels. Whereas most burners were tested with three different fuels in a single day, these burners were tested with different fuels on different days. Experiments for the burners on this range 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: L064 (PG&E), L065 (3A+N_2) and L067 (1C).

High relative humidity was measured in the gas sampling manifold during experiments L045 (PG&E line gas) and L048 (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 experiments, L054 and L056 (both 3A) the room (and combustion) air relative humidity was much lower than during other experiments.

In two experiments – both burns of L054 and second burn of L058 – the gas supply pressure dipped just below the design appliance manifold pressure of 6 in. H_2O. During these burns, the measured appliance manifold pressure dipped from 5.8 in. H_2O to 5.3-5.5 in. H_2O.

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 CT01.

Burner ID	CT01
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	Electronic ignition; sealed cooktop burners
Burner ratings (Btu/h)	Cooktop: LF = 7,000, others = 9,100; total = 34,300
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. Close-up of cooktop CT01 burner.

Figure 2. Close-up of cooktop CT01 flame under pot (PG&E line gas).

Table 2. Interchangeability experiments for cooktop CT01.

Exp.	Fuel	Date	Burner operation
L045	PG&E	12/18/07	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; experiments were then conducted for CT01, OV01, and BR01 before switching to next fuel.[1]
L048	3A	12/19/07	
L051	3A	12/20/07	
L054	3A	1/16/08	
L056	3A	1/18/08	
L058	3A+N_2	1/23/08	
L061	3A	1/24/08	
L064	PG&E	2/8/08	
L065	3A+N_2	2/8/08	
L067	1C	2/11/08	

[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 CT01.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L045	PG&E	L046	95.45	2.49	0.28	0.07	0.98	0.73	1017	1334
L048	3A	L047-350F	90.18	5.70	3.00	1.12	0.00	0.00	1124	1418
L048[3]	*3A*	*B1*	*89.91*	*5.71*	*2.99*	*1.12*	*0.26*	*0.00*	*1121*	*1413*
L051	3A	B1	90.09	5.81	2.99	1.11	0.00	0.00	1124	1418
L051	3A	B2	90.15	5.81	2.94	1.10	0.00	0.00	1123	1418
L054	3A	L053-B1	89.93	5.93	3.01	1.12	0.00	0.00	1126	1419
L054	3A	L055-B2	90.14	5.84	2.93	1.09	0.00	0.00	1123	1417
L056	3A	B1	90.19	5.82	2.94	1.05	0.00	0.00	1122	1417
L056	3A	B1	90.19	5.82	2.94	1.05	0.00	0.00	1122	1417
L057	3A+N_2	B1	88.41	5.73	2.88	1.13	1.85	0.00	1104	1385
L057	3A+N_2	B2	88.48	5.70	2.84	1.10	1.87	0.00	1102	1384
L058	3A+N_2	B1	88.51	5.70	2.80	1.07	1.91	0.00	1100	1383
L058	3A+N_2	B2	88.52	5.71	2.79	1.05	1.93	0.00	1100	1382
L061	3A	B1	90.04	5.96	2.88	1.12	0.00	0.00	1124	1418
L061	3A	B2	89.98	6.05	2.87	1.10	0.00	0.00	1124	1418
L064	PG&E	-	95.39	2.27	0.28	0.09	1.25	0.72	1014	1329
L065	3A+N_2	-	88.53	5.71	2.76	1.07	1.93	0.00	1100	1382
L067	1C	-	92.43	7.57	0.00	0.00	0.00	0.00	1068	1388

[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] Presence of N_2 suggests sample contamination by air leakage.

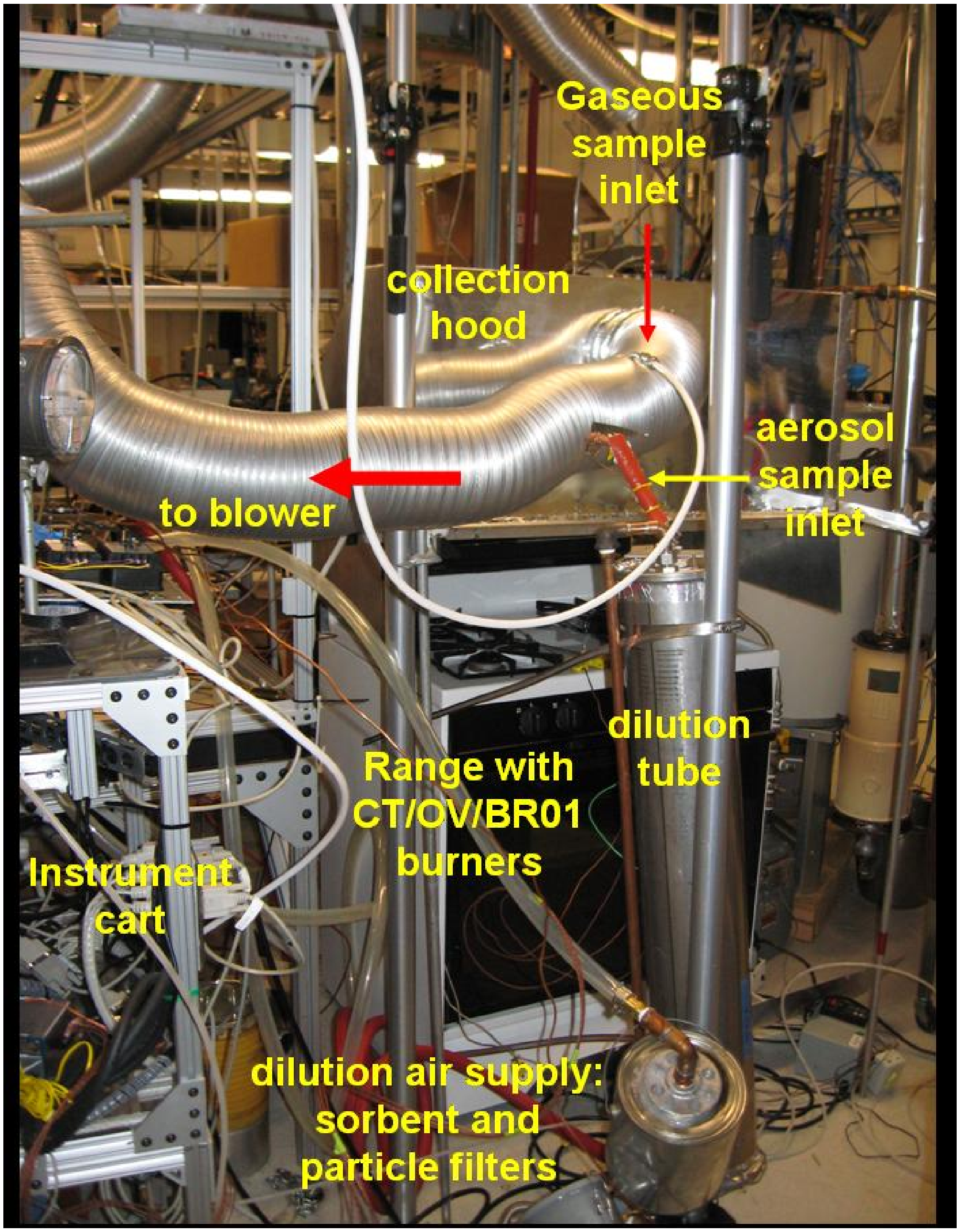

Figure 3. Installation and sampling configuration for CT01 / OV01 / BR01.
Front panel of collection hood is not installed in picture, but it was used during experiments.

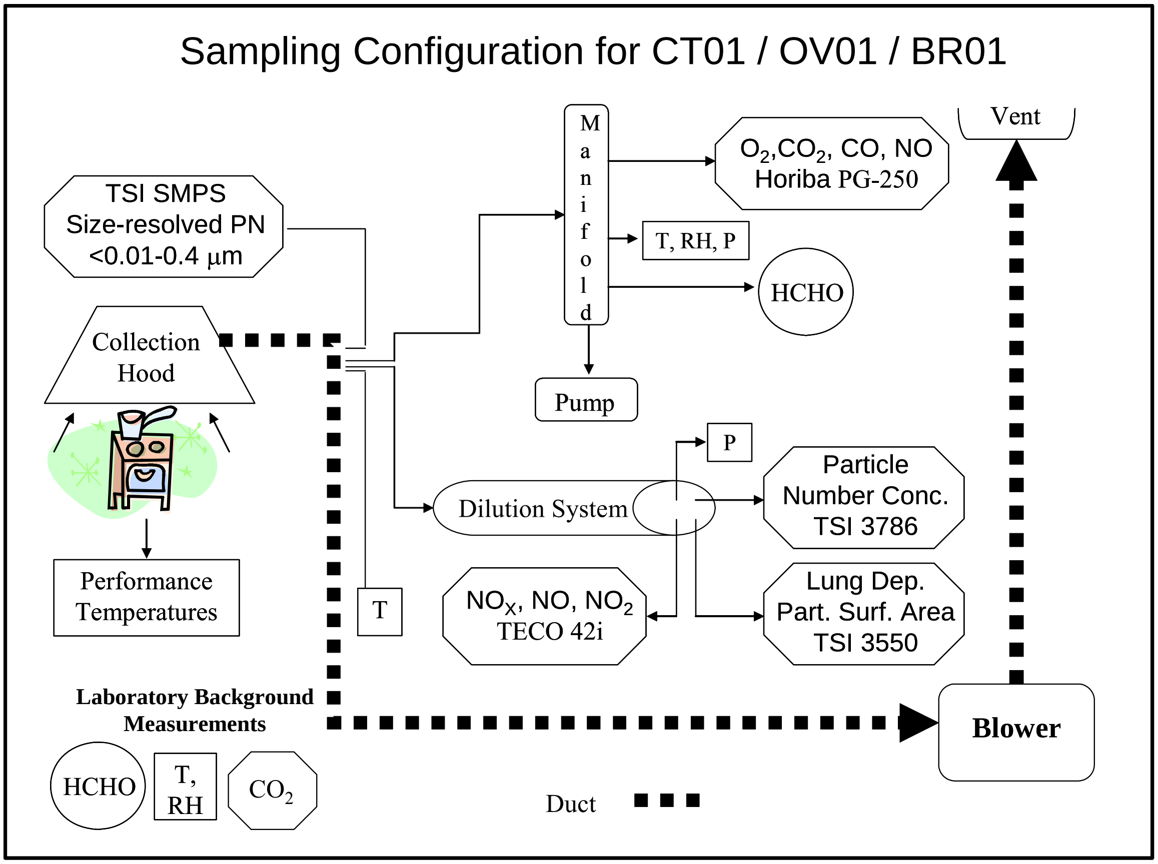

Figure 4. Analytical sampling configuration for CT01. SMPS used only for selected experiments.

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, 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 CT01

CO emissions were very low, generally just above the noise the level of the instrument. Excluding L048 (high RH observed in gas sample manifold), replicate experiments with fuel 3A (WN ~1418) yielded NO_X emission rates that varied (high-to-low) by approximately 10%. The highest NO_X emission rates occurred on the two days with very low relative humidity (24% on 1/16 and 31% on 1/18). There was not a clear trend of NO_X emissions with fuel Wobbe number. PN emission rates varied by more than 2 orders of magnitude across experiments; however PN emissions during the two burns of a single experiment were varied by less than a factor of 2.5. Of the three high-PN experiments (emissions exceeding 100 x 10^7 KJ^{-1}), two used PG&E line gas and the third used mix 3A. Two very high PN experiments occurred after periods in which the oven was not used for periods of at least a week (L045 and L064); but a third (L048) occurred the day following L045. PN concentrations decreased through the first several experiments (L045, L048, L051, L054), then appeared to settle at a lower level until L064. Full burn emission rates were <30 ng/J for CO, 30-33 ng/J for NO_X (excluding results for days with very low RH), 4-500 x10^4 J^{-1} for PN, and 0.46-0.65 ng/J for HCHO (based on 3 experiments)..

Table 7. Burner operating parameters for experiments with cooktop CT01.

Exp. (fuel)	Burn[1]	Start time	End time	Fuel flow rate (ft^3/h) [2]	Firing rate (kBtu/h) [2]	Supply P (in. H_2O)[3]	Manifold P (in. H_2O)[3]
	Purge	13:05:20	13:08:50				
L045	B1	13:27:30	13:42:20	31.6	32.1	8.2	5.72
(PG&E)	B2	14:02:50	14:17:20	31.9	32.4	8.1	5.68
L048 (3A)	B1	14:44:00	14:59:00	30.8	34.5	7.7	5.73
L051	B1	10:00:00	10:15:00	30.3	34.1	7.9	5.76
(3A)	B2	10:35:00	10:50:00	30.3	34.1	8.0	5.74
L054	B1	12:45:10	12:59:50	30.7	34.5	5.6*	5.48*
(3A)	B2	13:20:00	13:35:00	29.8	33.5	5.4*	5.38*
	Purge	09:37:00	09:38:10				
L056	B1	09:50:00	10:04:50	31.1	34.9	7.2	5.81
(3A)	B2	10:25:00	10:40:00	30.7	34.5	7.0	5.79
L058	B1	12:44:00	12:58:40	30.3	33.3	7.4	5.78
($3A/N_2$)	B2	13:19:10	13:33:40	29.0	32.0	5.5*	5.32*
L061	B1	11:51:30	12:06:00	30.6	34.4	6.5	5.72
(3A)	B2	12:26:00	12:40:40	30.2	34.0	6.4	5.66
L064	B1	10:31:30	10:46:30	32.4	32.8	7.3	5.75
(PG&E)	B2	11:06:40	11:21:30	32.0	32.4	7.4	5.75
L065 ($3A/N_2$)	B1	12:29:50	12:44:30	31.5	34.6	8.1	5.78
L067	B1	11:33:00	11:48:00	32.0	34.1	7.5	5.75
(1C)	B2	12:08:00	12:23:00	32.0	34.1	7.6	5.74

[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). B1 and B2 are the duplicate burns with load (pots filled with water).

[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] Pressure in fuel supply line and at outlet of appliance regulator, during burn. Asterisks mark experiments in which the supply pressure dropped below the rated manifold P, with consequent decrease in actual manifold P.

Table 8. Environmental conditions[1] for experiments with CT01.

Date	Burner	Exp.	T (°C)	RH (%) [2]
12/18/07	CT01	L045	19.9 ± 0.2	63 ± 1
12/19/07	CT01	L048	20.2 ± 0.1	49 ± 1
12/20/07	CT01	L051	20.6 ± 0.2	48 ± 1
1/16/08 [2]	*CT01*	*L054* [2]	*20.8 ± 0.3*	*24 ± 1*
1/18/08 [2]	*CT01*	*L056* [2]	*20.2 ± 0.1*	*31 ± 1*
1/23/08	CT01	L058	20.0 ± 0.4	41 ± <1
1/24/08	CT01	L061	20.3 ± 0.1	39 ± 1
2/8/08	CT01	L064	20.5 ± 0.1	47 ± 1
2/8/08	CT01	L065	20.8 ± 0.2	46 ± <1
2/12/08	CT01	L067	21.2 ± 0.1	48 ± <1

[1] Measured over period of formaldehyde sample.
[2] Room / combustion air RH was substantially lower than during other experiments.

Table 9. Sampling system conditions for experiments with cooktop CT01.

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2	B1	B2
L045[3]	*20.3 ± 0.2*	*20.7 ± 0.2*	*97* [3] *± 7*	*97 ± 6*	*21*	*21*
L048[3]	*20.9 ± 0.3*	*NA*	*101*[3] *± 7*	*NA*	*20*	*20*
L051	21.3 ± 0.2	20.9 ± 0.2	48 ± 5	50 ± 5	25	25
L054	20.5 ± 0.2	20.5 ± 0.2	59 ± 6	60 ± 6	28	27
L056	20.8 ± 0.1	19.9 ± 0.1	65 ± 5	68 ± 6	29	31
L058	20.7 ± 0.1	20.8 ± 0.1	64 ± 6	64 ± 5	26	27
L061	20.8 ± 0.2	20.8 ± 0.1	72 ± 6	76 ± 6	25	26
L064	20.8 ± 0.2	21.1 ± 0.1	74 ± 5	73 ± 5	25	25
L065	21.2 ± 0.2	21.5 ± 0.1	75 ± 5	75 ± 5	24	25
L067	21.3 ± 0.2	20.9 ± 0.2	48 ± 5	50 ± 5	21	21

[1] Measured in gas sampling manifold during each burn
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.
[3] 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 CT01.

Exp(s)	Location	Date	Sample times				Air vol. (L) [1]	Extract conc. (ng/μL)	Air conc.[1,2] (μg/m³)
			Start/End		Start/End				
L064	Bkg	2/8/08	10:31			13:19	192	0.445	10.9
L064	Exhaust	2/8/08	10:31	10:46	11:06	11:21	35	0.752	11.2
L065	Exhaust	2/8/08	12:29	12:44	13:04	13:19	35	1.026	12.2
L067	Bkg	2/11/08	11:26			13:07	115	0.308	21.0
L067	Exhaust	2/11/08	11:33			12:24	56	1.014	11.2

[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.

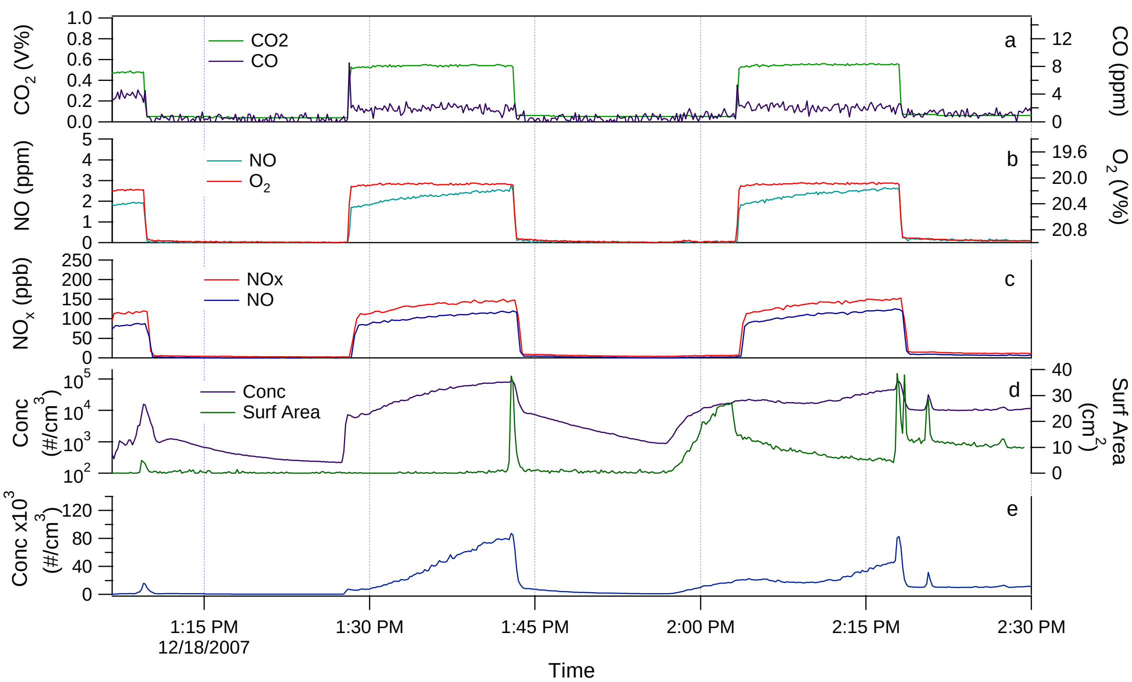

Figure 5. Measured analyte concentrations for cooktop CT01 with PG&E line gas (L045).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Surface area refers to particles that would deposit in lung alveoli.

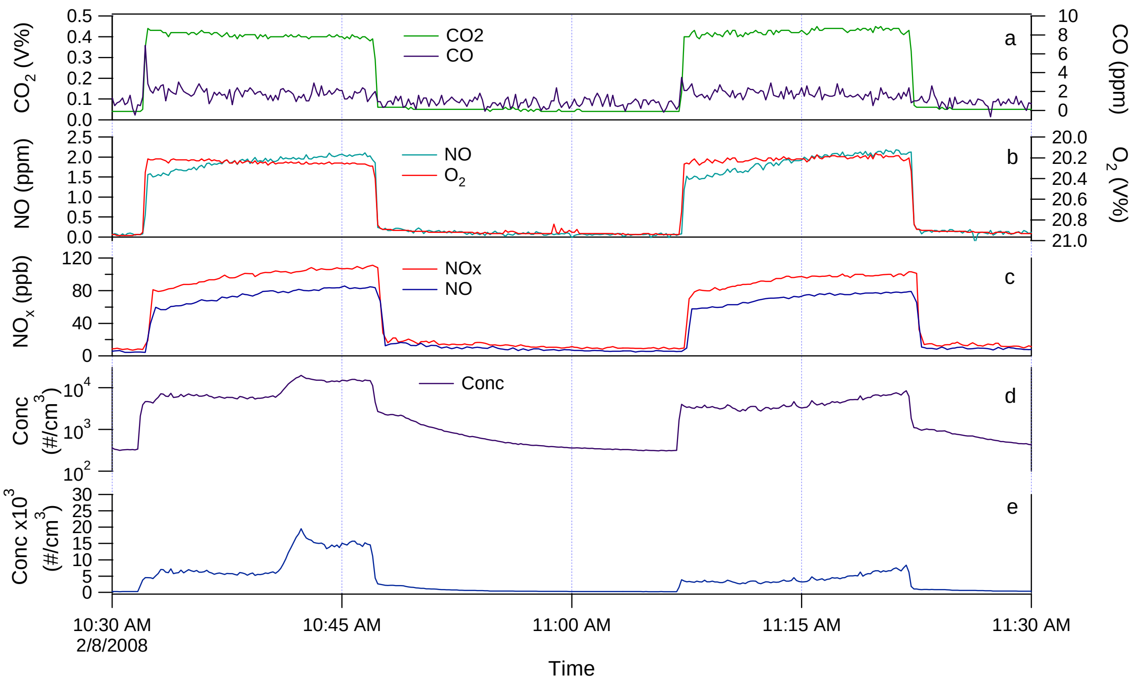

Figure 6. Measured analyte concentrations for cooktop CT01 with PG&E line gas (L064).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (possible instrument malfunction).

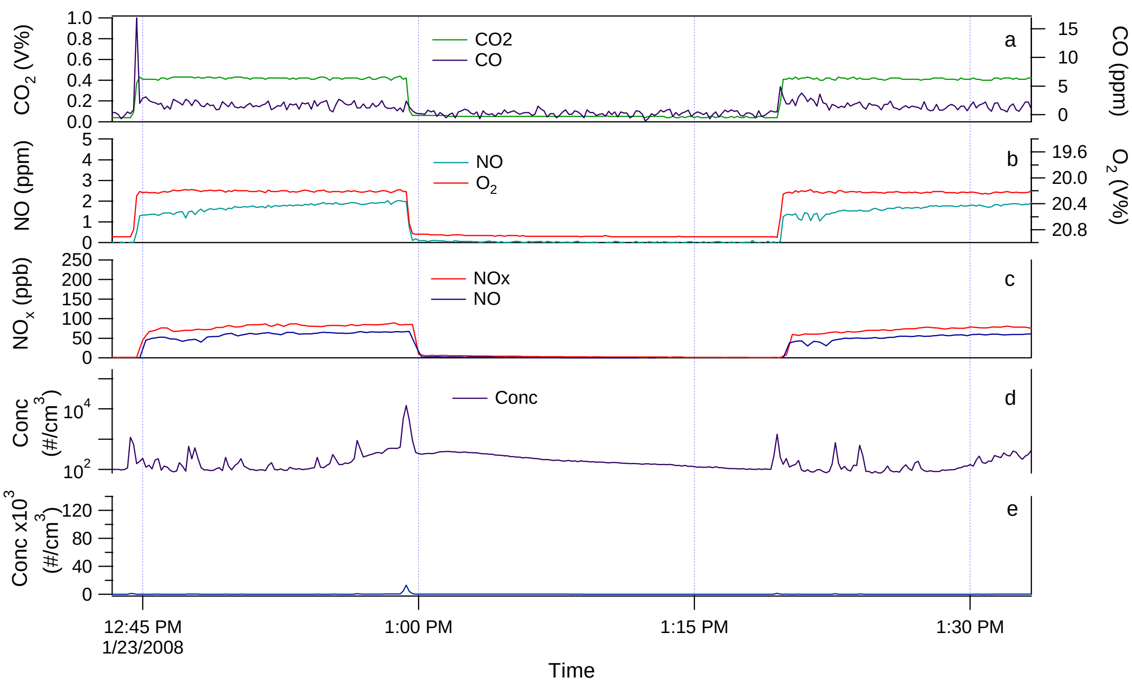

Figure 7. Measured analyte concentrations for cooktop CT01 with fuel 3A + N_2 (L058).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (possible instrument malfunction).

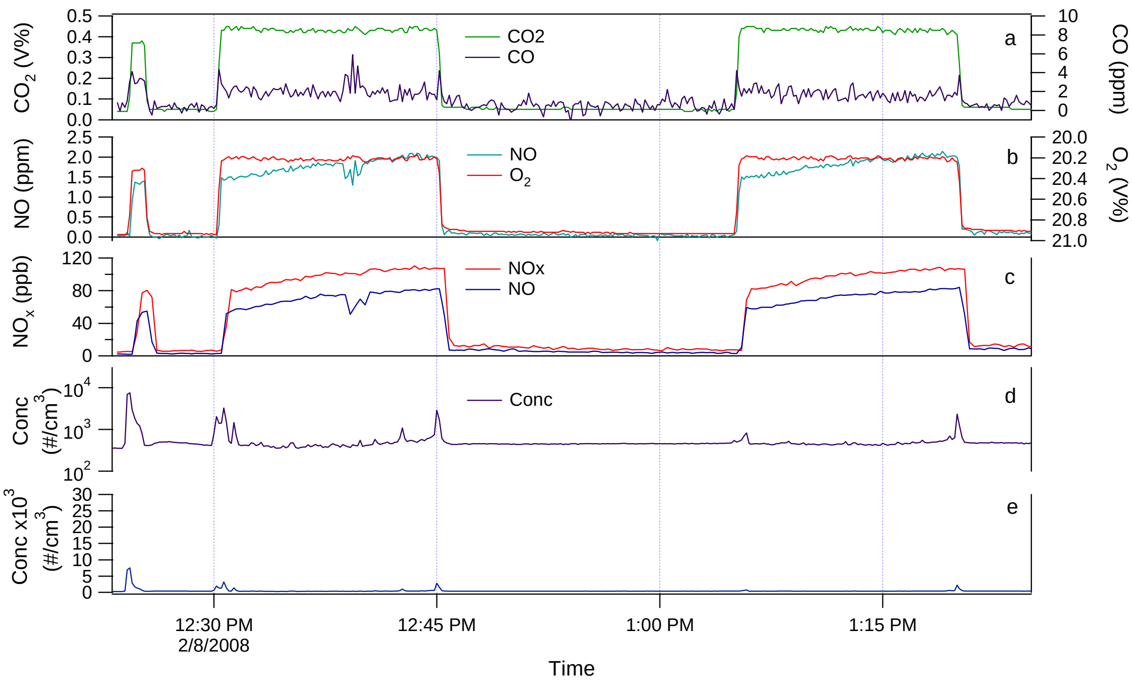

Figure 8. Measured analyte concentrations for cooktop CT01 with fuel 3A + N_2 (L065).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (possible instrument malfunction). Ethane tank ran out between burns; fuel composition not known for second burn.

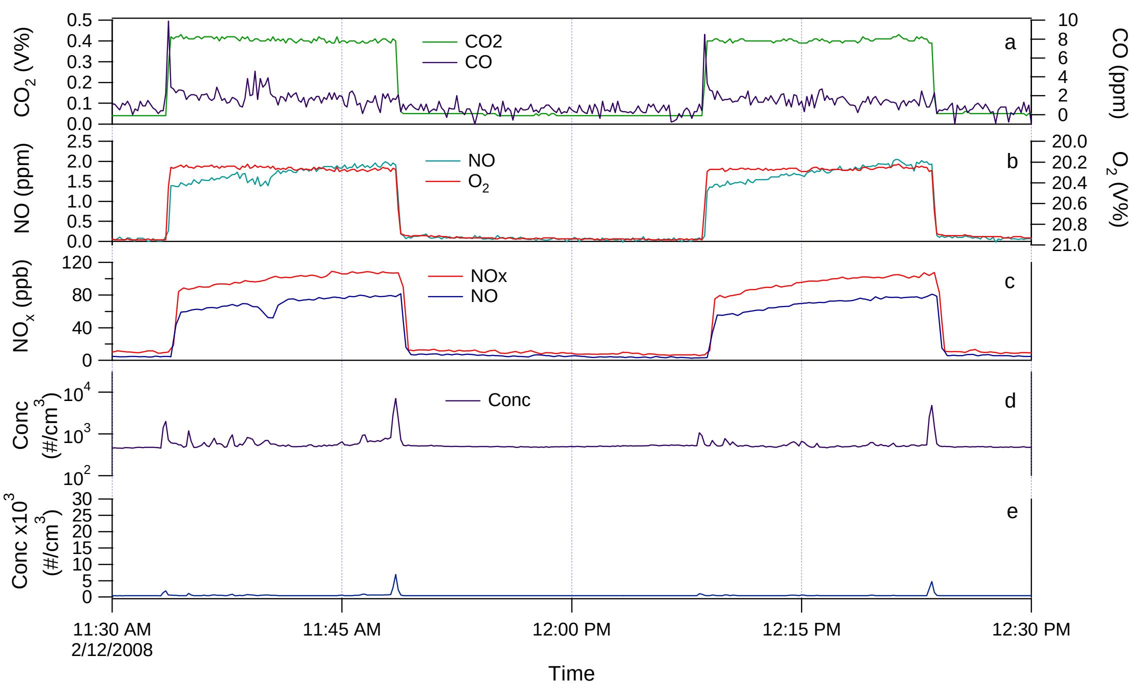

Figure 9. Measured analyte concentrations for cooktop CT01 with fuel 1C (L067).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (possible instrument malfunction).

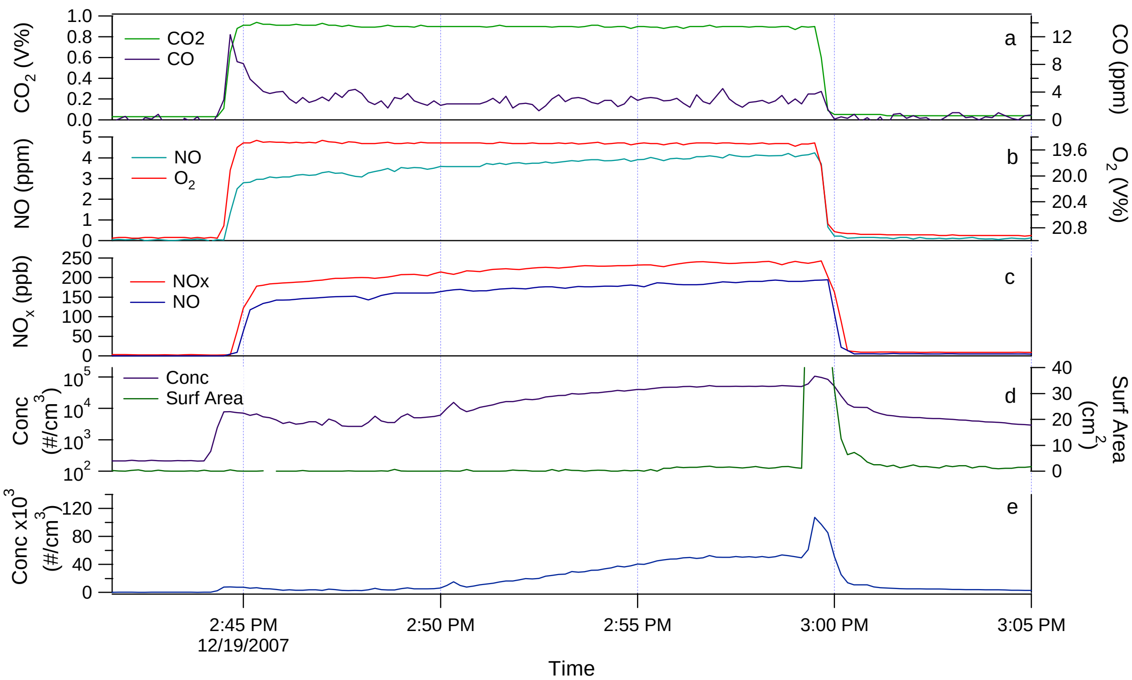

Figure 10. Measured analyte concentrations for cooktop CT01 with fuel 3A (L048).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Surface area refers to particles that would deposit in lung alveoli; units should be μm^2 cm^{-3}. Lung-depositing surface area monitor appears to not be reporting valid data.

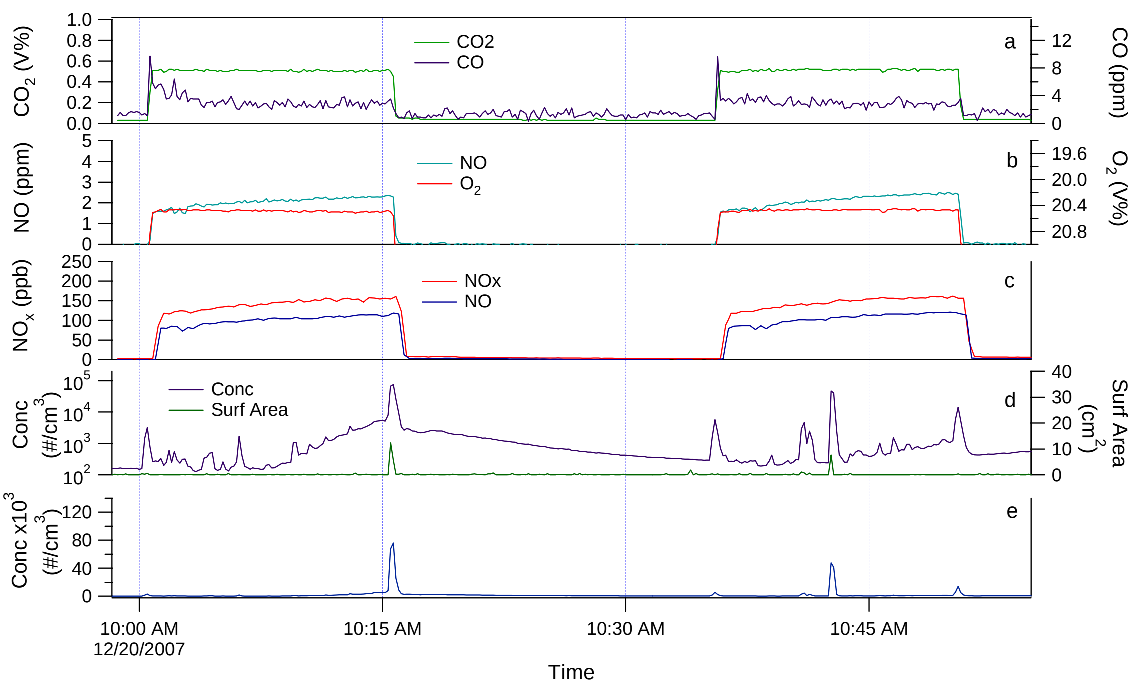

Figure 11. Measured analyte concentrations for cooktop CT01 with fuel 3A (L051).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration.

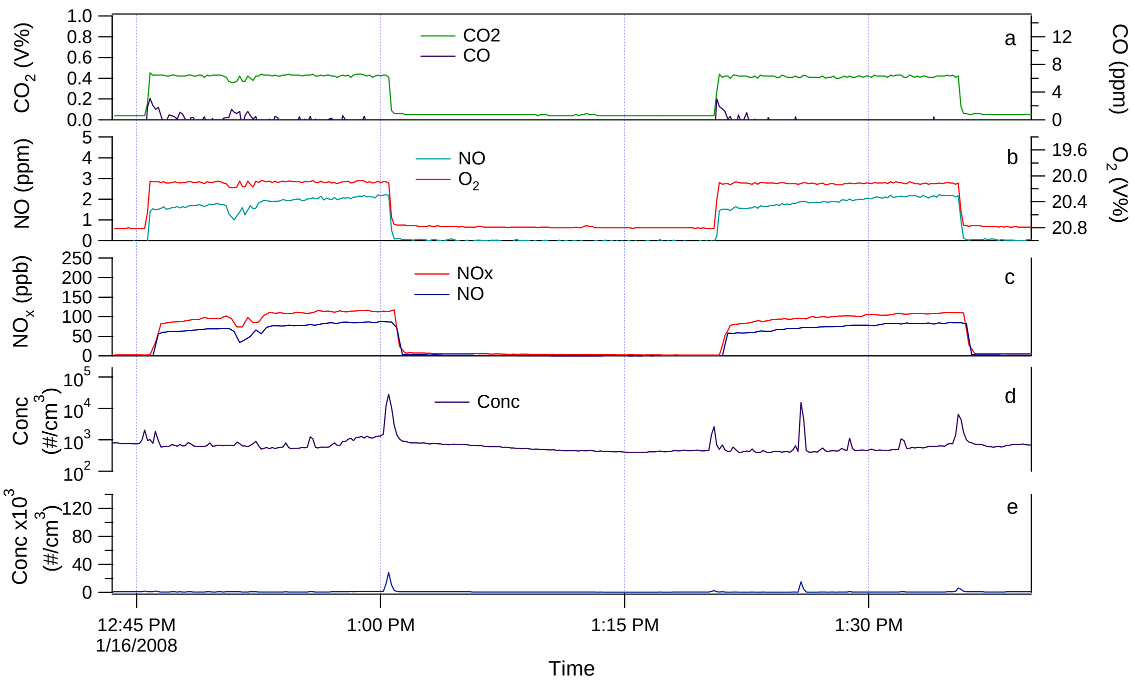

Figure 12. Measured analyte concentrations for cooktop CT01 with fuel 3A (L054).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Lung depositing particle surface area showed no response throughout the experiments (possible instrument malfunction).

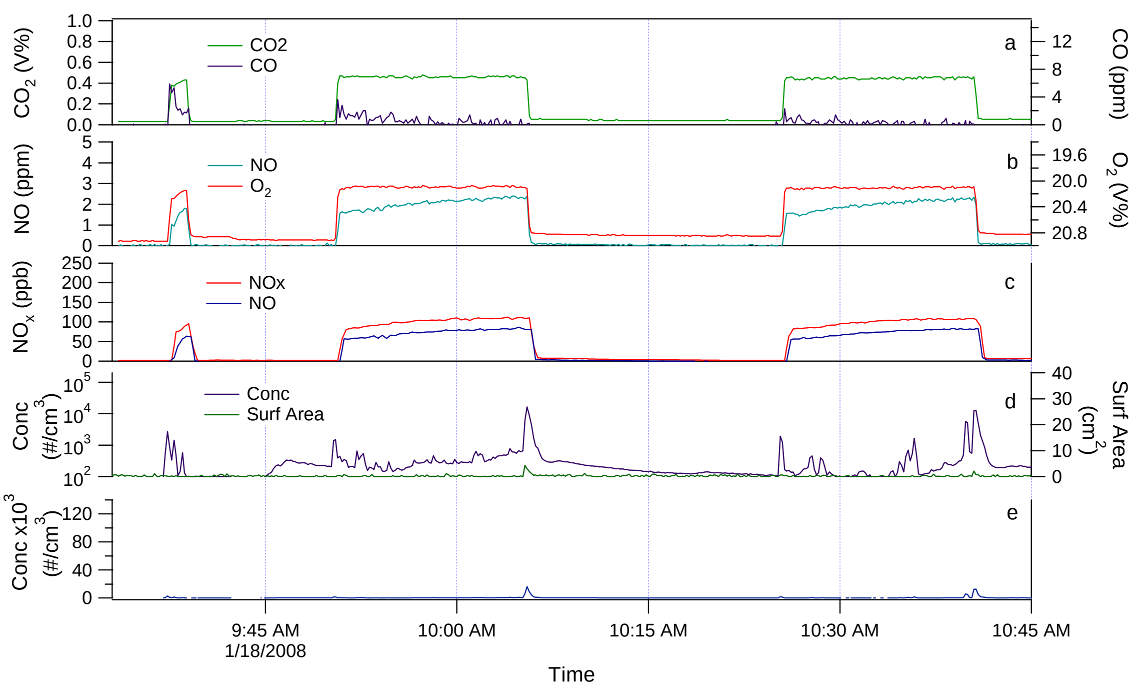

Figure 13. Measured analyte concentrations for cooktop CT01 with fuel 3A (L056).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. Panels (d)-(e) present particle number (PN) concentration. Surface area refers to particles that would deposit in lung alveoli. Lung-depositing surface area monitor appears to not be reporting valid data

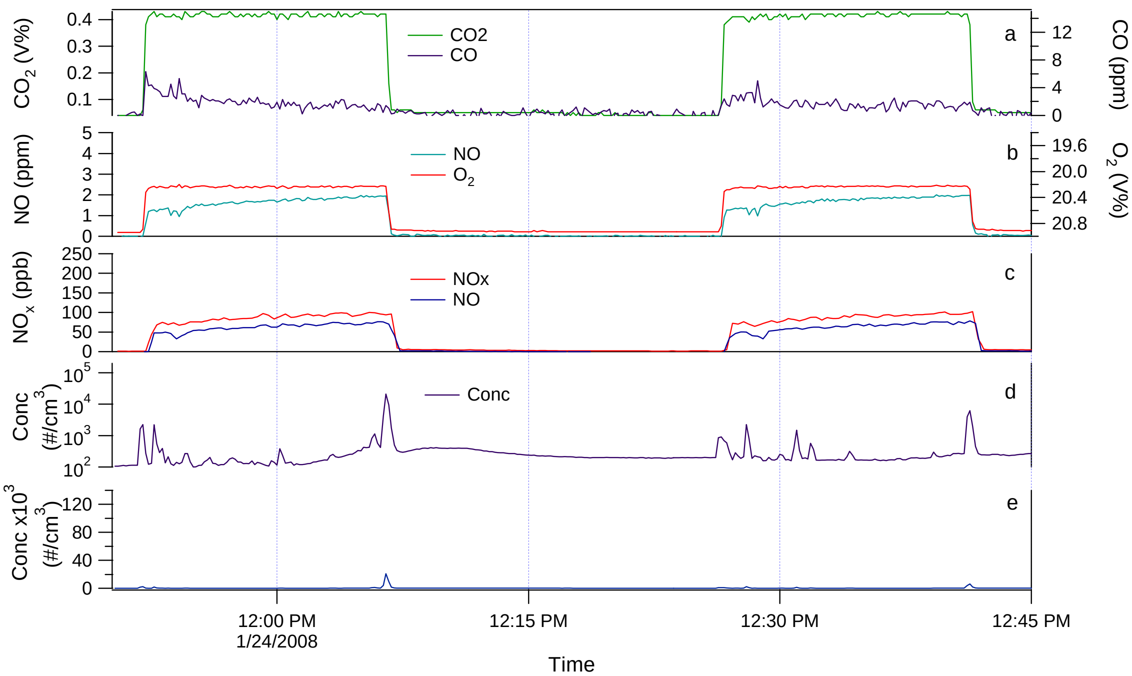

Figure 14. Measured analyte concentrations for cooktop CT01 with fuel 3A (L061).

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 (monitor appears to not be reporting valid data).

Table 11. Calculated air-free concentrations (using CO_2) over last 5 min of each burn.

Exp	Fuel	Wobbe	CO (ppm)		PG250 NO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L045[1]	PG&E	1334	38	42	60	61	74	73	60	61	14.2	12.6	350	170
L048[2]	3A	1418	33	-	56	-	71	-	56	-	14.6	-	140	-
L051	3A	1418	40	40	60	62	82	82	60	62	22.0	20.1	9.8	2.3
L054	3A	1419	77	54	67	70	88	89	67	70	21.5	18.9	3.0	0.7
L056	3A	1417	61	51	66	65	86	85	66	65	20.3	19.5	2.5	2.9
L058[3]	3A+N2	1382	47	39	61	60	78	76	61	60	16.3	16.3	1.0	0.7
L061	3A	1418	35	41	60	61	78	78	60	61	18.3	17.4	0.3	-0.2
L064	PG&E	1329	36	28	67	63	85	79	67	63	17.9	16.3	130	46
L065[4]	3A+N2	1382	41	29	60	62	80	80	60	62	20.2	17.9	0.4	0.1
L067	1C	1390	40	30	63	62	84	82	63	62	21.2	19.2	0.9	0.2

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream with possible losses of some NO_X (primarily NO_2). 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] L048 had only one sample burn.
[3] Supply pressure below 6" H_2O and manifold pressure below 5.5" H_2O on burn 2.
[4] Ethane ran out following first burn of L065. Results are presented despite the fuel composition uncertainty.

Table 12. Calculated emission rates over entirety of each burn, cooktop CT01.

Exp	Fuel	Wobbe	CO ($\mu g\ KJ^{-1}$)		PG250 NO_X ($\mu g\ KJ^{-1}$)		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	B1	B2	-
L045[1]	PG&E	1334	11	12	24	24	30	30	24	24	6.2	5.6	490	320	-
L048[2]	3A	1418	10	-	22	-	29	-	22	-	6.3	-	190	-	-
L051	3A	1418	13	12	24	24	33	33	24	24	9.3	8.7	34	20	-
L054	3A	1419	24	17	26	28	35	36	26	28	9.3	8.0	16	7.6	-
L056	3A	1417	19	16	26	26	35	35	26	26	9.1	9.0	12	11	-
L058[3]	3A+N2	1382	14	12	24	23	31	30	24	23	7.7	7.2	6.5	3.1	-
L061	3A	1418	15	13	23	24	31	32	23	24	8.1	7.9	8.8	3.6	-
L064	PG&E	1329	11	9	26	25	34	32	26	25	7.7	7.3	180	79	0.31
L065[4]	3A+N2	1382	12	10	23	24	32	32	23	24	8.3	7.6	2.6	0.9	0.42
L067	1C	1390	15	12	25	25	34	33	25	25	9.5	8.4	4.7	2.5	0.43

[1] High sample manifold RH indicates potential for water condensation in gas sampling stream with possible losses of some NO_X (primarily NO_2). 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] L048 had only one sample burn.

[3] Supply pressure below 6" H_2O and manifold pressure below 5.5" H_2O on burn 2.

[4] Ethane ran out following first burn of L065. Results are presented despite the fuel composition uncertainty.

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2.0 Cooktop CT02

2.1. Experimental information for CT02

Several sets of experiments were conducted with this cooktop.

The first seven experiments occurred in September 2007. During the first four experiments (L024, L026-L028), the blower for the collection hood was operated at a lower speed that resulted in higher exhaust concentrations at the hood outlet and relative humidity approaching saturation in the glass sampling manifold. The PG-250 combustion gas analyzer – which was used to quantify CO_2, O_2, CO and NO in the direct sampling stream – has an internal water removal system. High RH and potential condensation of water in the sampling lines or glass manifold could have affected NO_2 and HCHO concentrations but this is not expected to affect any of the other analytes. The blower speed was increased during the next three experiments. Of the seven total experiments, there were 3 with PG&E line gas (WN = 1329-1342) and two each with fuel 3A undiluted (WN = 1416-1418) and fuel 3A diluted with N_2 (WN = 1384-1386). Experiments L026-L028 were conducted on the same day and included one experiment with each fuel. Experiments L029-L031 had higher hood flow, lower sample manifold RH and included one experiment with each fuel.

In these seven experiments the aerosol inlet heater was not functioning; the inlet was therefore heated only by the exhaust gas stream.

It was determined in February 2008 that the critical orifices used in the aldehyde sampling trains for the September 2007 experiments had reduced flow (in Feb 2008). CT02 experiments were conducted in September 2007 after the critical orifice flows were measured in June 2007. Since flow rates were not measured during these experiments, it is not possible to determine if the sample flows were affected. Aldehyde results are not presented for these experiments owing to uncertainty in sample flow rates, concentrations, and emission rates.

Three additional experiments were conducted in December 2008 to obtain data on formaldehyde emission rates. These included one experiment each with PG&E line gas (WN=1332), fuel mix 1C (WN=1390) and fuel mix 3C (WN=1419), all on the same day.

Table 13. Appliance and burner information.

Burner ID	CT02
Burner category	Cooktop
Burner technology	Open burners with pilot ignition (legacy)
Appliance manufacturer	Frigidaire
Model	6F82000796
Serial number	MPF500PBWB
Other information	Cooktop of 24” range
Design manifold P	4 in. H_2O
Burner ratings (Btu/h)	9,000 each × 4 burners = 36,000 total
Age (years)	Purchased new in 1995
Test location	Laboratory
History notes	Procured from original owner for $50; advertised by owner on craigslist.org. Stated reason for sale: owner purchased new, full-size range. Owners reported regular use of both cooktop and oven. Stored between experimental uses in Sept 2007 and Nov 2008.

Figure 15. Cooktop CT02 burners.

Table 14. Interchangeability experiments for cooktop CT02.

Exp.	Fuel	Date	Burner operation
September 2007 experiments			Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20 min between burns. When switching fuels, purge for several minutes prior to first burn.[1]
L024	PG&E	09/13/07	
L026	3A	09/14/07	
L027	3A+N_2	09/14/07	
L028	PG&E	09/14/07	
L029	PG&E	09/18/07	
L030	3A	09/18/07	
L031	3A+N_2	09/20/07	
December 2007 experiments			
L124	PG&E	12/10/08	
L125	1C	12/10/08	
L126	3C	12/10/08	

[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 15. Fuel analysis for interchangeability experiments with cooktop CT02.

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										
L024	PG&E	L024Pre	95.7	2.15	0.18	0.06	1.14	0.72	1012	1329
L026	3A	L026Pre	90.2	5.71	3.05	1.03	0.00	0.00	1122	1417
		L026Post	90.3	5.65	2.99	1.04	0.00	0.00	1121	1416
L027	3A+N_2	L027Pre	88.8	5.57	2.94	1.03	1.69	0.00	1103	1386
		L027Post	88.8	5.59	2.91	0.96	1.79	0.00	1100	1384
L028	PG&E	L028Pre	95.5	2.36	0.31	0.11	1.07	0.68	1017	1334
L029	PG&E	L029Pre	94.7	2.75	0.58	0.17	0.77	0.76	1028	1342
L030	3A	L030Pre	90.1	5.84	3.02	1.06	0.00	0.00	1124	1418
		L030Post	90.2	5.73	3.00	1.09	0.00	0.00	1123	1418
L031	3A+N_2	L031Pre	88.5	5.63	2.99	1.08	1.79	0.00	1104	1386
December 2008 experiments										
L124	PG&E	Distrib[2]	95.5	2.27	0.25	0.08	0.99	0.75	1015	1332
L125	3C	Cylinder[3]	86.4	12.0	1.60	-	-	-	1125	1419
L126	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 16. **Lab installation and sampling configuration of range featuring cooktop CT02 (Sept. 2007).** This photograph was taken during sampling for the oven burner in 2007. The hood was raised for the cooktop sampling to ensure undisturbed airflow to the burners. The dilution aerosol sampler, installed on a photographic pole at left of photograph, is drawing sample from the flexible duct, approximately 2 feet from the outlet of the collection hood.

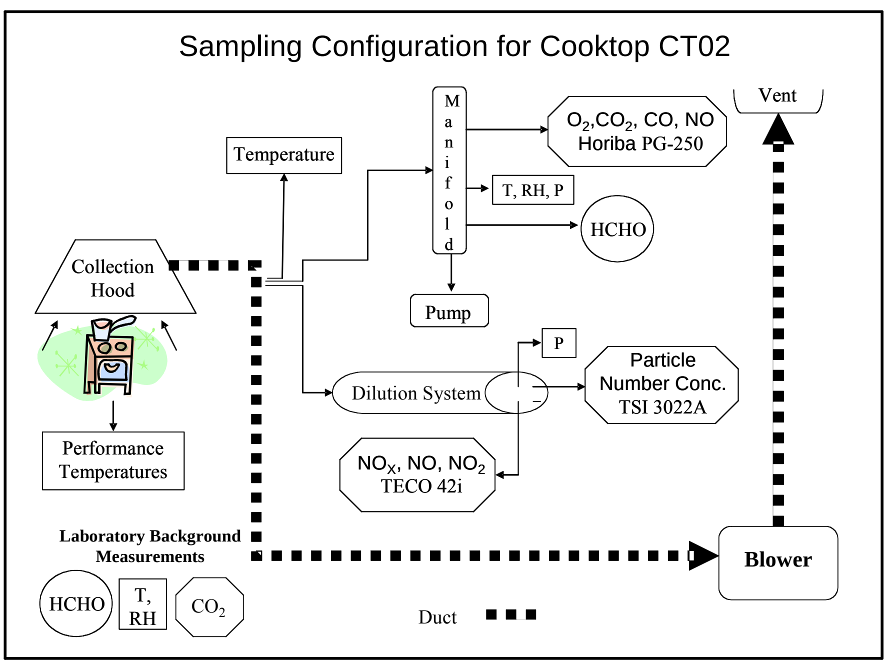

Figure 17. **Analytical sampling configuration for cooktop burner CT02, September 2007 experiments.**

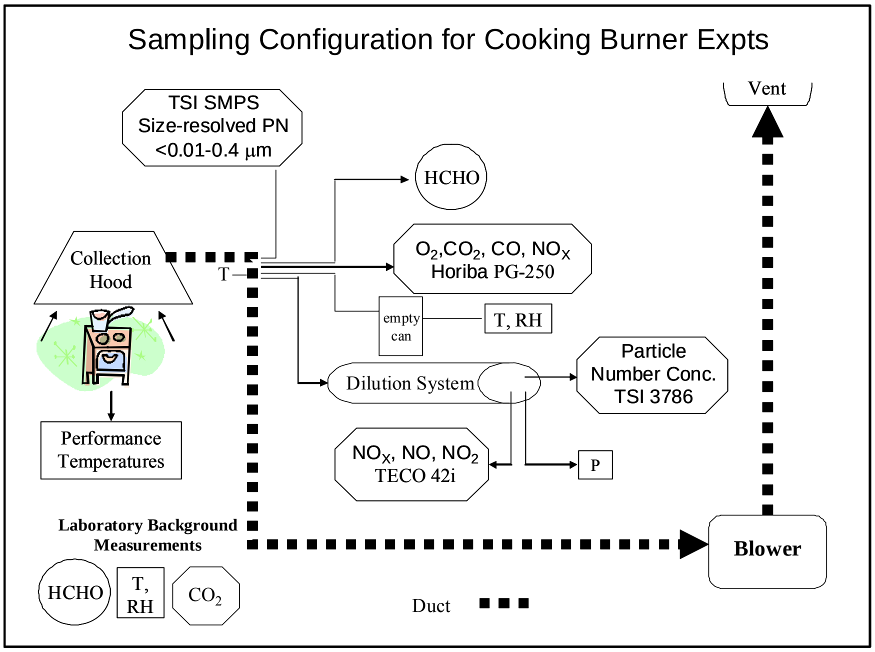

Figure 18. Analytical sampling configuration for CT02, December 2008 experiments.
The empty can is used to measure RH of the airstream from the collection hood at room temperature. This indicates the potential for condensation in sampling system. PG-250 also has water removal system. HCHO sampled through 30-cm Teflon tubing (nominal ¼" diameter) for primary sample, duplicate sampled through 90-cm Teflon tubing.

Table 16. Analyte ranges and calibration levels for September 2007 experiments with cooktop CT02.

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)	dilution sampler	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

[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.

Table 17. Analyte ranges and calibration levels for December 2008 experiments with cooktop CT02.

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 cooktop CT02, September 2007 experiments.

Analyte	Instrument[1]	Configuration	Min. size $(D_{50})^2$	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3022A CPC	sample from dilution tube 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}

[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 19. Aerosol instrumentation used for cooktop CT02, December 2008 experiments.

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 20. Other measurements for experiments with cooktop CT02.

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
Temp., 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)

2.2. Results for CT02

In the first round of experiments, CO emissions were low and roughly consistent throughout each burn; air-free concentrations during the last 5 min of each burn were in the range of 100-150 ppm. CO emission rates varied within the burns and experiments of each fuel but were on average higher for 3A (37-41 ng/J) relative to 3A+N_2 (32-36 ng/J) and PG&E (29-34 ng/J). NO_X air-free concentrations and emission rates were substantially lower in the experiments with lower hood dilution flow and near-saturation RH levels in the gas sampling manifold; full-burn emission rates in these experiments were 36-37 ng/J. Full burn NO_X emission rates in experiments with higher hood dilution flow rates were 42-45 ng/J. Most of the difference was in NO. Within each group, there were no clear trends of NO_X emissions varying with fuel WN. NO accounted for about 75% of total NO_X. PN emission rates were higher for PG&E line gas (190-460 $\times 10^7$ KJ^{-1}) compared to fuel 3A with N_2 (54-120 $\times 10^7$ KJ^{-1}) and fuel 3A undiluted (36-210 $\times 10^7$ KJ^{-1}).

In the second round of experiments (Dec 2008), CO emission rates were lower overall but still trended higher with increasing fuel WN. NO_X, NO and NO_2 emission rates (in ng/J) were similar to those obtained in the earlier experiments with lower hood dilution rates and higher manifold RH, and again there were no clear changes in NO_X emissions with fuel WN. PN emission rates were similar across five of the burns (100-160 $\times 10^7$ KJ^{-1}) and lower (29×10^7 KJ^{-1}) for one of the L125 (fuel 3C) burns. Formaldehyde emissions appeared to increase somewhat with fuel WN, from 0.55 ng/J for PG&E gas to 0.58 ng/J for fuel 1C to 0.72 ng/J for fuel 3C.

Table 21. Burner operating parameters for experiments with cooktop CT02.

Exp.	Burn[1]	Start time	End time	Fuel flow (ft^3 min^{-1})[2]	Firing rate (kBtu/h)[2]
September 2007 experiments					
L024	B1	13:50	14:05	31	32
PG&E	B2	14:24	14:39	31	32
L026	B1	10:05	10:20	29	33
3A	B2	10:41	10:56	28	32
L027	B1	11:41	11:56	29	32
3A+N_2	B2	12:15	12:30	28	31
L028	B1	13:42	13:57	32	32
PG&E	B2	14:15	14:30	31	32
L029	B1	13:48	14:03	31	32
PG&E	B2	14:25	14:40	30	31
L030	B1	16:02	16:17	29	33
3A	B2	16:37	16:20	29	33
L031	B1	10:35	10:50	29	32
3A+N_2	B2	11:10	11:25	29	32
December 2008 experiments					
L124	B1	11:10	11:25	32	32
PG&E	B2	11:45	12:00	31	32
L125	B1	12:55	13:10	30	34
3C	B2	13:30	13:45	30	34
L126	B1	14:15	14:30	31	33
1C	B2	14:49	15:05	30	32

[1] B1 and B2 are the duplicate burns with load (pots filled with water). [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.

Table 22. Environmental conditions[1] for experiments with cooktop CT02.

Exp.	T (°C)			RH (%)		
September 2007 experiments						
L024	23.2	±	0.2	53	±	1
L026	22.4	±	0.3	65	±	1
L027	22.8	±	0.2	61	±	1
L028	22.6	±	0.1	59	±	1
L029	22.5	±	0.2	50	±	1
L030	22.3	±	0.1	50	±	<1
L031	20.9	±	0.2	50	±	1
December 2008 experiments						
L124	21.0	±	0.2	38	±	1
L125	21.5	±	0.1	40	±	1
L126	21.9	±	0.1	41	±	1

[1] Mean ± standard deviation measured over period of aldehyde sampling, i.e. over entire experiment.

Table 23.Gas sampling manifold temperature and RH.

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
September 2007 experiments				
L024	26.0 ± 0.2	26.3 ± 0.2	*93 ± 2*	*90 ± 1*
L026	25.4 ± 0.2	26.2 ± 0.3	*98 ± 2*	*94 ± 2*
L027	26.6 ± 0.2	26.2 ± 0.2	*88 ± 1*	*88 ± 1*
L028	26.0 ± 0.2	25.9 ± 0.3	*89 ± 1*	*89 ± 1*
L029	25.7 ± 0.2	26.0 ± 0.2	68 ± 1	67 ± 1
L030	25.4 ± 0.1	25.1 ± 0.2	69 ± 1	70 ± 1
L031	23.4 ± 0.1	23.7 ± 0.1	72 ± 1	70 ± 1
December 2008 experiments				
L124	19.0 ± 0.0	19.3 ± 0.0	67 ± 1	65 ± 1
L125	19.9 ± 0.0	20.2 ± 0.1	64 ± 1	63 ± 1
L126	20.4 ± 0.1	20.4 ± 0.0	64 ± 1	64 ± 1

[1] Measured in gas sampling manifold for each burn. High manifold RH resulted from lower dilution associated with lower hood air flow rate during experiments L024-L028.

Table 24. Sampling system conditions, September 2007 experiments.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
September 2007 experiments				
L024	65 ± 5	62 ± 5	31	31
L026	62 ± 5	61 ± 5	32	32
L027	69 ± 5	62 ± 4	33	33
L028	67 ± 5	63 ± 5	34	35
L029	66 ± 5	65 ± 5	28	28
L030	66 ± 5	66 ± 5	29	29
L031	65 ± 5	63 ± 5	30	30
December 2008 experiments				
L124	N/A	N/A	27	25
L125	N/A	N/A	26	25
L126	N/A	N/A	25	26

[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 25. Formaldehyde samples for experiments with cooktop CT02.

Exp(s)	Location	Date	Sample start/end time		Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m³)
Bkg	Lab air	12/11/2008	10:48	15:07	297	0.979	7
L124	Collection hood outlet	12/11/2008	11:07	12:02	57	2.561	90
L125			12:53	13:47	58	3.334	115
L126			14:13	15:07	57	2.680	94

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

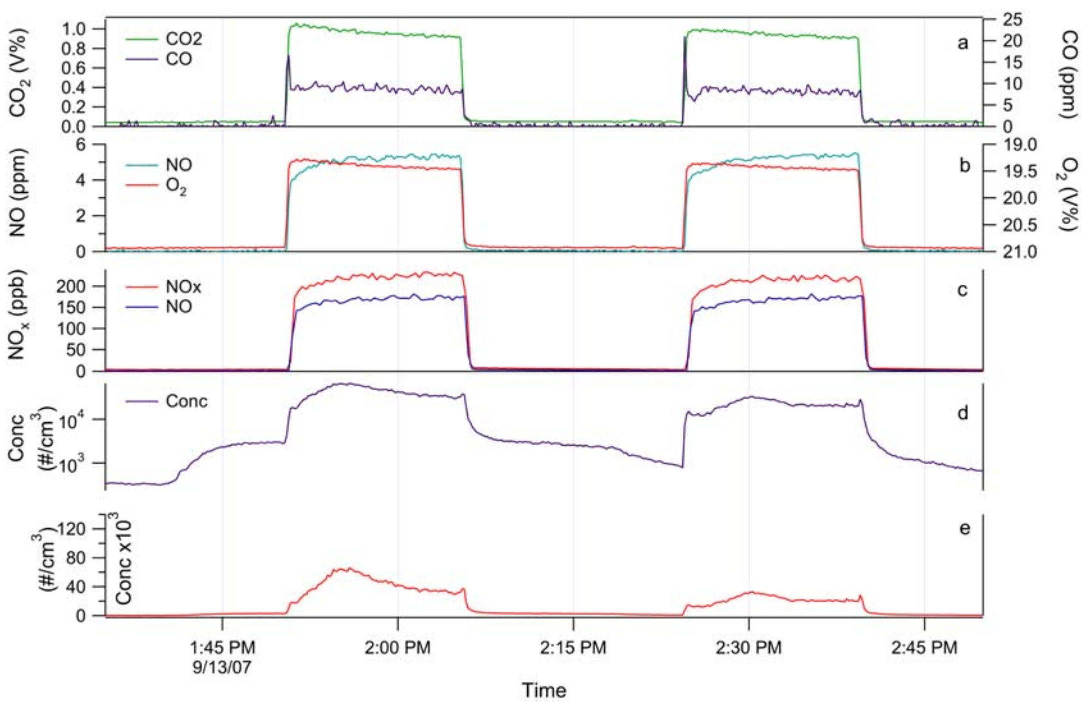

Figure 19. Measured analyte concentrations with PG&E line gas, Sept 2007 (L024).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

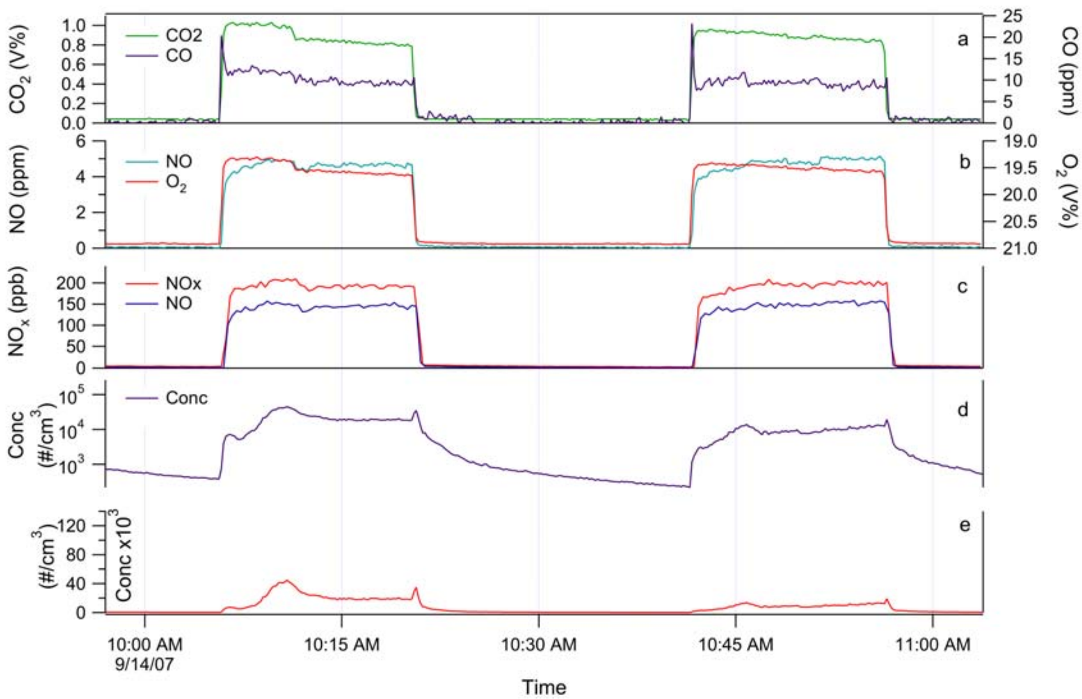

Figure 20. **Measured analyte concentrations with fuel 3A, Sept 2007 (L026).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

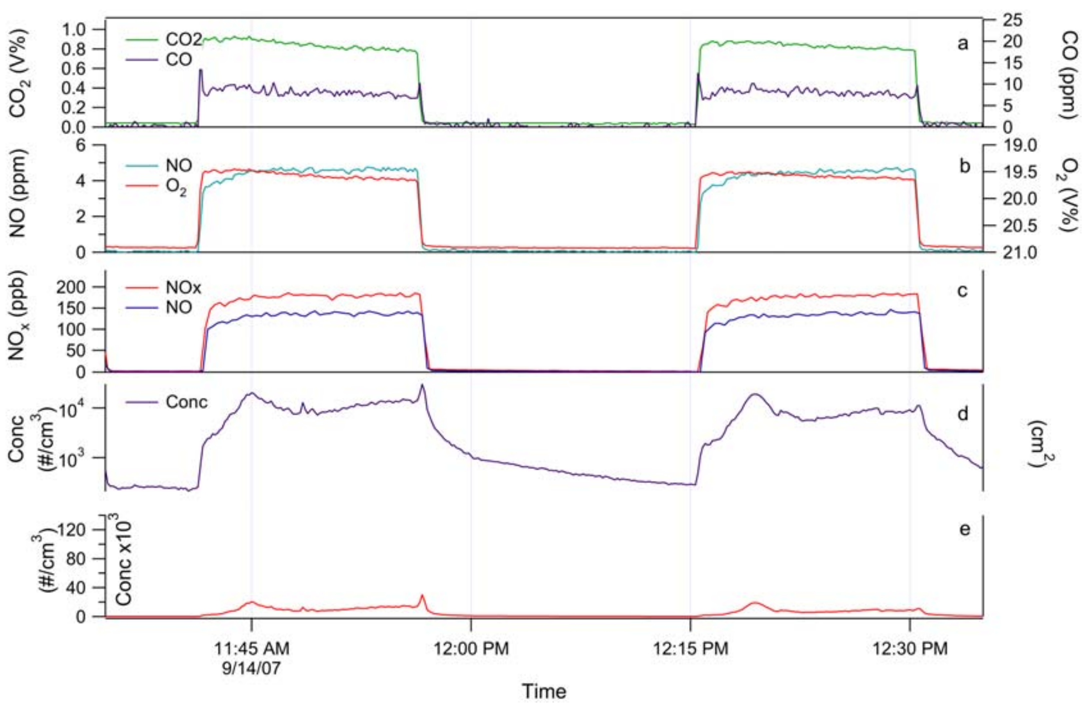

Figure 21. **Measured analyte concentrations with fuel 3A+N$_2$, Sept 2007 (L027).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

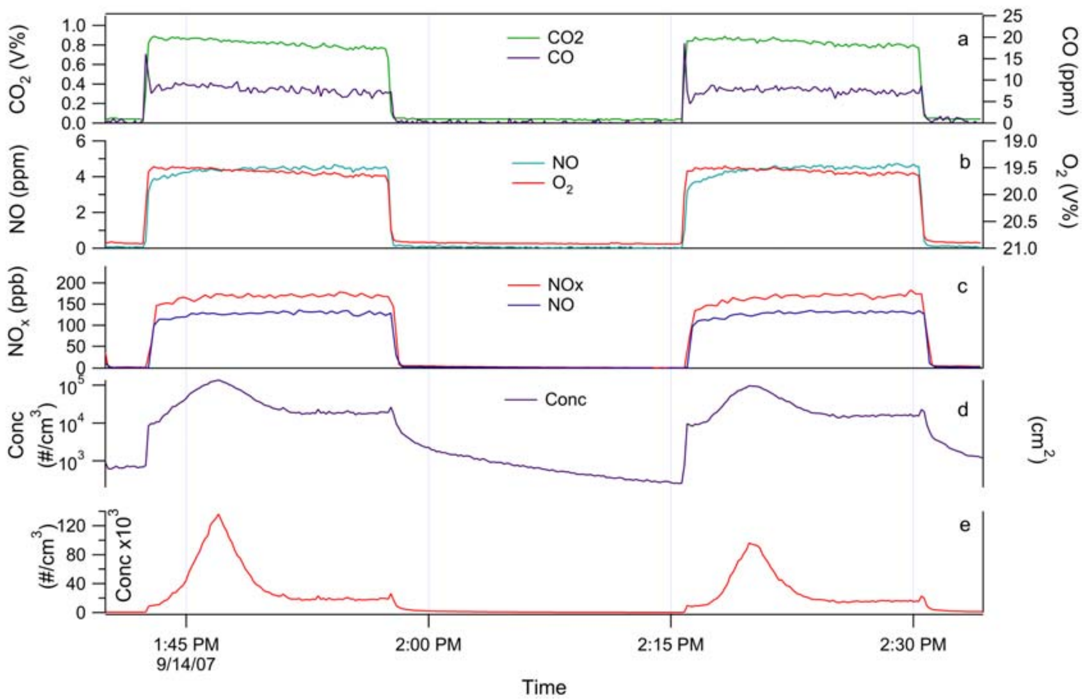

Figure 22. Measured analyte concentrations with PG&E line gas, Sept 2007 (L028).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

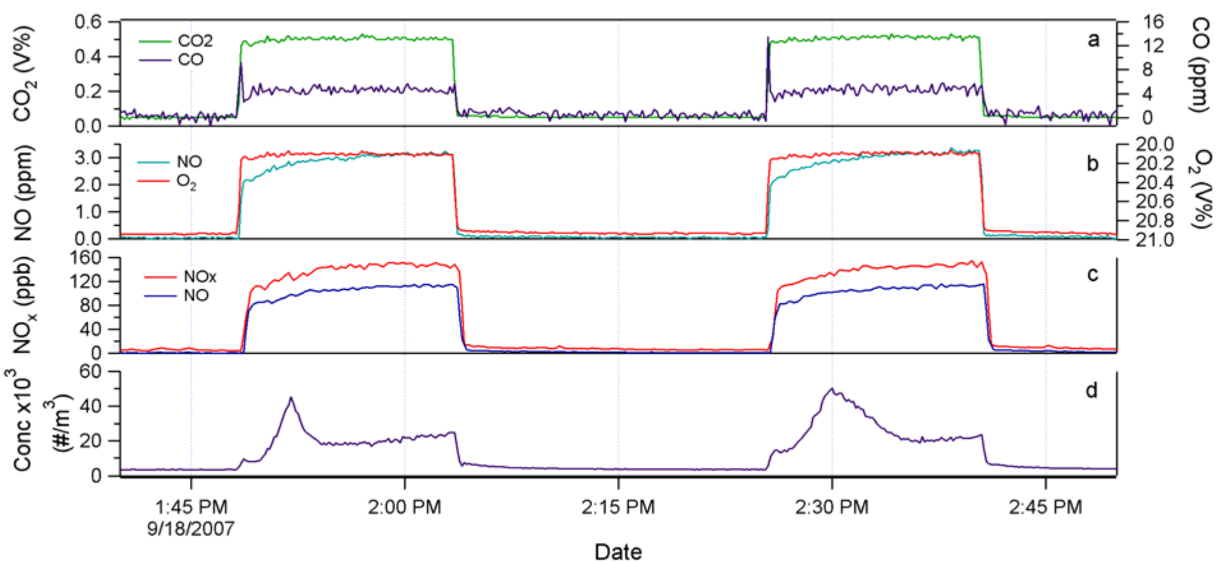

Figure 23. Measured analyte concentrations with PG&E line gas, Sept 2007 (L029).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

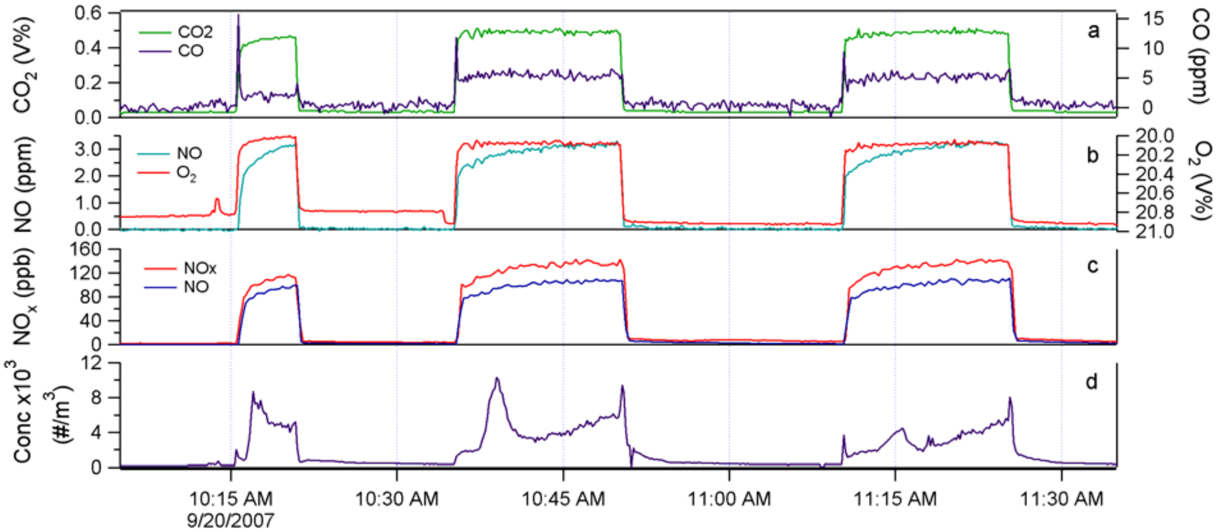

Figure 24. Measured analyte concentrations with fuel 3A+N_2, Sept 2007 (L031).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

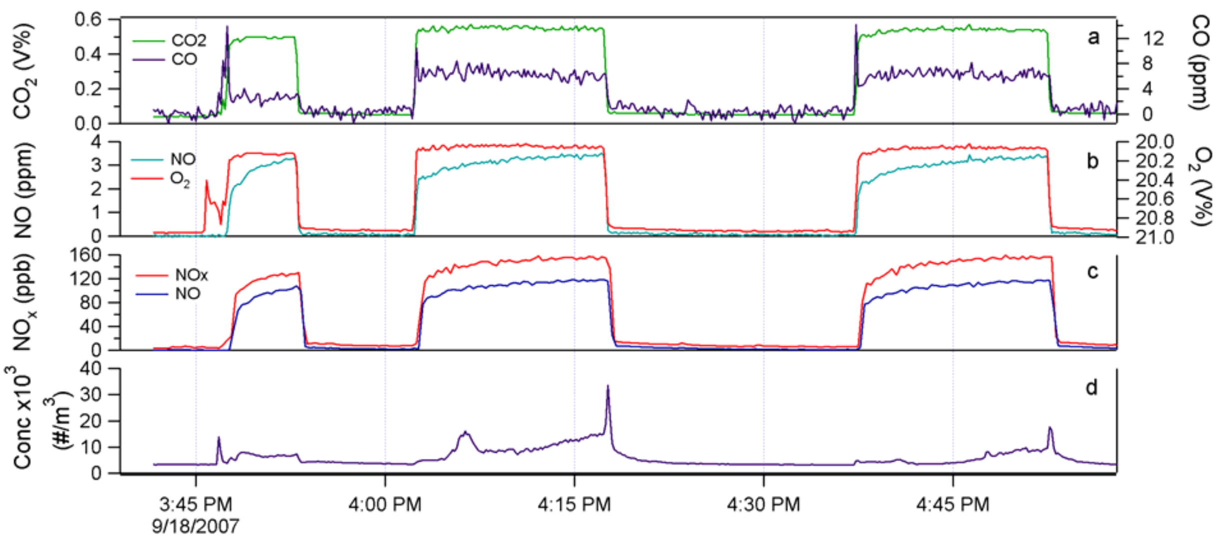

Figure 25. Measured analyte concentrations with fuel 3A, Sept 2007 (L030).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

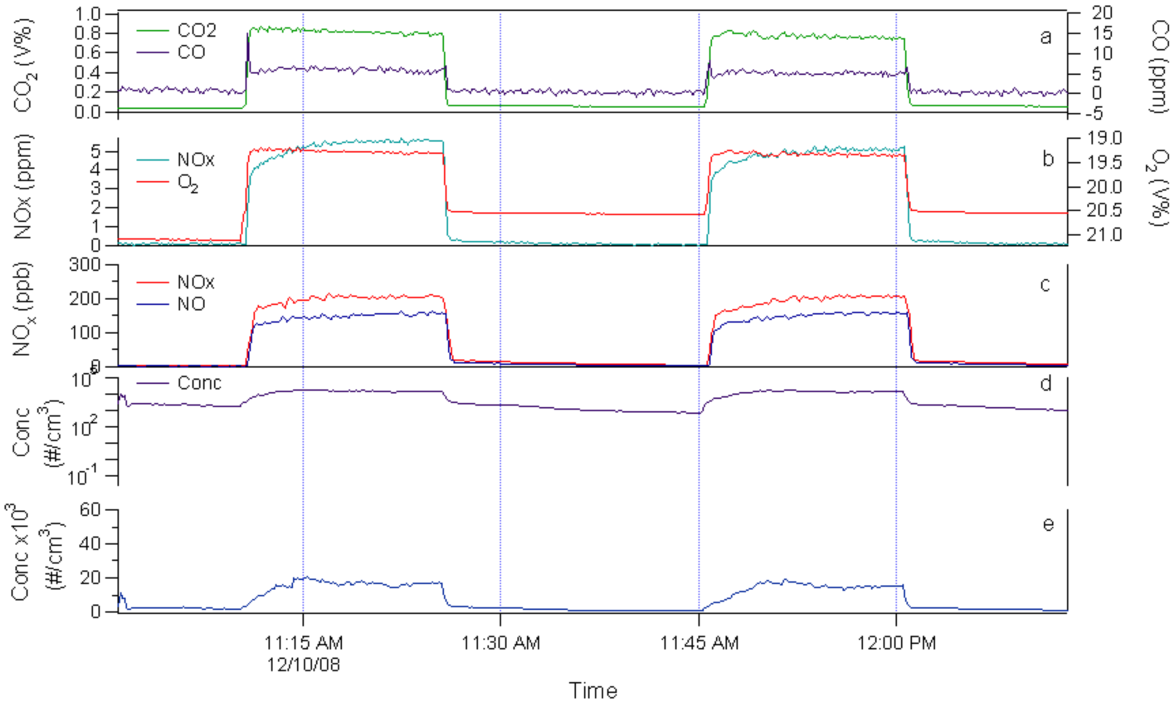

Figure 26. Measured analyte concentrations with PG&E line gas, Dec 2008 (L124).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

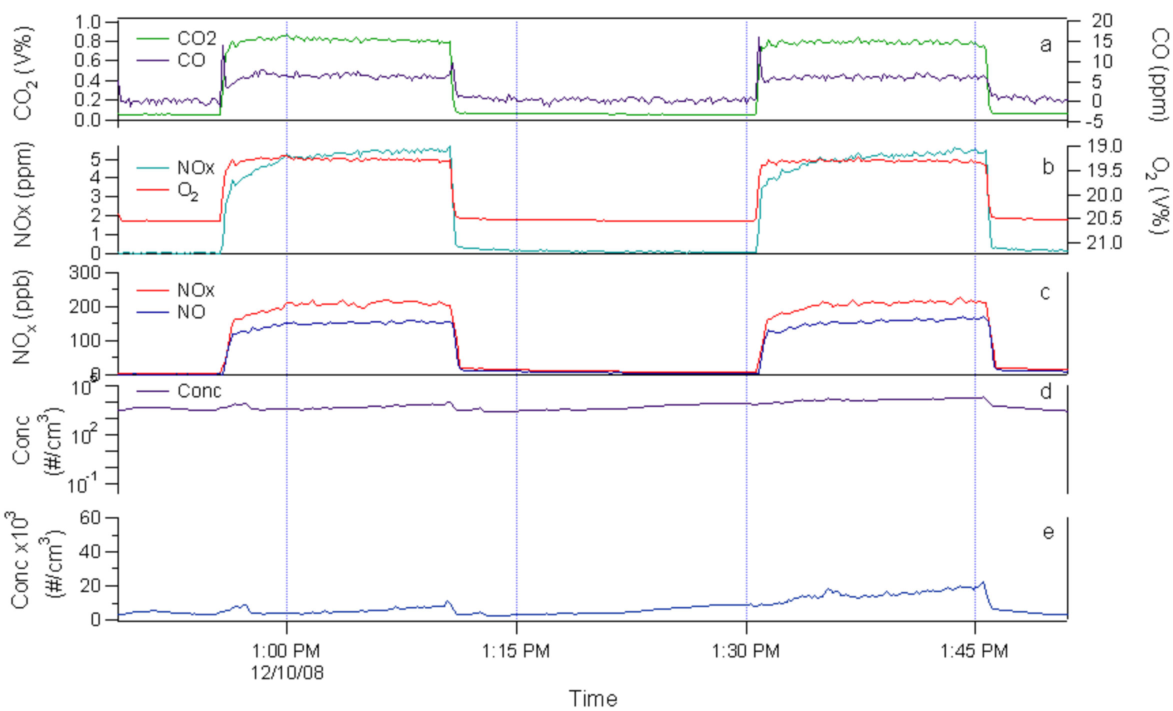

Figure 27. Measured analyte concentrations with fuel 3C, Dec 2008 (L125).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

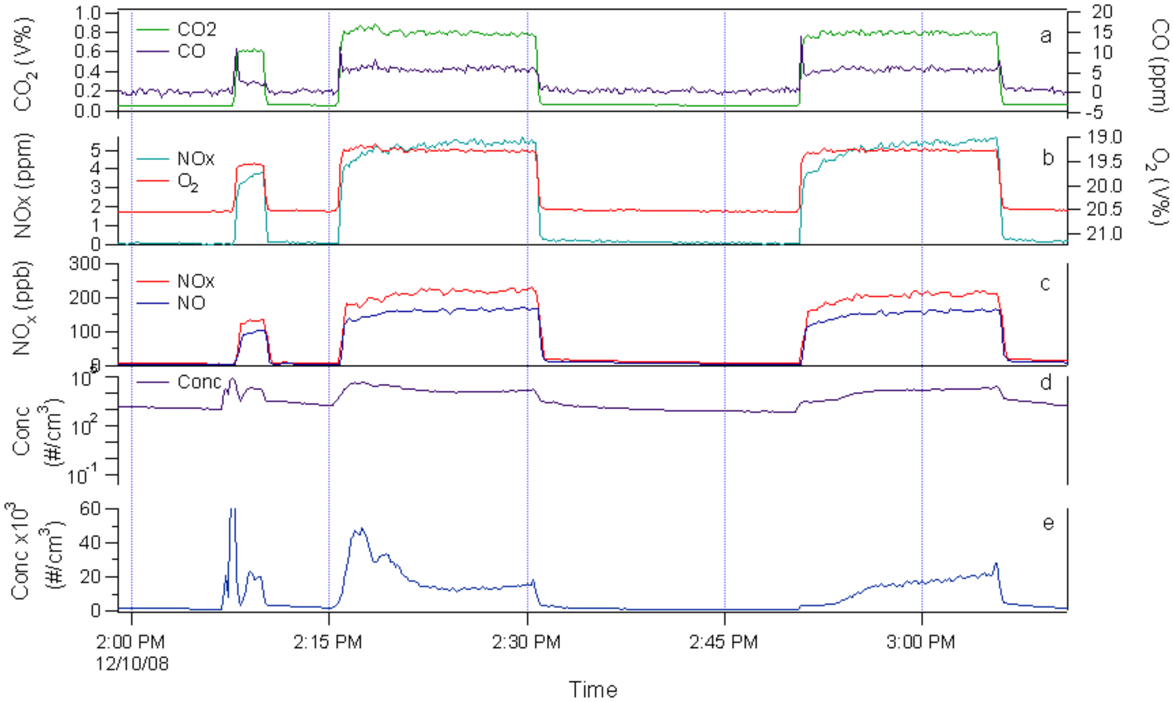

Figure 28. Measured analyte concentrations with fuel 1C, Dec 2008 (L126).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration.

Table 26. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, September 2007 experiments.

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
L024	PG&E	1329	111	107	92	90	71	72	21.3	18.2	140	80
L026	3A	1417	147	133	92	92	71	71	21.4	20.3	90	48
L027	3A+N2	1386	116	116	93	92	72	71	21.3	21.2	63	42
L028	PG&E	1334	123	119	92	91	70	70	22.0	21.2	98	81
L029	PG&E	1342	119	120	104	104	81	82	22.5	22.2	130	130
L030	3A	1418	137	142	105	106	81	81	23.5	24.9	61	31
L031	3A+N2	1386	133	128	110	112	87	87	23.0	24.7	38	31

Table 27. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, December 2008 experiments.

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
L124	PG&E	1332	85	79	86	84	66	65	20.1	19.1	59	50
L125	3C	1419	93	95	85	86	63	66	22.4	20.4	17	60
L126	1C	1390	92	88	86	86	66	66	20.3	20.1	45	68

Note: PG-250 set to measure NO_X in these experiments

Table 28. Calculated emission rates over entirety of each burn, cooktop CT02, September 2007 experiments.

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})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L024	PG&E	1329	30	29	36	36	28	29	8.2	7.7	360	190
L026	3A	1417	41	37	37	37	28	28	9.2	8.5	210	90
L027	3A+N2	1386	32	32	37	37	28	28	8.9	8.7	120	87
L028	PG&E	1334	34	32	37	36	28	28	9.0	8.4	460	340
L029	PG&E	1342	32	32	42	42	33	33	9.5	9.1	290	380
L030	3A	1418	40	40	43	43	33	32	10.4	10.5	110	36
L031	3A+N2	1386	36	34	44	45	35	35	9.5	10.0	78	54

Table 29. Calculated emission rates over entirety of each burn, cooktop CT02, December 2008 experiments.

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	
L124	PG&E	1329	24	21	34	34	26	26	8.5	7.8	120	100	0.55
L125	3C	1417	26	26	34	35	26	27	8.8	8.6	29	110	0.72
L126	1C	1386	24	24	36	36	27	27	8.5	8.5	160	110	0.58

Note: PG-250 set to measure NO_X in these experiments

3.0 Cooktop CT03

3.1. Experimental information for CT03

Two sets of experiments were conducted on this cooktop. The first set included 4 experiments conducted in August-September 2007; a follow-up set of 3 experiments occurred in April 2008. In the first set, experiments were conducted in pairs on two different days: PG&E line gas (WN = 1341) and mix 1B (WN = 1386) were tested together on 8/17/07; mix 3A undiluted (L021, WN = 1418) and 3A diluted with N_2 (L022, WN = 1387) were tested on 9/6/07. The second set of experiments was conducted on 4/25/08 and included PG&E line gas (WN = 1326), fuel mix 1C (WN = 1390) and fuel mix 3C (WN = 1419).

The following notes apply to the first 4 experiments. The collection hood air flow rate was initially set too low during the first experiment on 9/6 (L021); the flow rate was changed during the middle of the first burn. The aerosol dilution system inlet heater was not functioning during CT02 experiments; the inlet was therefore heated only by the exhaust gas stream. It was determined in February 2008 that the critical orifices used in the aldehyde sampling trains had reduced flow at that time. CT03 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.

Table 30. Appliance and burner information.

Burner ID	CT03
Burner category	Cooktop
Burner technology	Sealed burners, electronic ignition
Appliance manufacturer	Jenn-Air (Maytag)
Model	23650441ZD
Serial number	JGR8850ADW
Other information	Cooktop of 30” range
Design manifold P	4 in. H_2O
Burner ratings (Btu/h)	LF, RR = 12,000; LR, RF = 9,200. Total = 42,400
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 29. **Cooktop CT03.**

Figure 30. **Close-up of CT03 left-front burner.**

Figure 31. **CT03 burner flames with PG&E line gas.**

Table 31. Interchangeability experiments for cooktop CT03.

Exp.	Fuel	Date	Burner operation
L013	PG&E	08/17/07	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 12-17 min between burns for L013-L022; 15 min between burns for L086-L088. When switching fuels, purge for 1-6 min prior to first burn.[1]
L014	1B	08/17/07	
L021	3A	09/06/07	
L022	3A+N_2	09/06/07	
L086	PG&E	04/25/08	
L087	3C	04/25/08	
L088	1C	04/25/08	

[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 32. Fuel analysis for interchangeability experiments with cooktop CT03.

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
L013	*PG&E*	*line*[2]	*95.7*	*2.38*	*0.18*	*0.07*	*0.84*	*0.78*	*1024*	*1341*
L014	1B	-	92.7	6.63	0.54	0.00	0.09	0.05	1067	1386
L021	3A	Pre	90.1	5.81	3.03	1.09	0.00	0.00	1124	1418
		Post	90.3	5.70	2.95	1.05	0.00	0.00	1122	1417
L022	$3A+N_2$	Pre	88.8	5.60	2.90	1.05	1.66	0.00	1103	1387
		Post	88.8	5.59	2.89	1.03	1.73	0.00	1102	1386
L086	PG&E	L086	95.4%	2.29%	0.22%	0.06%	1.28%	0.76%	1012	1326
L087	3C	Cylinder	86.4%	12.00	1.60%	-	-	-	1125	1419
L088	1C	Cylinder	92.0%	8.00%	-	-	-	-	1071	1390

[1] Calculated using the American Gas Association interchangeability program.
[2] Sample collected at LBNL contaminated; data shown are from online GC analysis in PG&E distribution system (J01 Btu district), for period between 8/16/07 11 AM and 8/17/07 10 AM.

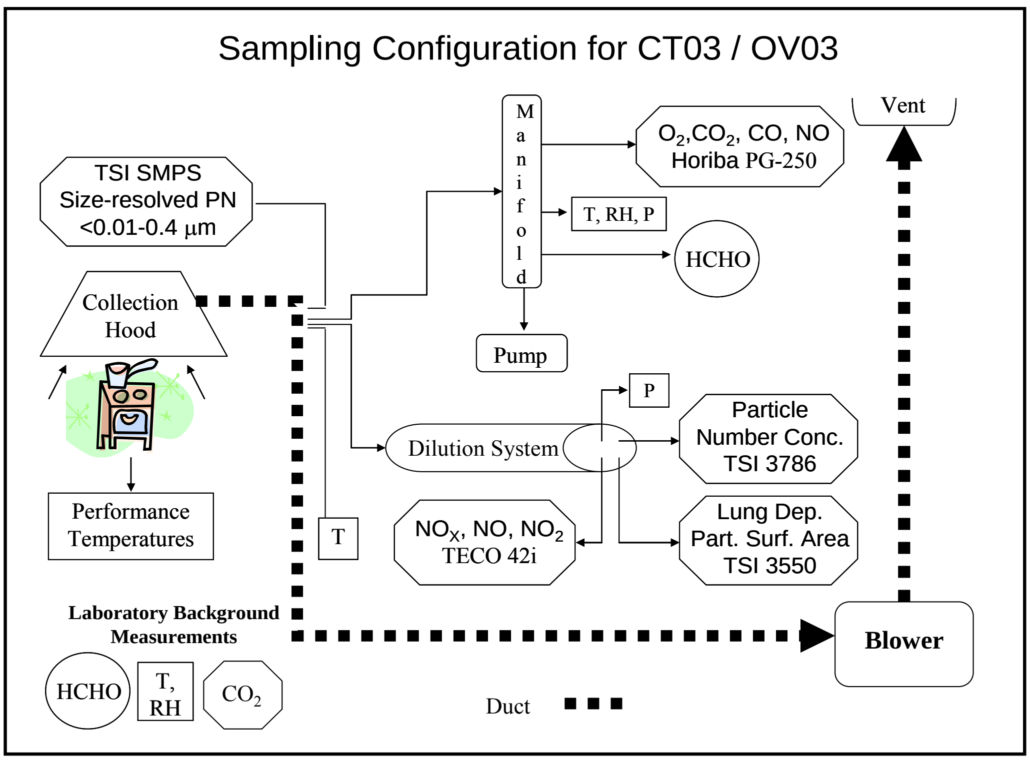

Figure 32. Pollutant sampling configuration for cooktop burner CT03 during April 2008. Experiments during August-September 2007 did not include SMPS or TSI3550, and used CPC model 3022A.

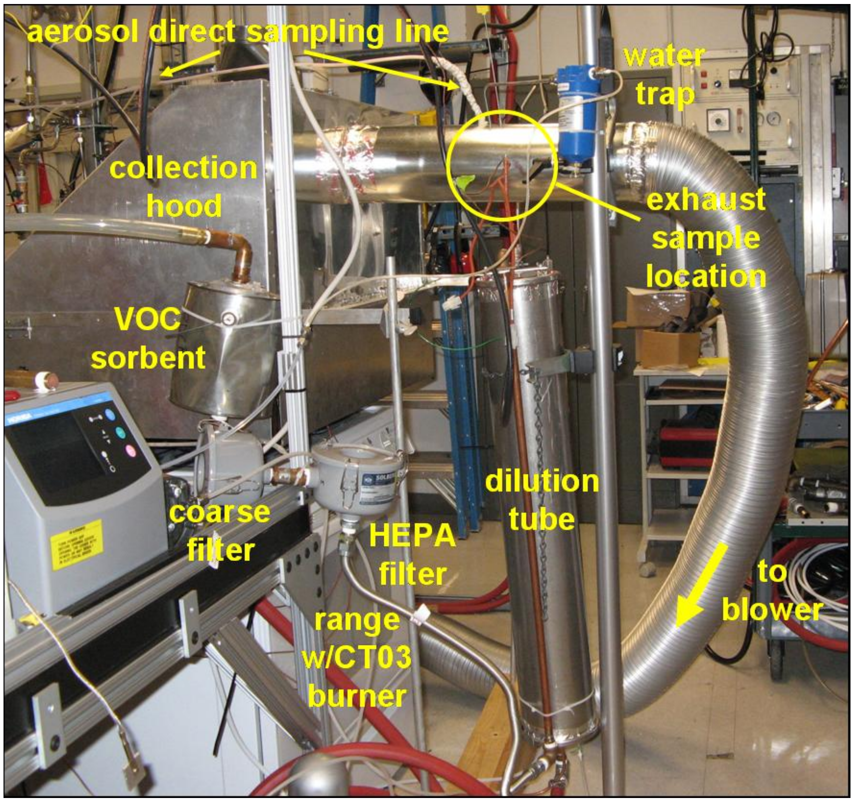

Figure 33. Laboratory installation and sampling configuration of range featuring cooktop CT03 (August-September 2007).

Table 33. Analyte ranges and calibration levels for experiments with cooktop CT03.

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%[5] 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[5] 0, 40 ppm[6]
Nitrogen oxide(s): NO[5], NO_X[6]	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 5.0 ppm[3,5] 0, 2.4 ppm[6]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-10 ppm[5] 0-5 ppm[6]	0, 5.0 ppm[3,5] 0, 2.4 ppm[6]
Carbon dioxide (CO_2)	ambient air in laboratory[4]	PPSystems EGM-4	5000 ppm	factory calibrated; check at 507 ppm
Carbon dioxide (CO_2)	ambient air in laboratory[4]	TSI Q-Trak Model 8554	5000 ppm	factory calibrated

[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] EGM-4

used for experiments L013-L014 and L086-L088; TSI Q-Trak used for experiments L021-L022. [5] Experiments L013-L022. [6] Expts L086-L088.

Table 34. Aerosol instrumentation used for cooktop CT03 experiments in August-September 2007.

Analyte	Instrument[1]	Configuration	Min. size (D_{50})[2]	Max. Conc.	Accuracy
Total particle number conc. (PN), # cm^{-3}	TSI 3022A CPC	sample from dilution tube 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}

[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 35. Aerosol instrumentation used for CT03 experiments in April 2008.

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 36. Other measurements for experiments with cooktop CT03.

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	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 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)

3.2. Results for CT03

Results were generally consistent between the two sets of experiments.

During the first set of experiments, CO emissions were substantial throughout each burn; end-of-burn air-free concentrations were 800 to 1200 ppm. CO emissions appeared to increase with fuel WN. For full-burn CO emissions, an increase of approximately 25% was found between line gas and mix 3A; CO emissions were a bit higher on average for the mid-Wobbe fuels owing to the highest single burn emission rate for fuel 1B. There was no discernible trend in total NO_X emissions as a function of fuel WN, but the NO fraction was lower for experiments with all three simulated LNGs relative to PG&E line gas. PN emission rates were higher with fuel 3A (350-390 $\times 10^7$ KJ^{-1}), relative to the mid-Wobbe fuels 1B and 3A + N_2 (160-320 $\times 10^7$ KJ^{-1}), and PG&E line gas (90-120 $\times 10^7$ KJ^{-1}). The statistical significance of this trend has yet to be evaluated. Full burn emission rates were 230-390 ng/J for CO, 35-42 ng/J for NO_X, and 90-390 $x10^4$ J^{-1} for PN.

During follow-up experiments, CO emissions were again substantial through each burn (end-of-burn air-free concentrations were 780-1300 ppm). CO end of burn concentrations and full-burn emission rates increased by 50-70% for fuels 1C and 3C relative to PG&E line gas. For There was a slight increase in total NO_X (6-7%), a slight decrease in NO (4-8%), and a larger increase in NO_2 (25-35%) full-burn emissions for 1C and 3C compared with line gas. PN emission rates were within a factor of 2 for all three fuels. Formaldehyde emission rates were higher by factors of 1.8 and 2.2 for fuels 1C and 3C relative to PG&E line gas. Full burn emission rates were 210-400 ng/J for CO, 33-35 ng/J for NO_X, 180-480 x 10^4 J^{-1} for PN, and 1.0-2.2 ng/J for HCHO.

Table 37. Burner operating parameters for experiments with cooktop CT03 in August-September 2007.

Exp. (fuel)	Burn times			Fuel vol. (ft^3)		Firing rate[1] (kBtu/h)		Manifold pressure[2]
	Purge[3]	Burn 1	Burn 2	Burn 1	Burn 2	Burn 1	Burn 2	(in. H_2O)
L013 (PG&E)	none	11:00–11:15	11:32–11:47	38.4	37.6	41.0	40.1	NA[2]
L014 (1B)	(1 min)	14:52–15:07	15:19–15:34	38.0	36.8	40.6	39.3	NA[2]
L021 (3A)	12:34–12:38	12:55–13:10	13:24–13:39	38.3	38.0	43.1	42.7	NA[2]
L022 (3A+N_2)	14:03–14:09	14:19–14:34	14:49–15:04	37.4	36.9	41.2	40.7	NA[2]

[1] 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.
[2] Manifold pressure could not be accessed/measured without dismantling the appliance internal gas supply line. Supply pressure was 7-7.5 for L013-L014. For L021-L022, supply P started at 7.3-8.4 and decreased to 6.7-6.8 over course of each burn (all units are in. H_20).
[3] The "purge" burn is used to flush fuel from the previous experiment; it is executed using all four cooktop burners without load (no pots). B1 and B2 are the duplicate burns with load (pots filled with water). The purge burn was not needed for L013 because the appliance had been last used with line gas. The timing of the purge burn for L014 was not recorded; it occurred more than 15 min before first experimental burn.

Table 38. Burner operating parameters for experiments with cooktop CT03 in April 2008.

Exp. (fuel)	Burn[1]	Start time	End time	Fuel flow rate (ft^3/h)[2]	Firing rate (kBtu/h)[2]	Supply P (in. H_2O)[3]	Manifold P (in. H_2O)[3]
L086	B1	14:37	14:52	38	39	7.3	NA
(PG&E)	B2	15:13	15:28	38	38	7.3	NA
L087	B1	16:14	16:29	37	41	7.8	NA
(1C)	B2	16:49	17:04	37	41	7.8	NA
L088	B1	17:37	17:52	37	39	7.8	NA
(3C)	B2	18:12	18:27	37	40	7.8	NA

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[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] 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 39. Environmental conditions[1] for experiments with CT03 August-September 2007.

Exp	T, Burn 1 (°C)	T, Burn 2 (°C)	RH, Burn 1 (%)	RH, Burn 2 (%)
L013	22.0 ± 0.2	22.5 ± 0.2	49 ± <1	47 ± <1
L014	22.6 ± 0.2	22.8 ± 0.2	47 ± <1	46 ± <1
L021	24.3 ± 0.2	24.6 ± 0.2	52 ± <1	51 ± <1
L022	24.7 ± 0.1	24.7 ± 0.2	51 ± <1	51 ± <1

[1] Mean ± standard deviation measured for each burn

Table 40. Environmental conditions[1] for experiments with CT03 in April 2008.

Exp.	Fuel	T (°C)	RH (%)
L086	PG&E	23.5 ± 0.2	35 ± 0
L087	3C	23.9 ± 0.2	31 ± 1
L088	1C	24.0 ± 0.3	33 ± 1

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

Table 41. Gas sampling manifold T, RH for experiments with cooktop CT03 in August-September 2007.

Exp.	Glass Manifold T (°C)[1]		Glass Manifold RH (%)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2	Burn 1	Burn 2
L013	25.0 ± 0.7	25.8 ± 0.5	68 ± 6	62 ± 4	28	28
L014	25.4 ± 0.7	26.1 ± 0.4	64 ± 6	61 ± 5	27	29
L021	27.5 ± 0.4	27.5 ± 0.3	73 ± 12	63 ± 4	27	25
L022	27.4 ± 0.4	27.6 ± 0.4	64 ± 4	63 ± 4	25	24

[1] Measured in gas sampling manifold for each burn
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 42. Sampling system conditions for experiments with cooktop CT03 in April 2008.

Exp.	Hood Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L093	78 ± 1	78 ± 1	19	20
L070	83 ± 1	80 ± 1	16	16
L094	81 ± 1	81 ± 1	17	19

[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 43. Formaldehyde samples for experiments with cooktop CT03 on April 25, 2008.

Exp(s)	Location	Sample start/end time		Sample start/end time		Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m^3)
Bkg	Lab air	14:02	14:17	14:35:40	18:27:30	283	0.990	16
L086	Glass Manifold	14:35:40	15:29:00			59	2.062	70
L087		16:12:20	16:29:30	16:47:30	17:04:30	35	3.371	191
L088		17:35:30	17:52:30	18:10:30	18:27:30	35	2.911	165

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

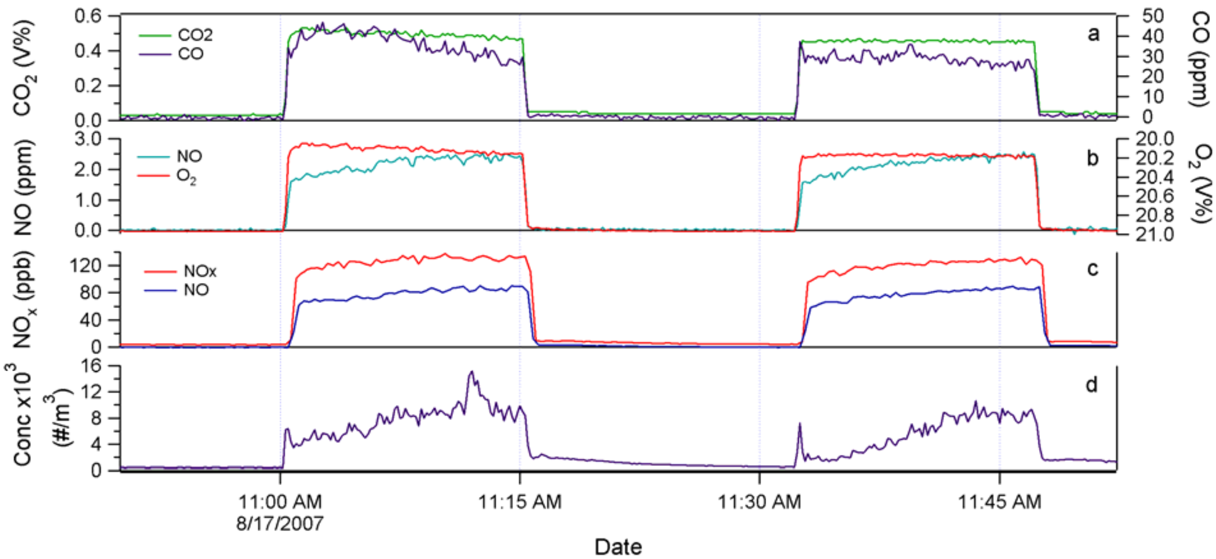

Figure 34. Measured analyte concentrations for cooktop CT03 with PG&E line gas (L013).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

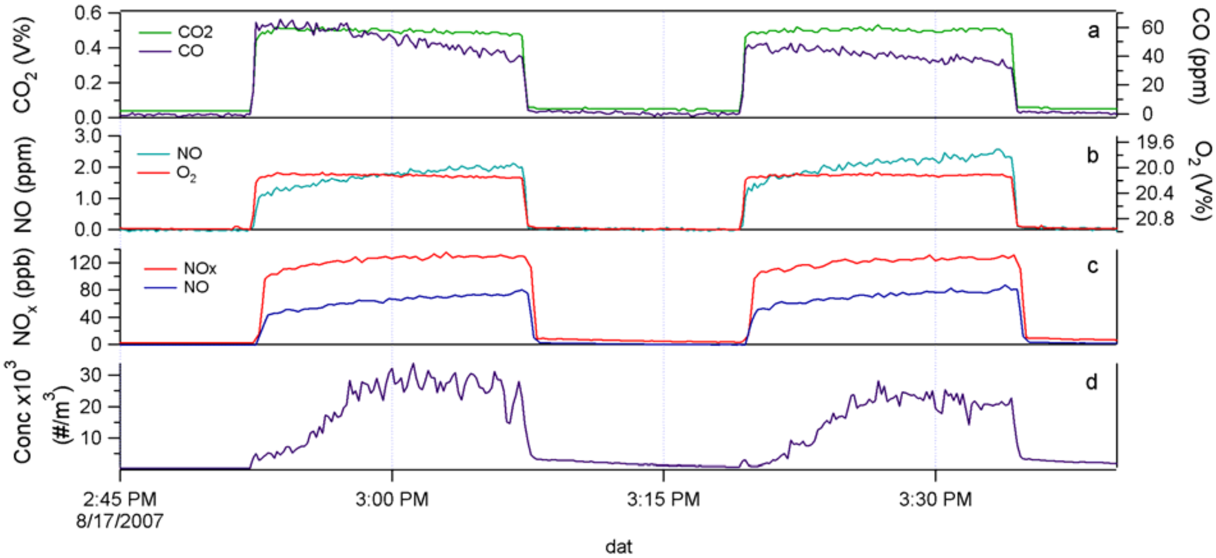

Figure 35. Measured analyte concentrations for cooktop CT03 with fuel 1B (L014).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

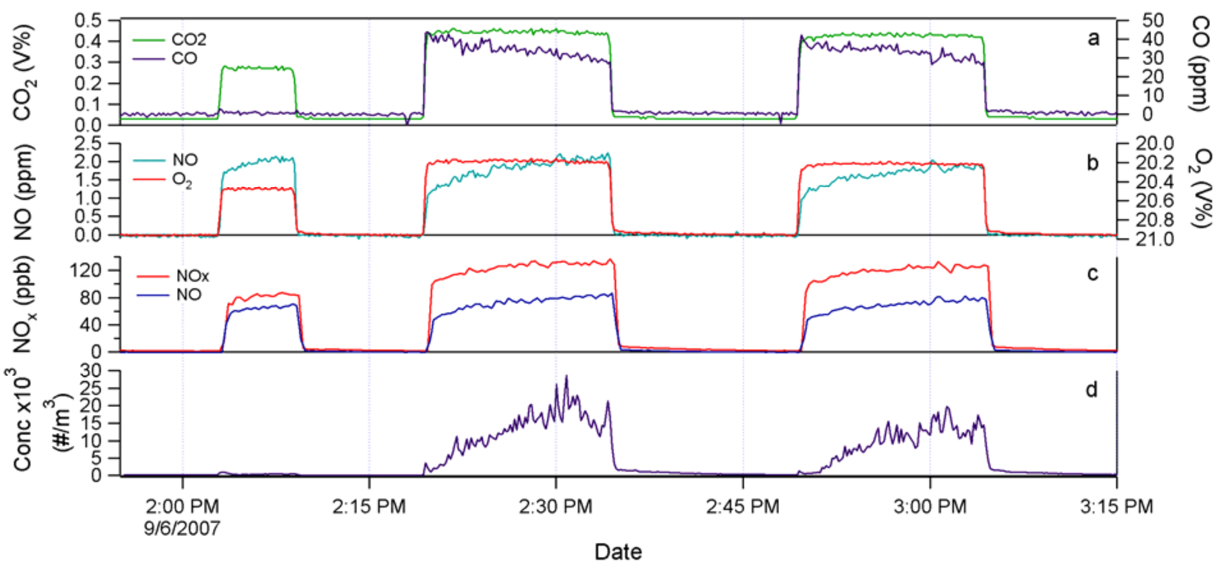

Figure 36. Measured analyte concentrations for cooktop CT03 with fuel 3A + N_2 (L022).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration.

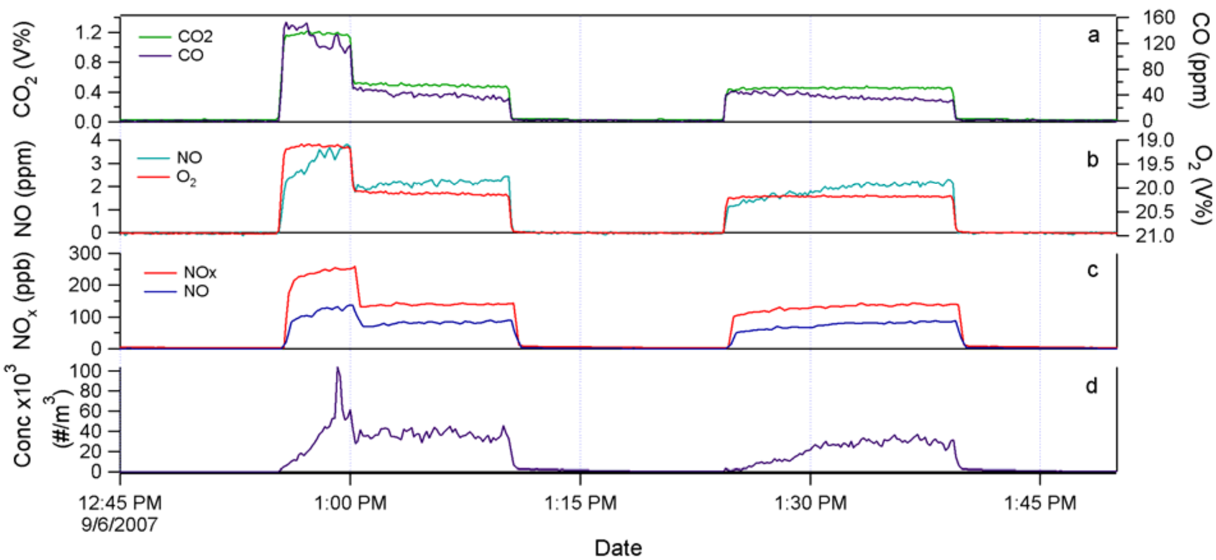

Figure 37. **Measured analyte concentrations for cooktop CT03 with fuel 3A (L021).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number concentration. The shift in concentrations during the first burn resulted from a change in the blower setting for the collection hood; dilution air was increased to avoid water condensation in the sample manifold. The sample manifold RH peaked at 94% during the first 5 min or burn 1, then decreased to below 70% after the dilution air was increased.

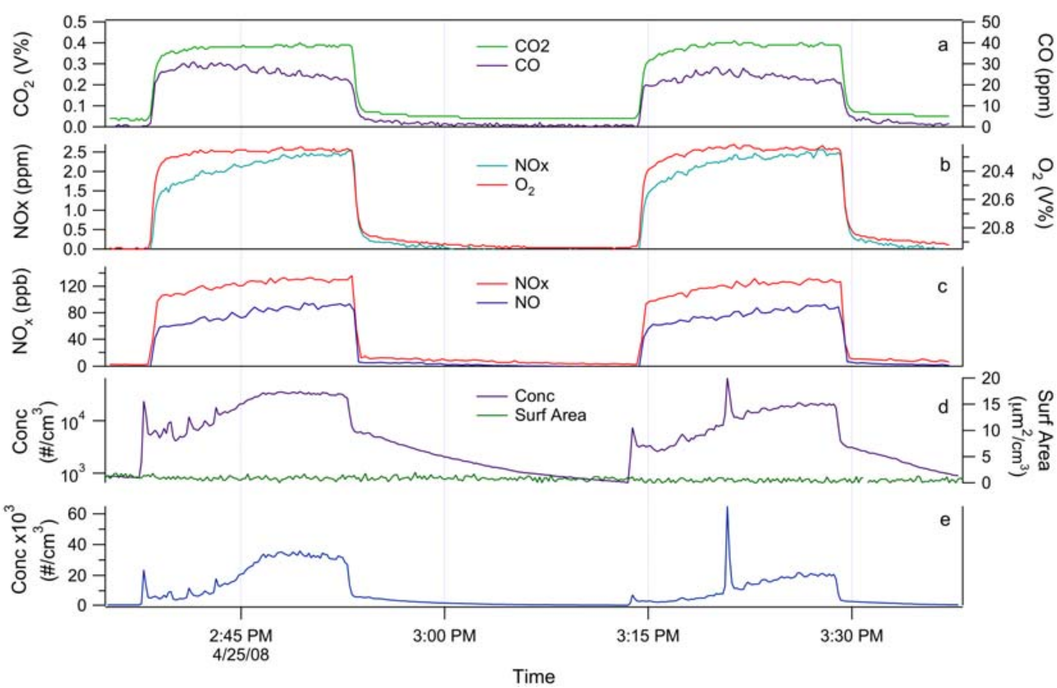

Figure 38. **Measured analyte concentrations for cooktop CT03 with PG&E line gas (L086).**
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

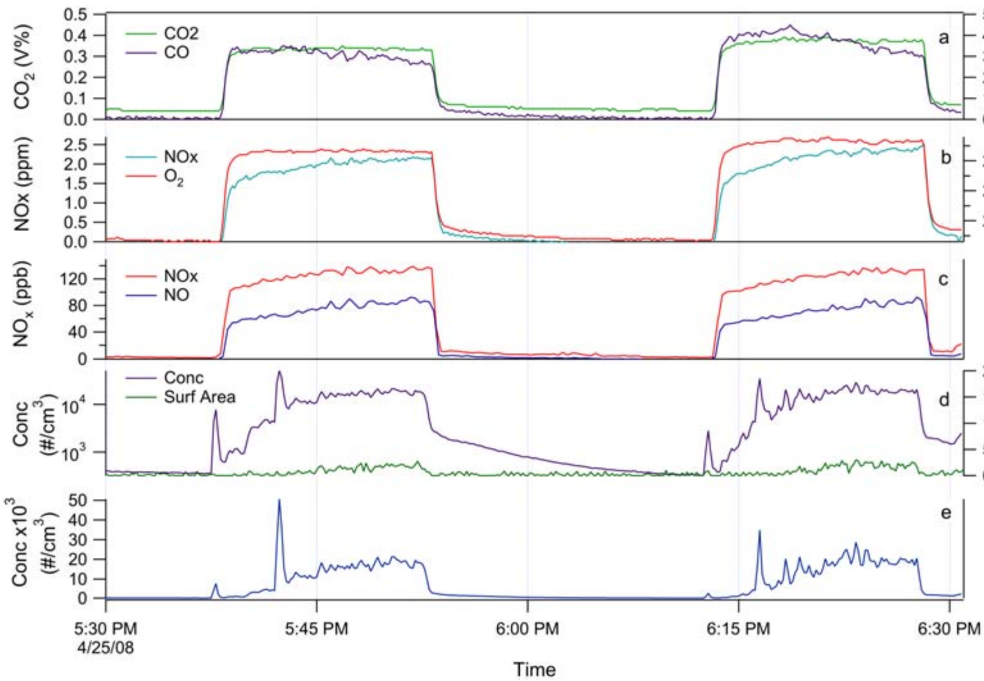

Figure 39. Measured analyte concentrations for cooktop CT03 with fuel 1C (L088).

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.

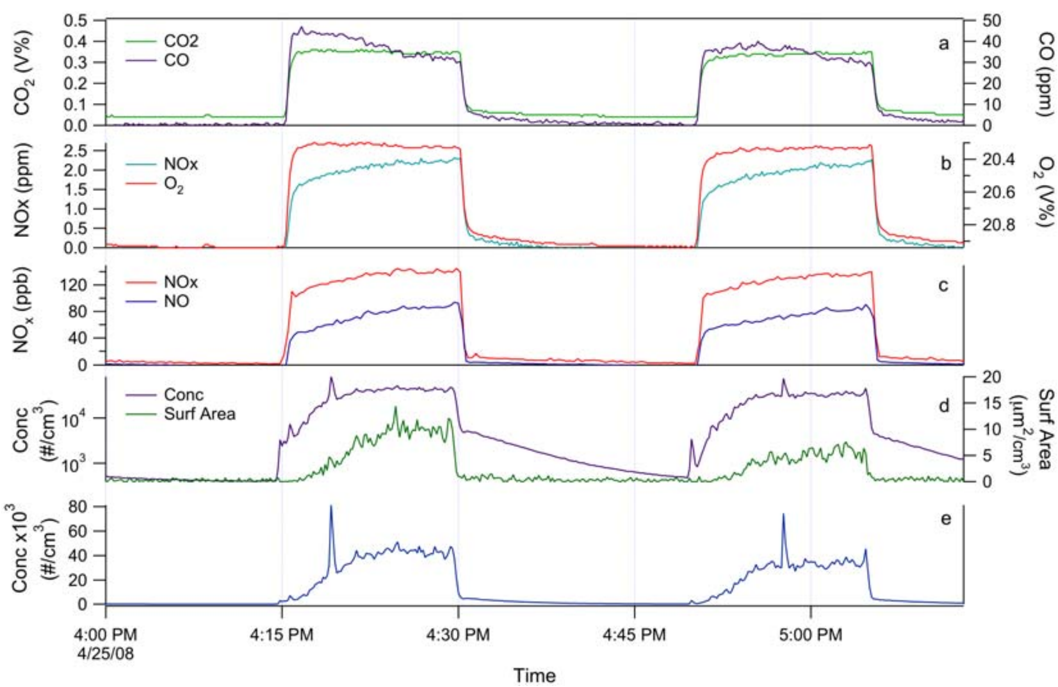

Figure 40. Measured analyte concentrations for cooktop CT03 with fuel 3C (L087).

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 44. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT03 in August-September 2007.

Exp	Fuel	Wobbe	CO (ppm)		PG250 NO_X (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L013	PG&E	1329	848	786	65	70	97	101	65	70	32	31	71	64
L014	1B	1386	1210	980	53	61	93	96	53	61	40	35	190	160
L021	3A	1417	1023	953	61	62	99	101	61	62	39	39	270	220
L022	3A+N2	1386	926	944	62	58	99	95	62	58	37	37	140	110

Table 45. Calculated emission rates over entirety of each burn, cooktop CT03 in August-September 2007.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		PG250 NO_X (μg KJ^{-1})		NO_X (μg KJ^{-1})		NO (μg KJ^{-1})		NO_2 (μg KJ^{-1})		PN (10^7 KJ^{-1})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L013	PG&E	1329	256	223	25	27	39	41	25	27	14.1	13.7	120	90
L014	1B	1386	377	292	20	24	38	40	20	24	17.8	16.0	320	270
L021	3A	1417	324	290	19	24	35	41	19	24	16.0	17.3	390	350
L022	3A+N2	1386	270	273	23	22	40	38	23	22	16.1	15.9	210	160

Table 46. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT03 in April 2008.

Exp	Fuel	Wobbe	CO (ppm)		PG250 NO_X (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L086	PG&E	1326	840	780	85	85	85	85	60	60	25	25	220	130
L088	1C	1390	1310	1260	91	88	91	88	57	55	34	33	280	220
L087	3C	1419	1170	1210	88	87	88	87	58	56	31	31	120	130

Table 47. Calculated emission rates over entirety of each burn, cooktop CT03 in April 2008.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		PG250 NO_X (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	B1	B2	
L086	PG&E	1326	240	210	33	34	33	34	22	23	11.2	11.3	300	180	1.00
L088	1C	1390	400	380	36	36	36	36	21	21	15.6	15.1	480	390	1.76
L087	3C	1419	340	360	36	35	36	35	22	21	14.2	14.0	190	200	2.15

4.0 Cooktop CT04

4.1. Experimental information for CT04

This was the first of three appliances tested at this residence (CT04, CF02, and WH02). Set-up of the experimental apparatus for this freestanding range cook top was complicated by a request by the homeowner to not move the refrigerator next to the range. The collection hood could not be installed with the range in place so the range was pulled out from the wall into the middle of the kitchen. The resulting installation of analytical instrumentation and supporting equipment (pumps, fans, etc.) occupied the entire kitchen, as shown in Figure 43.

Set-up was further complicated and delayed by repeated tripping of ground-fault circuit interrupter (GFCI) outlets and GFCI extension cords by various combinations of analytical instruments. By process of elimination the Thermo NO_X analyzer was determined to be incompatible with use of a GFCI at this residence. Subsequent examination of the analyzer by the LBNL engineering division verified that the instrument grounding and electrical supply was intact and safe for operation. A gasoline-powered generator was rented from a local equipment supplier and the NO_X analyzer operated without a problem on power from the generator. With each GCFI trip we had to wait for the Horiba combustion gas analyzer to complete its 30 min warm-up cycle; this first delayed a range finding experiment then delayed calibrations. Isolating the NO_X analyzer as the cause of the GFCI tripping also took time.

The set-up challenges delayed the start of experiments on CT04 by several hours. As a result, only 2 experiments were conducted before the equipment had to be removed; experiments were conducted with PG&E line gas (WN ~1330) and fuel 3C (WN ~1420).

Two additional instrument problems occurred. The condensation particle counter (CPC) had a drainage problem that caused in to turn off just prior to the start of F017. The CPC was restarted during F017 and PN data are available for the second burn of this experiment. The pulse counter on the gas meter also malfunctioned (cause unknown) during these experiments. Fuel use and firing rates are therefore calculated from the manual timing of fuel flow by stopwatch and meter dial.

A problem with the aldehyde sample system was discovered after the experiments. The system used at the time depended on critical orifices to set a consistent sample flow. It was determined in February 2008 that the critical orifices used in the aldehyde sampling trains had reduced flow at that time. Flow rates were not measured during CT04 experiments. Aldehyde results are not presented owing to uncertainty in sample flow rates which affect calculation of concentrations and emission rates.

Table 48. Appliance and burner information.

Burner ID	CT04
Burner category	Cooktop
Technology	Modern sealed burners; electronic ignition; 16 and 12 kbtu/h burners
Appliance manufacturer	Frigidaire (Electrolux)
Model	PLGFZ390ECD
Serial number	VF62856735
Other information	Cooktop of 30" range
Design manifold P	4 in. H_2O
Burner ratings (btu/h)	LF = 9500; LR = 12000; RF = 16000; RR = 5000; Total = 42500 Additional central burner of 9000 btu/h not used
Age (years)	Installed new in late 2006
Test location	Laboratory
History notes	Light to moderate use by family of 2 adults and 2 toddlers.

Figure 41. Close-up of cooktop CT04 front left burner.

Table 49. Interchangeability experiments for cooktop CT04.

Exp.	Fuel	Date	Burner operation
F017	PG&E	11/26/07	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 20-34 min between burns. When switching fuels, purge for 1-6 min prior to first burn.[1]
F018	1B	11/26/07	

[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 50. Fuel analysis for interchangeability experiments with cooktop CT04.

Expt. ID	Fuel ID	Sample ID (N)	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
F017	PG&E	post	95.4	2.43	0.26	0.06	1.15	0.74	1015	1330
F018	3C	1B	86.4	12.1	1.57	0.00	0.00	0.00	1125	1419

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

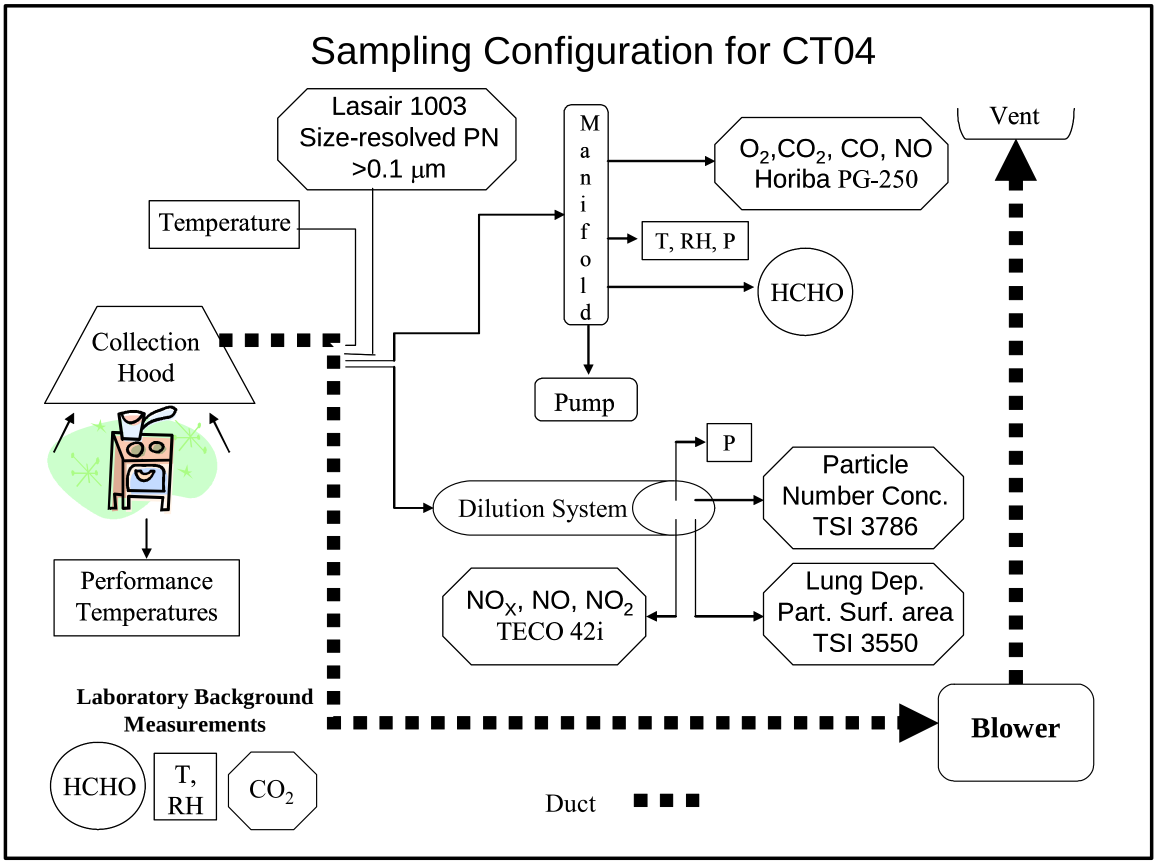

Figure 42. Pollutant sampling configuration for cooktop burner CT04.

Figure 43. Installation and sampling configuration for cooktop CT04 in home kitchen.
From left: instrument cart with gas sampling manifold visible at top, dilution sampling system mounted to poles (above and to left of hood), collection hood and flexible duct leading to variable speed blower. Configuration shown was for PG&E line gas. Range was pulled into center of room to avoid moving refrigerator (behind range and hood) at request of homeowner.

Table 51. Analyte ranges and calibration levels for experiments with cooktop CT04.

Analyte	Sample location[1]	Equipment[2]	Range	Calibration levels
Carbon dioxide (CO_2)	outlet of collection hood	Horiba PG-250	0-5%	0, 1% [(3)]
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 oxide (NO)	outlet of collection hood	Horiba PG-250	0-25 ppm	0, 2.5 ppm[4]
Nitrogen oxides (NO, NO_X)	dilution sampler	Thermo 42i	0-10 ppm	0, 2.5 ppm[4]
Carbon dioxide (CO_2)	ambient air in kitchen	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] Dilution of calibration cylinder of 10% CO_2 in nitrogen; made using gas divider. [4] Calibrated from mixture of NO in N_2.

Table 52. Aerosol instrumentation used for CT04.

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}
Number conc. of particles 0.1-2.0 µm diameter	Lasair 1003 optical particle counter (OPC)	Sample direct from exhaust via ~2.5 m × 1.7 mm ID flexible copper tubing.	0.1 µm	1.4×10^4 cm^{-3}	<10%[5]

[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 53. Other measurements for experiments with cooktop CT04.

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	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

[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 CT04

CO emissions peaked at ignition and gradually decreased throughout all burns. CO emissions were low: air-free concentrations during the last 5 min of each burn were in the range of 60-120 ppm and full-burn emission rates averaged less than 50 µg KJ^{-1} for each experiment. Total NO_X emissions and the NO fraction of NO_X were similar between the two experiments. PN emissions were higher during the second burn with PG&E line gas (1200 $\times 10^7$ KJ^{-1}) compared to both burns with fuel 3C (310-400 $\times 10^7$ KJ^{-1}). The magnitude of the difference (3-4×) is substantial but variations of similar or larger magnitude have been observed in PN emissions between replicate cooktop experiments with the same fuel. Lasair data indicate that the number concentration of particles larger than 100 nm (0.1 µm) decreases when the burners are on; thus the increase in particle number observed by the CPC is indicative of ultrafine particle formation. Full burn emission rates were <60 ng/J for CO, 46-48 ng/J for NO_X, and 310-1200 $x10^4$ J^{-1} for PN.

Table 54. Burner operating parameters for experiments with cooktop CT04.

Exp.	Burn[2]	Start time	End time	Fuel flow (ft^3 min^{-1})[1]	Firing rate (kBtu/h)[1]	Line P (in. H_2O)[2]
F017	B1	14:00	14:15	37.2	37.7	7.39
	B2	14:49	15:04	37.2	37.8	7.39
F018	B1	15:36	15:51	33.6	37.7	7.02
	B2	16:10	16:25	34.4	38.6	7.03

[1] Fuel flow rate ft^3 h^{-1} measured using by timing 4 turns of ¼-ft dial of gas meter. Firing rate calculated from 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.
[2] B1 and B2 are the duplicate burns with load (pots filled with water). A 1 min purge burn was used to purge fuel 3C through the system at the start of F018; it used four cooktop burners without load (no pots). .

Table 55. Environmental conditions[1] for experiments with cooktop CT04.

Exp	T, Burn 1 (°C)	T, Burn 2 (°C)	RH, Burn 1 (%)	RH, Burn 2 (%)
F017	21.3 ± 1.0	20.6 ± 0.2	41 ± 1	42 ± <1
F018	20.6 ± 0.5	20.8 ± 0.3	42 ± 1	42 ± <1

[1] Mean ± standard deviation measured for each burn

Table 56. Sampling system conditions for experiments with cooktop CT04.

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2	Burn 1	Burn 2
L029	21.4 ± 0.3	21.7 ± 0.3	73 ± 10	72 ± 9	19.0	19.5
L030	22.1 ± 0.5	22.4 ± 0.3	70 ± 9	67 ± 8	19.3	19.6

[1] Measured in gas sampling manifold for each burn
[2] Calculated by comparing NO measured in gas manifold (PG-250) and dilution sampler (Thermo 42i) for each burn.

Table 57. Formaldehyde samples for experiments with cooktop CT04.

Exp(s)	Location	Date	Sample start, stop times	Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m^3)
F017	Glass manifold	11/26/07	14:00-14:41, 14:49-14:49	19	0.214	*≤23* [2]
F018	Glass manifold	11/26/07	15:30-16:30	19	0.270	*≤29* [2]
F017-F018	Room air	11/26/07	13:50-16:30	179	0.556	*6.2* [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.

[2] Measurements made subsequent to these experiments indicated a partial blockage of the critical orifice that reduced flow relative to the fully open value. Airflow and sample volume use the values measured during this subsequent check. The actual sample flow rates may have been higher and the sample volume lower. Concentrations are therefore uncertain.

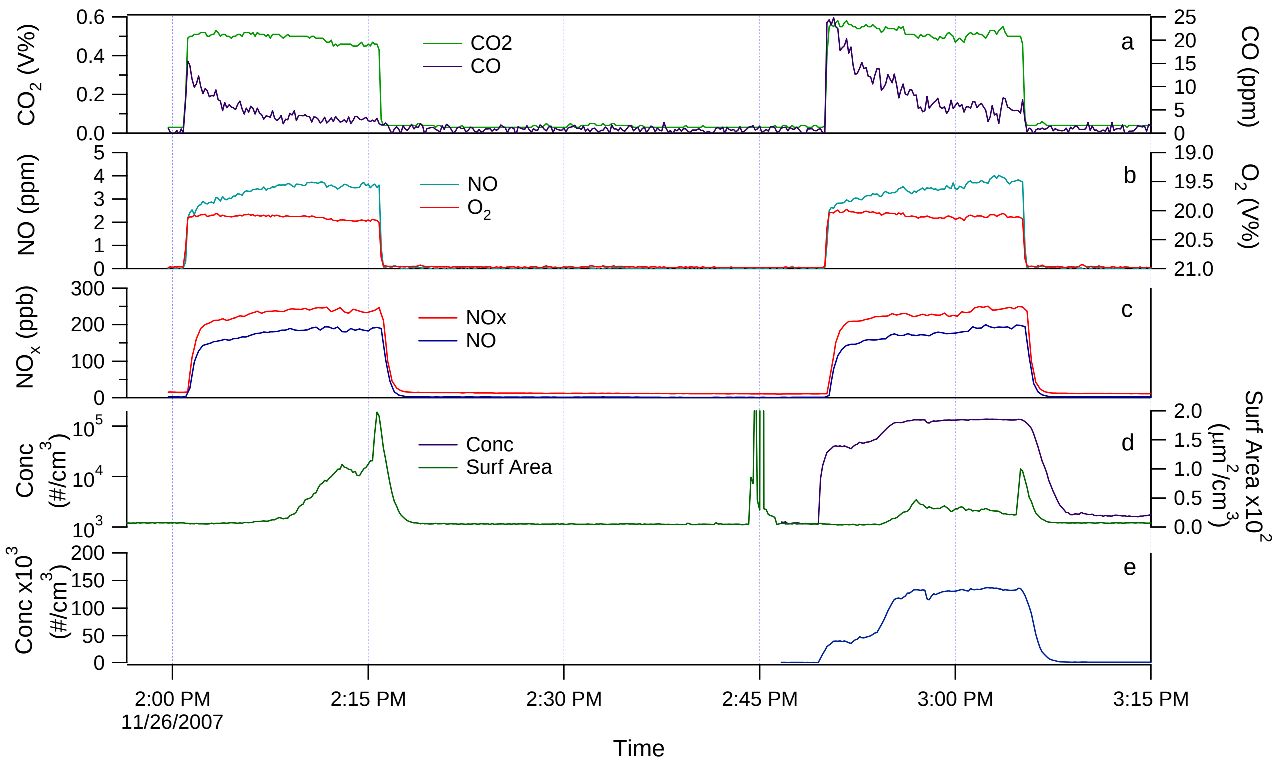

Figure 44. Measured analyte concentrations for cooktop CT04 with PG&E line gas (F017).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(d) present measurements from the dilution system. Panel (d) is particle number (PN) concentration on log scale and surface area on linear scale. Panel (e) is PN on linear scale.

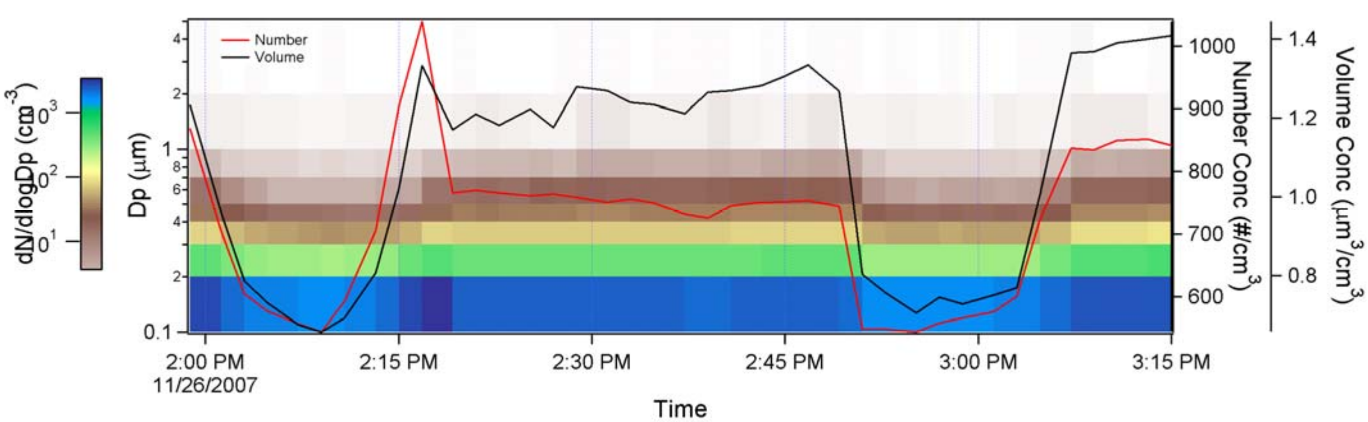

Figure 45. Size-resolved number concentrations of particles larger than 0.1 μm for experiment F017 (Lasair data).

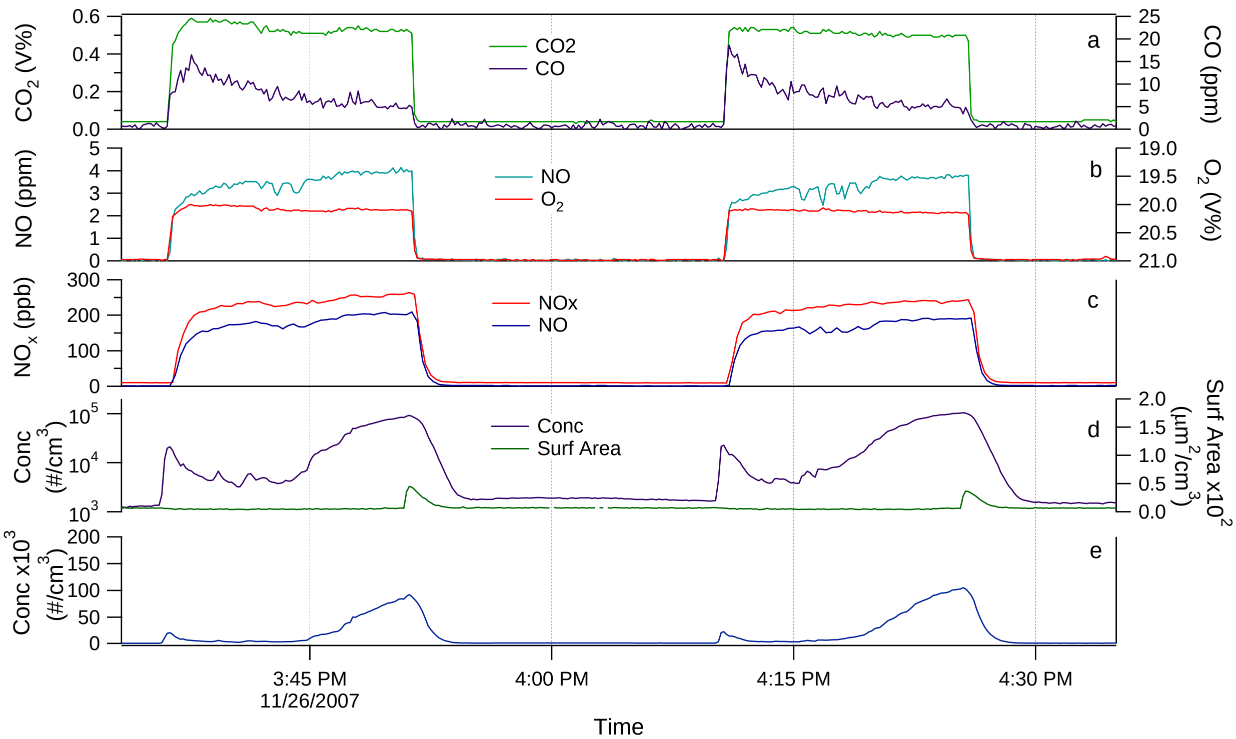

Figure 46. Measured analyte concentrations for cooktop CT04 with fuel 3C (F018).

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 (PN) concentration on log scale and surface area on linear scale. Panel (e) is PN on linear scale.

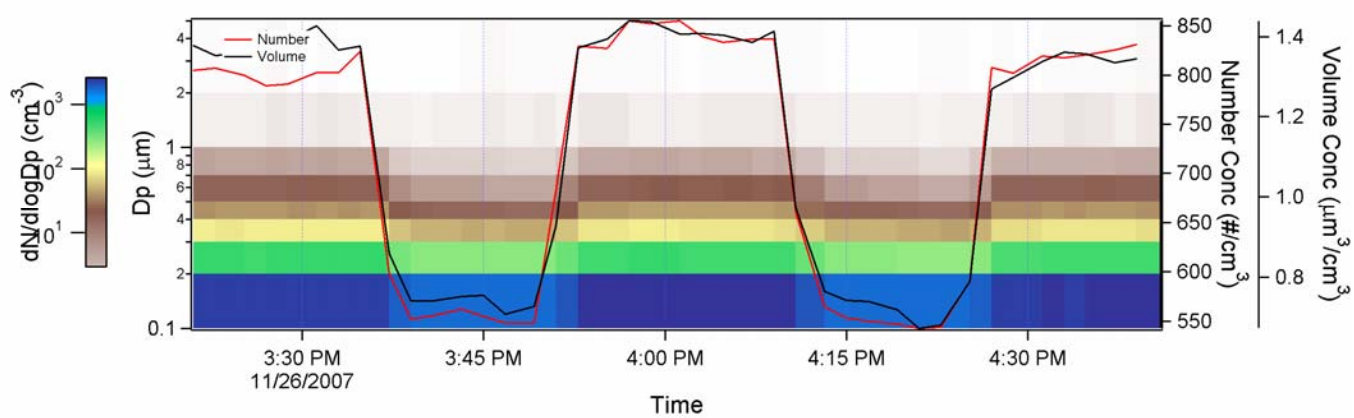

Figure 47. Size-resolved number concentrations of particles larger than 0.1 µm for experiment F018 (Lasair data).

Table 58. Preliminary results for cooktop CT04: calculated air-free concentrations (using CO_2) over last 5 min of each burn.

Exp.:	F017		F018	
Fuel:	PG&E		3C	
Wobbe:	1330		1419	
Burn→	B1	B2	B1	B2
CO, ppm	60	110	120	120
PG-250 NO, ppm	100	95	98	99
NO_X, ppm	123	116	119	121
NO, ppm	100	95	98	98
NO_2, ppm	23	21	22	22
PN, 10^5 cm^{-3}	NA[1]	670	250	380

[1]CPC was offline during the first burn of F017.

Table 59. Preliminary results for cooktop CT04: calculated emission rates over entirety of each burn.

Exp.:	F017		F018	
Fuel:	PG&E		3C	
Wobbe:	1330		1419	
Burn→	B1	B2	B1	B2
CO, μg KJ^{-1}	28	56	48	49
PG-250 NO, μg KJ^{-1}	38	36	38	38
NO_X, μg KJ^{-1}	48	46	47	48
NO, μg KJ^{-1}	38	36	38	37
NO_2, μg KJ^{-1}	10.1	9.8	9.9	10.9
PN, 10^7 KJ^{-1}	NA[2]	1200	310	430
HCHO[1], μg KJ[1]	*≤0.31* [3]		*≤0.49* [3]	

[1] Over entire period of sample.
[2] CPC was offline during the first burn of F017.
[3] Flow rates and thus concentrations for exhaust aldehyde samples uncertain because partial blockage of critical orifice discovered subsequent to experiments. Upper bound estimate based on flow rate measured subsequently.

5.0 Cooktop CT05

5.1. Experimental information for CT05

The inlet for dilution sampler was set to automatic mode. The SMPS was used to collect size-resolved particle number concentrations. The appliance manifold pressure not measured because access was not possible without dismantling the internal fuel transfer lines.

Table 60. Appliance and burner information CT05.

Burner ID	CT05
Appliance manufacturer	Frigidaire (Electrolux)
Model number	F1F316BSA
Serial number	VF31227072
Design manifold P	4" H_2O (original factory setting based on label)
Age	~4 years at time of testing
Burner technologies	Electronic ignition; open cooktop burners
Burner ratings (Btu/h)	All burners 9,000 Btu/h ; total = 36,000
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. Purchased new in 2003.

Figure 48. Cooktop CT05.

Figure 49. Close-up of CT05 burner.

Figure 50. CT05 left front burner with PG&E line gas.

Table 61. Interchangeability experiments for cooktop CT05.

Exp.	Fuel	Date	Burner operation
L069	PG&E	2/13/08	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]
L070	PG&E	2/13/08	
L071	1C	2/13/08	
L072	3C	2/13/08	

[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 62. Fuel analysis for interchangeability experiments with CT05.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L069	Line	L069	95.8	2.14	0.29	0.10	0.85	0.84	1016	1333
L071	1C	L071	92.1	7.87	0.00	0.00	0.00	0.00	1070	1389
L072	3C	L072	86.7	11.8	1.53	0.00	0.00	0.00	1123	1418

[1] Samples generally drawn from fuel supply line while burner is operating.
[2] Calculated using the American Gas Association interchangeability program.

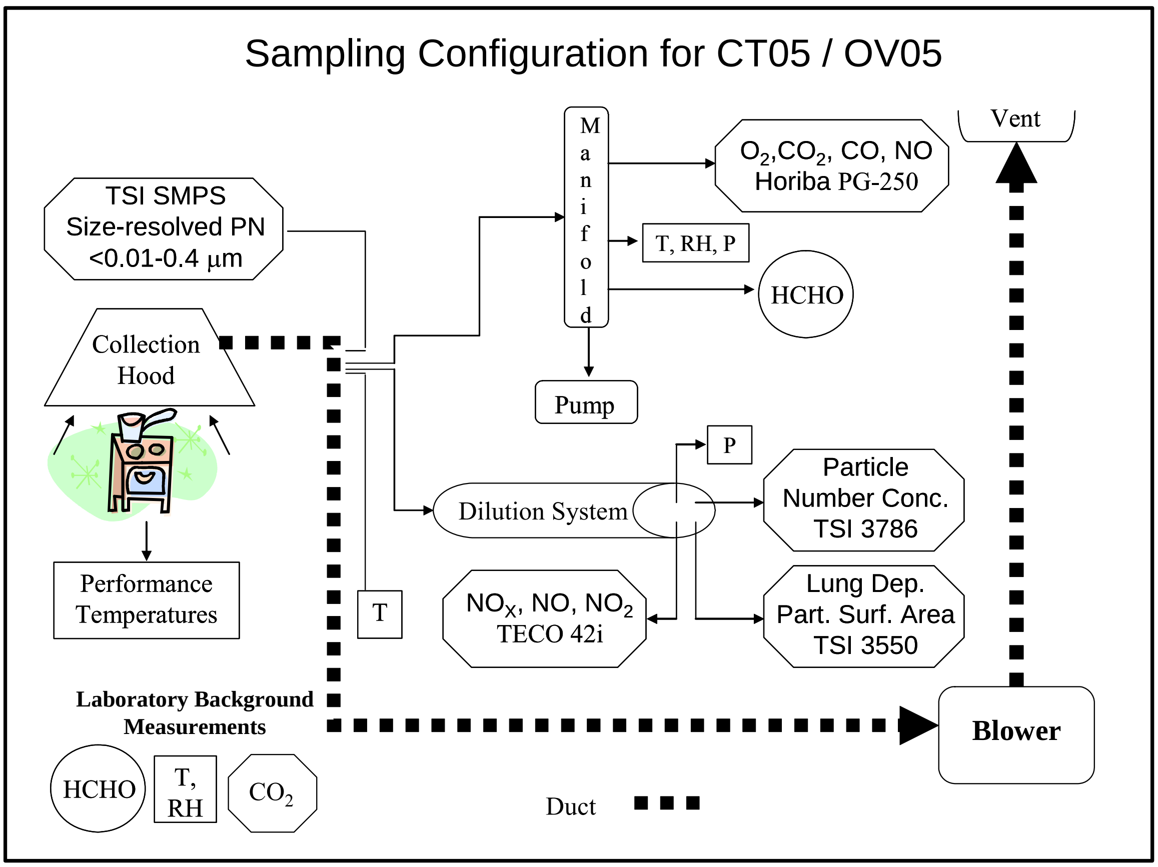

Figure 51. Analytical sampling configuration for CT05.

Table 63. Analyte ranges and calibration levels for experiments with CT05.

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 64. 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 65. 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)
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)

5.2. Results for CT05

CO emissions moderate (300 ppm air-free during stabilized burner operation) for a used appliance with no substantial trend with fuel WN. NO_X increased slightly with WN, by ~7% from PG&E (WN ~1330) to fuel 3C (WN ~1420); this increase may or may not be statistically significant. NO was approximately 75% of total NO_X in all experiments. Particle number (PN) decreased substantially (70-85%) between first and second runs with PG&E line gas, and between first and second burns with fuel 1C (50%). Other than PN, duplicate experiments with PG&E produced very similar results. Full burn emission rates were 83-92 ng/J for CO, 42-46 ng/J for NO_X, 620-9400 $\times 10^4$ J^{-1} for PN and 0.59-0.75 ng/J for HCHO.

Table 66. Burner operating parameters for experiments with cooktop CT05.

Exp. (fuel)	Burn[1]	Start time	End time	Fuel flow rate (ft^3/h)[2]	Firing rate (kBtu/h)[2]	Supply P (in. H_2O)[3]	Manifold P (in. H_2O)[3]
L069	B1	10:46	11:01	34	35	7.3	N/A
(PG&E)	B2	11:21	11:45	33	34	7.7	
L070	B1	12:06	12:21	34	35	7.6	N/A
(PG&E)	B2	12:41	12:56	34	34	7.7	
L071	B1	13:16	13:31	33	35	7.3	N/A
(1C)	B2	13:51	14:06	33	35	7.5	
L072	B1	14:27	14:42	32	36	7.3	N/A
(3C)	B2	15:02	15:17	32	36	7.3	

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[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] 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 67. Environmental conditions[1] for experiments with CT05.

Exp.	Fuel	T (°C)	RH (%)
L069	PG&E	20.6 ± 0.3	44 ± 1
L070	PG&E	21.1 ± 0.1	41 ± 1
L071	1C	21.6 ± 0.2	35 ± 1
L072	3C	21.8 ± 0.2	27 ± 2

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

Table 68. Gas sampling manifold T, RH for experiments with cooktop CT05.

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
L069	20.3 ± 0.1	21.1 ± 0.3	51 ± 5	70 ± 5
L070	21.3 ± 0.2	21.3 ± 0.2	68 ± 5	66 ± 6
L071	21.8 ± 0.1	21.8 ± 0.2	60 ± 5	60 ± 5
L072	22.1 ± 0.1	21.9 ± 0.2	54 ± 5	50 ± 5

[1] Mean ± standard deviation measured in gas sampling manifold during each burn

Table 69. Sampling system conditions for experiments with cooktop CT05.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L069	63 ± 8	66 ± 7	26	25
L070	63 ± 7	63 ± 7	25	25
L071	65 ± 7	64 ± 7	25	25
L072	67 ± 7	66 ± 8	25	26

[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 70. Formaldehyde samples for experiments with cooktop CT05.

Exp(s)	Location	Date	Sample start/end time		Sample start/end time		Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m³)
Bkg	Lab air	2/13/2008	10:36	15:18			274	0.624	4.6
L069	Glass Manifold	2/13/2008	10:42	11:01	11:21	11:45	41	1.862	91.9
L070			12:04	12:21	12:41	12:56	30	1.108	72.8
L071			13:15	13:31	13:51	14:06	29	1.431	97.5
L072			14:27	14:42	15:02	15:18	29	1.316	91.5

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

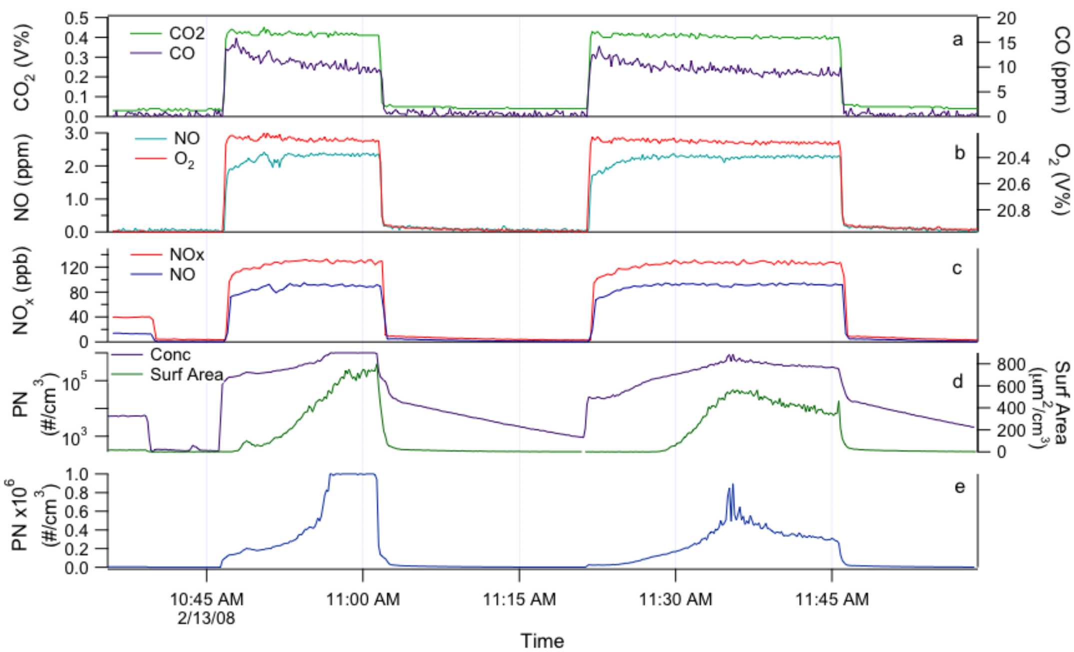

Figure 52. Measured analyte concentrations for cooktop CT05 with PG&E line gas (L069). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. Activity prior to Burn 1 is a purge burn.

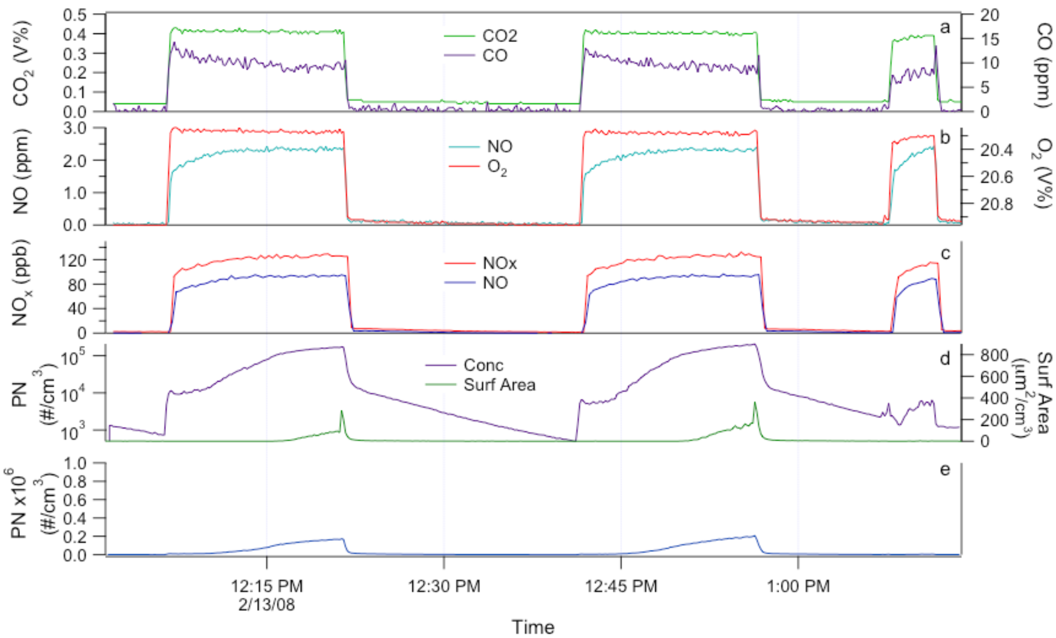

Figure 53. Measured analyte concentrations for cooktop CT05 with PG&E line gas (L070). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area. Actitivity after Burn 2 is a purge burn.

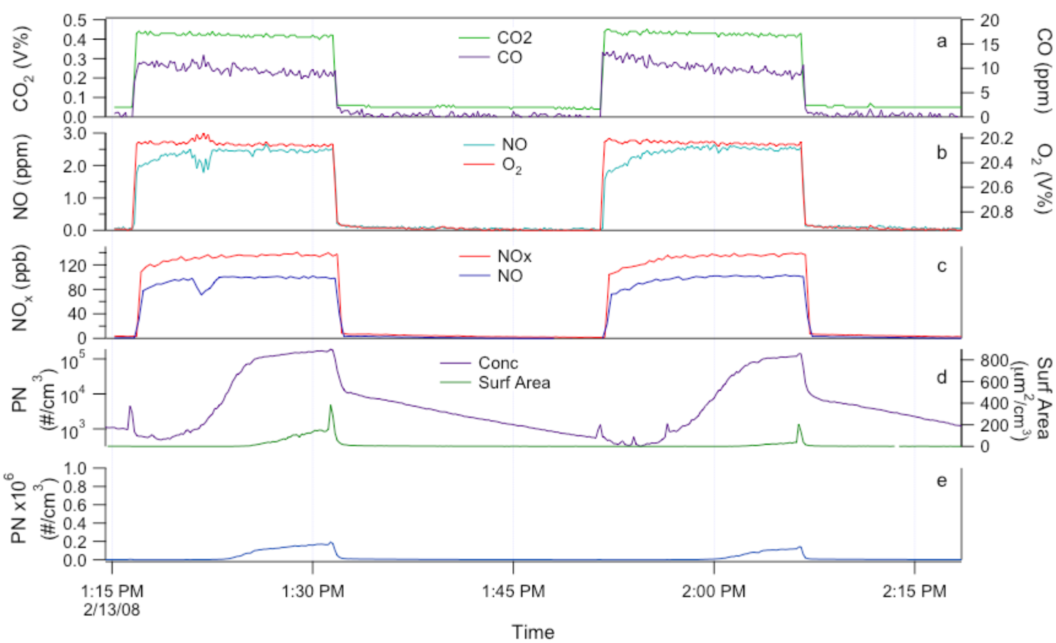

Figure 54. Measured analyte concentrations for cooktop CT05 with fuel 1C (L071). Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

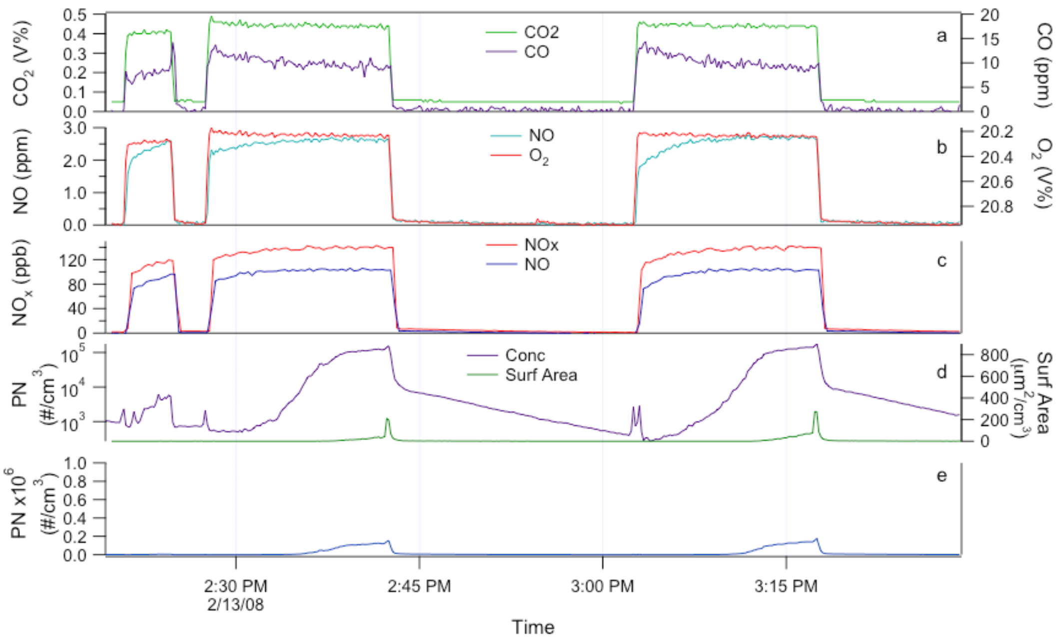

Figure 55. Measured analyte concentrations for cooktop CT05 with fuel 3C (L072).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface 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.

Table 71. Calculated air-free concentrations (using CO2) over last 5 min of each burn, cooktop CT05.

Exp	Fuel	Wobbe	CO (ppm)		PG250 NO (ppm)		NO_X (ppm)		NO (ppm)		NO_2 (ppm)		PN (10^5 cm^{-3})	
			B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
L069	PG&E	1333	310	290	74	75	105	103	75	77	30	26	8000	2700
L070	PG&E	1333	290	300	75	76	102	104	77	77	25	26	1200	1300
L071	1C	1389	290	290	79	79	108	106	80	80	28	26	1100	630
L072	3C	1418	290	280	80	82	108	111	81	83	27	28	720	810

Table 72. Calculated emission rates over entirety of each burn, cooktop CT05.

Exp	Fuel	Wobbe	CO (μg KJ^{-1})		PG250 NO (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	B1	B2	
L069	PG&E	1333	92	83	30	31	44	43	31	32	12.6	11.3	9400[a]	4900	0.75
L070	PG&E	1333	86	86	31	31	42	43	31	32	10.7	11.0	1400	1600	0.59
L071	1C	1389	84	88	33	33	46	45	33	33	12.6	11.5	1200	620	0.75
L072	3C	1418	83	85	33	34	46	46	34	34	11.6	12.0	720	800	0.68

[a] Particle number concentrations during this burn exceeded the upper limit of the particle counter (see Figure 5); the reported value is thus a lower limit on the actual emission rate during this burn.

6.0 Cooktop CT06

6.1. Experimental information for CT06

This cooktop was very clean upon purchase and was not additionally pre-conditioned before our experiments. One experiment each with PG&E line gas (WN = 1324), mix 1C (WN = 1389) and mix 3C (WN = 1419) were conducted on the same day. 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 low (<30%) but similar in all three experiments.

Table 73. Appliance and burner information CT06.

Burner ID	CT06
Appliance manufacturer	General Electric
Model number	JGSP33WEV3WW
Serial number	DS218239Q
Design manifold P	4" H_2O
Age	~10 years at time of testing
Burner technologies	Electronic ignition; sealed cooktop burners
Burner ratings (Btu/h)	LF: 9500; LR: 9500; RR: 5000; RF: 12000; total = 36,000
Other information	Procured April 2008
Test location	Laboratory
History notes	Purchased from owner since 1999, advertised on Craig's List. Owner reported regular use (3-4x per week). Believed to be purchased new and installed during kitchen remodel in 1998.

Figure 56. Cooktop CT06.

Figure 57. Close-up of CT06 burner.

Figure 58. CT06 burners during experiment.

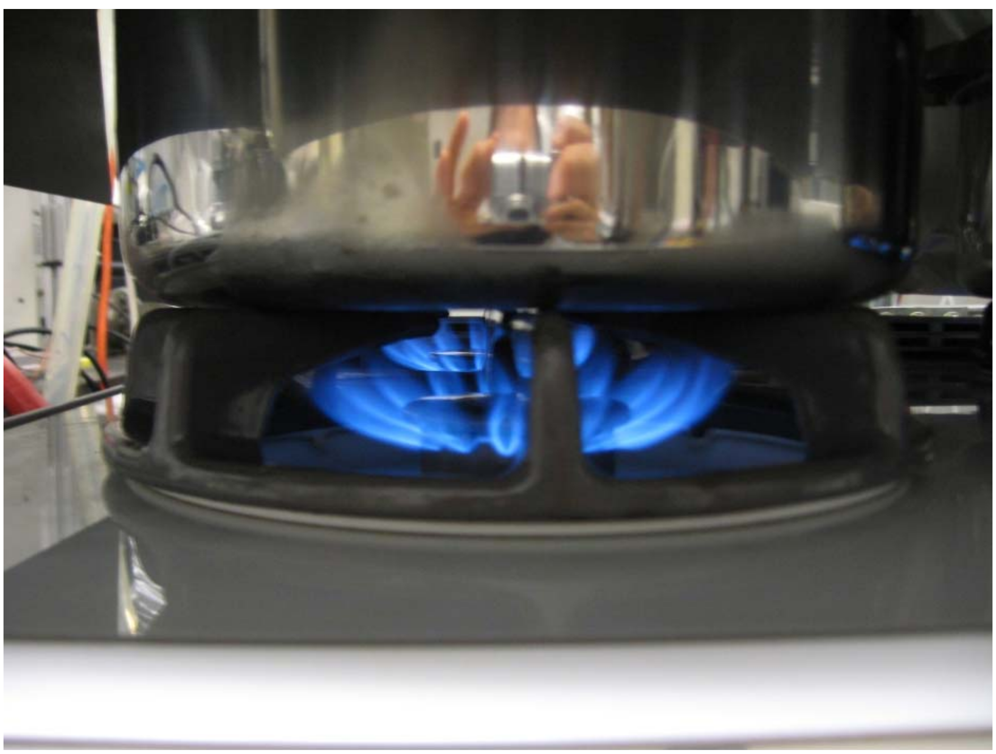

Figure 59. CT06 left front burner flame, with pot.

Table 74. Interchangeability experiments for cooktop CT06.

Exp.	Fuel	Date	Burner operation
L093	PG&E	4/30/08	Duplicate 15 min burns of all 4 burners fully open, loaded with pots containing 4 L water each. 15 min between burns. A single purge burn occurred for each fuel change.[1]
L094	1C	4/30/08	
L095	3C	4/30/08	

[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 75. Fuel analysis for interchangeability experiments with CT06.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[2] (Btu/scf)	Wobbe[2] number
L093	Line	L093	96.0	1.68	0.28	0.12	0.79	1.17	1010	1324
L094	1C	L094	92.0	8.00	-	-	-	-	1071	1390
L095	3C	L095	86.4	12.00	1.60	-	-	-	1125	1419

[1] Samples generally drawn from fuel supply line while burner is operating.
[2] Calculated using the American Gas Association interchangeability program.

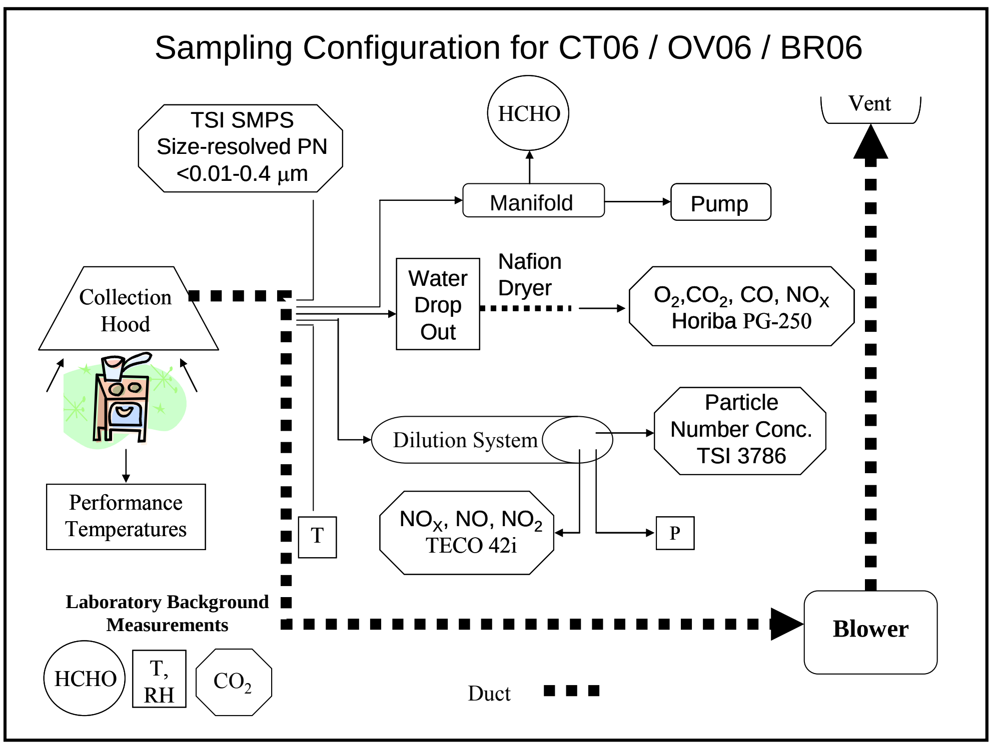

Figure 60. Analytical sampling configuration for CT06.

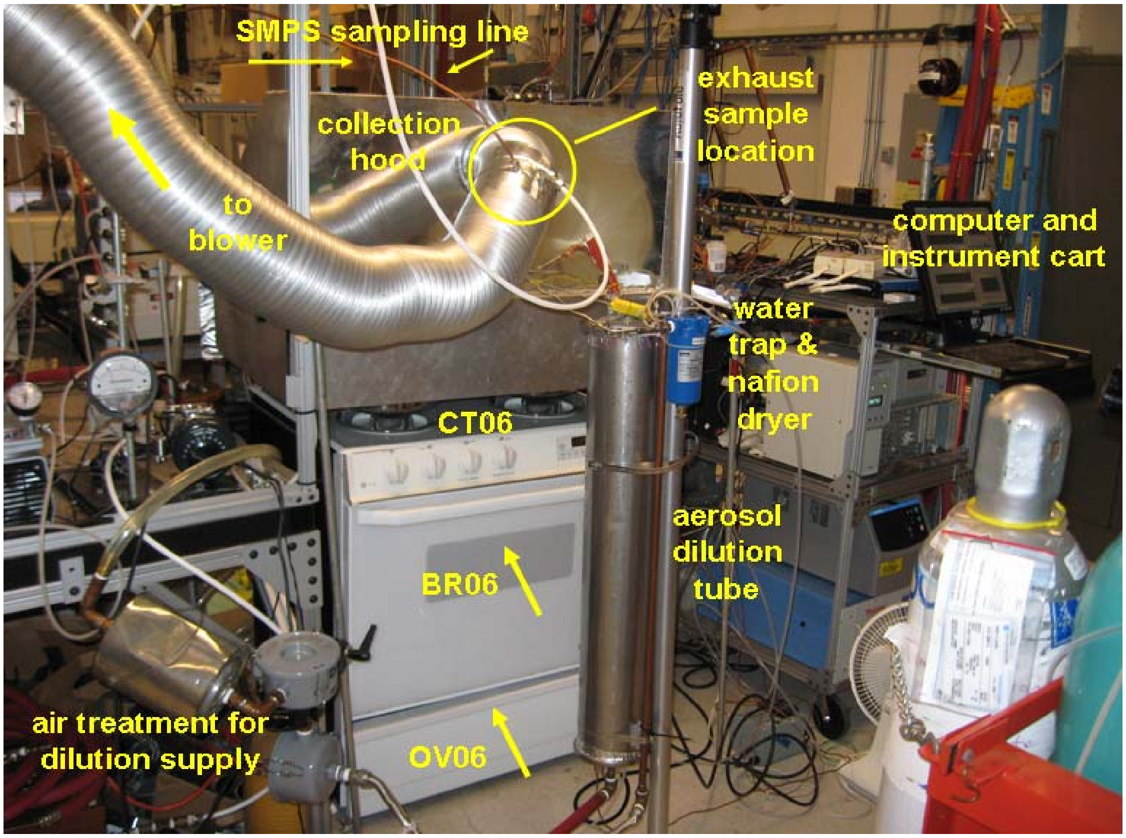

Figure 61. Installation of CT06.

Table 76. Analyte ranges and calibration levels for experiments with CT06.

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 77. 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%
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 78. 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, 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 CT06

Full burn emission rates were 13-38 ng/J for CO, 38-40 ng/J for NO_X, 190-1100 $x10^4$ J^{-1} for PN and 0.10-0.12 ng/J for HCHO. There was a clear trend of CO increasing with fuel WN; for example, full-burn emissions for 3C were roughly a factor of 3 higher than for PG&E line gas. While this increase is large on a relative basis, the overall levels of CO were relatively low for a used cooktop: air-free CO concentrations were in the range of 40-110 ppm. Total NO_X and the NO fraction of this total varied very little among experiments, i.e. among fuels. Particle number (PN) emissions decreased with successive experiments, starting with PG&E and finishing with fuel 3C; PN emission rates with PG&E were roughly a factor of 4 higher than for 3C.

Table 79. Burner operating parameters for experiments with cooktop CT06.

Exp. (fuel)	Burn[1]	Start time	End time	Fuel flow rate (ft^3/h)[2]	Firing rate (kBtu/h)[2]	Supply P (in. H_2O)[3]	Manifold P (in. H_2O)[3]
L093	B1	12:37	12:52	31	31	7.4	N/A
(PG&E)	B2	13:12	13:27	30	30	7.4	
L094	B1	14:00	14:15	31	33	7.8	N/A
(1C)	B2	14:35	14:50	29	32	7.8	
L095	B1	15:30	15:45	29	32	7.9	N/A
(3C)	B2	16:05	16:20	29	32	7.9	

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[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. These values were obtained from measurements with a pulse counter on the gas meter; results of stopwatch timing of the meter dial were consistent with these values.
[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 80. Environmental conditions[1] for experiments with CT06.

Exp.	Fuel	T (°C)	RH (%)
L093	PG&E	23.2 ± 0.5	24 ± 1
L094	1C	23.8 ± 0.4	28 ± 1
L095	3C	24.0 ± 0.4	27 ± 1

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

Table 81. Sampling system conditions for experiments with cooktop CT06.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L093	70 ± 1	69 ± 1	25	25
L094	72 ± 1	73 ± 1	25	25
L095	74 ± 1	74 ± 1	26	25

[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 82. Formaldehyde samples for experiments with cooktop CT06.

Exp(s)	Location	Sample start/end time		Sample start/end time		Air vol. (L)	Extract conc. (ng/μL)	Air conc.[1] (μg/m³)
Bkg	Lab air	12:36	16:21			230	0.309	2.7
L093	Glass Manifold	12:36:00	12:53:30	13:11:30	13:28:30	32.4	0.349	21.6
L094		13:59:00	14:16:30	14:34:00	14:51:30	32.9	0.295	18.0
L095		15:29:00	15:46:30	16:04:00	16:21:30	32.9	0.349	21.2

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

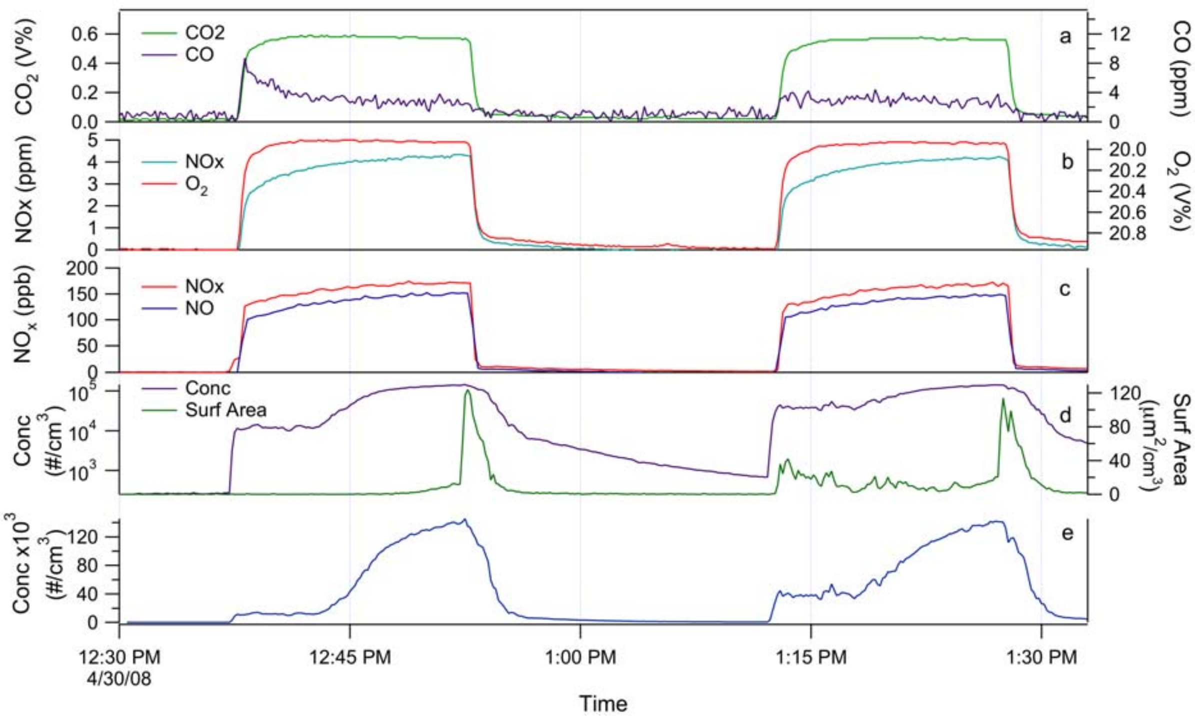

Figure 62. Measured analyte concentrations for cooktop CT06 with PG&E line gas (L093).
Panels (a)-(b) present data measured with the Horiba PG-250 analyzer in the gas manifold; panels (c)-(e) present measurements from the dilution system. PN refers to particle number concentration. Panel (d) presents surface area of particles that would deposit on human lung alveoli, not total particle surface area.

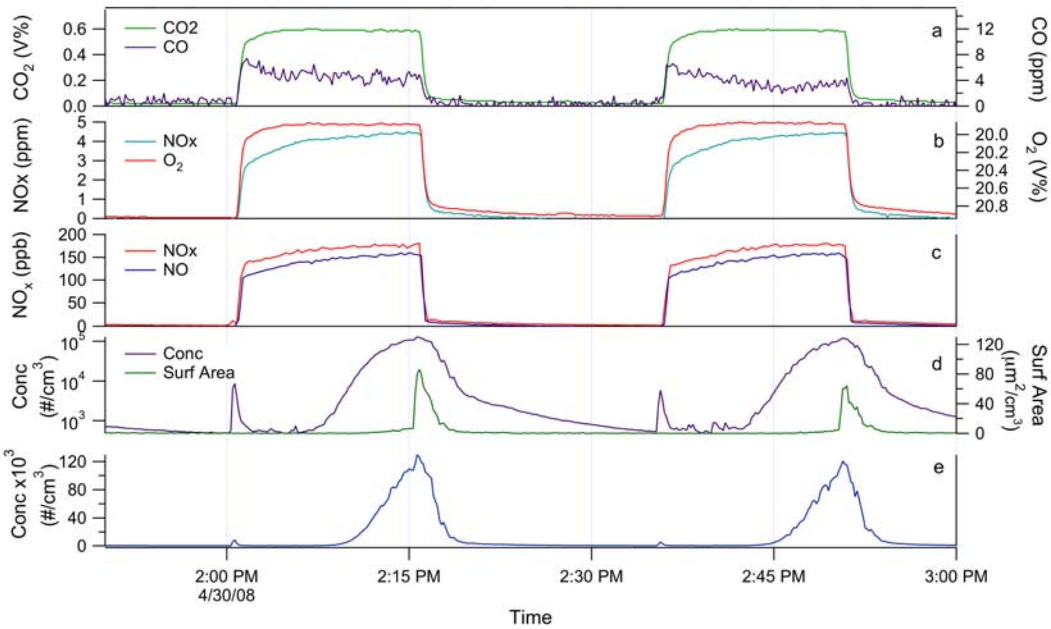

Figure 63. Measured analyte concentrations for cooktop CT06 with fuel 1C (L094).

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.

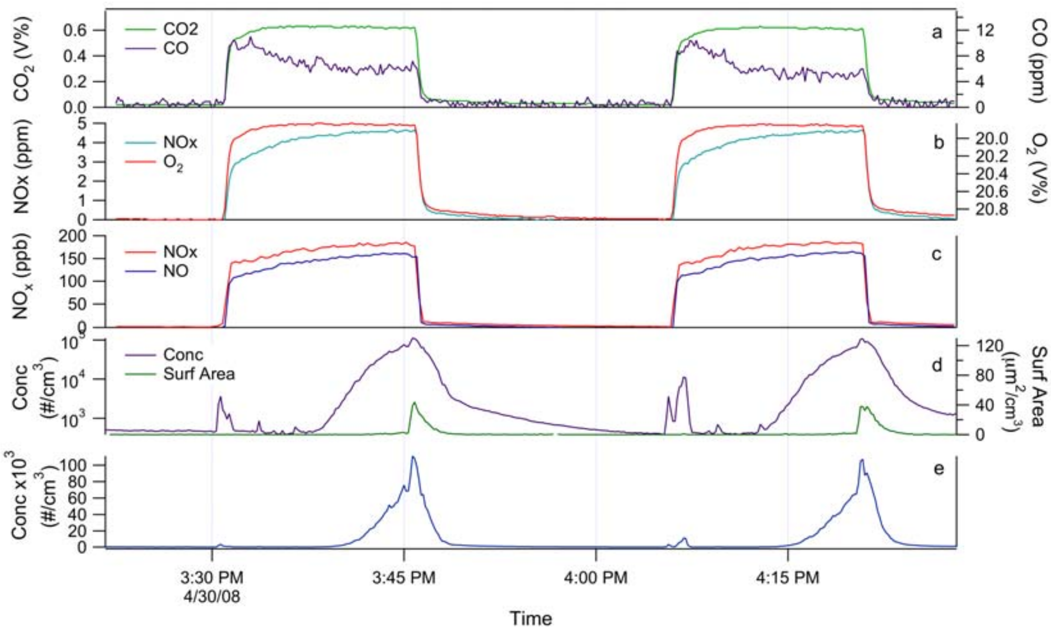

Figure 64. Measured analyte concentrations for cooktop CT06 with fuel 3C (L095).

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 83. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT06.

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
L093	PG&E	1324	35	38	96	96	86	85	10.6	10.7	700	720
L094	1C	1390	87	59	97	97	87	86	9.8	10.4	300	230
L095	3C	1419	113	98	96	97	86	87	10.7	10.3	160	130

Table 84. Calculated emission rates over entirety of each burn, cooktop CT06.

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	
L093	PG&E	1324	14	11	38	39	33	34	5.2	4.7	850	1100	0.12
L094	1C	1390	27	22	40	40	35	35	5.0	4.6	350	290	0.10
L095	3C	1419	38	34	39	40	34	35	5.2	4.8	210	190	0.11

7.0 Cooktop CT07

7.1. Experimental information for CT07

The oven associated with this range was evaluated in May 2008 as part of the experiments conducted for Task 9. The range was stored in the laboratory from this time until this cooktop (CT07) was evaluated in December 2008 as part of the supplement cooking experiments conducted for Task 14. Four experiments (L131-L134) were conducted on the same day using, in order, PG&E line gas (WN=1334), mix 3C (WN=1419), mix 1C (WN=1389) 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). 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 85. Appliance and burner information CT07.

Burner ID	CT07
Appliance manufacturer	General Electric
Model number	JGB20GEV4WH (XL44)
Serial number	VM129300P
Design manifold P	4” H_2O
Year of manufacture	1995
Burner technologies	Electronic ignition; open cooktop burners
Burner ratings (Btu/h)	LF: 9000; LR: 9000; RR: 9000; RF: 9000; total = 36,000
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.

Table 86. Interchangeability experiments for cooktop CT07.

Exp.	Fuel	Date	Burner operation
L131	PG&E	12/19/08	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]
L132	3C	12/19/08	
L133	1C	12/19/08	
L134	PG&E	12/19/08	

[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).

Figure 65. Cooktop CT07.

Figure 66. Cooktop CT07 burners with PG&E line gas.

Table 87. Fuel analysis for interchangeability experiments with CT07.

Expt.	Fuel ID	Sample ID	C_1 (%)	C_2 (%)	C_3 (%)	C_{4+} (%)	N_2 (%)	CO_2 (%)	HHV[1] (Btu/scf)	Wobbe[1] number
L131, L134	PG&E	L131 [2]	95.4	2.48	0.30	0.10	0.95	0.77	1018	1334
L132	3C	Cylinder[3]	86.4	12.00	1.60	-	-	-	1125	1419
L133	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).

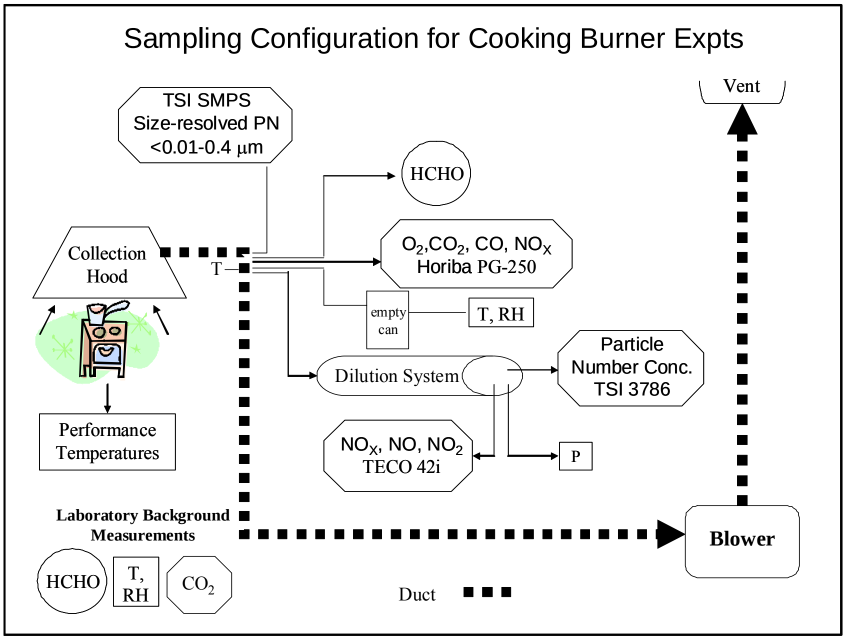

Figure 67. Analytical sampling configuration for CT07.

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 88. Analyte ranges and calibration levels for experiments with CT07.

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 89. Aerosol instrumentation used for CT07.

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 90. Other measurements for experiments with CT07.

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)

7.2. Results for CT07

Full burn emission rates were 53-76 ng/J for CO, 33-35 ng/J for NO_X, 6.7-8.7 ng/J for NO_2, 380-2300 x10^4 J^{-1} for PN and 0.41-0.73 ng/J for HCHO. Formaldehyde emissions showed a clear trend with fuel Wobbe number, going from 0.41 and 0.48 ng/J on the two PG&E experiments, to 0.62 ng/J for fuel 1C and 0.73 ng/J for fuel 3C. CO full-burn emissions were higher with fuel 1C and 3C (individual burn emission rates of 72-76 ng/J) relative to PG&E (individual burn emission rates of 53, 59, 60 and 65 ng/J). A similar trend was observed for end-of-burn CO with air-free concentrations of roughly 220-260 ppm for PG&E line gas and 290-310 ppm for fuels 1C and 3C. Thus, CO increased by roughly 20-25% when going from PG&E line gas to the simulated LNG mixtures. NO_2 followed a similar trend with PG&E experiments having full-burn emission rates of 6.7-7.4 ng/J and the simulated LNG fuels having emission rates of 8.4-8.7 ng/J. For both CO and NO_2, there were not substantial differences between 1C and 3C. There was not a fuel-related trend of emissions for total NO_X. 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, 3C then 1C) then remained the same between the 3rd and 4th experiments. The possibility of an experiment order effect is being investigated with the dataset of previous experiments.

Table 91. Burner operating parameters for experiments with cooktop CT07.

Exp. (fuel)	Burn[1]	Start time	End time	Firing rate (kBtu/h)[2]	Supply P (in. H_2O)[3]
L131	B1	09:12	09:27	32	7.3
(PG&E)	B2	09:47	10:02	31	7.3
L132	B1	10:26	10:41	31	7.6
(3C)	B2	11:01	11:16	32	7.6
L133	B1	13:08	13:23	32	7.7
(1C)	B2	13:43	13:58	33	7.7
L134	B1	14:27	14:42	33	7.3
PG&E	B2	15:02	15:17	33	7.3

[1] B1 and B2 are the duplicate burns with load (pots filled with water).
[2] For L134, fuel flow calculated from measured fuel use over entire period of burner operation using counter on gas meter. For other experiments, fuel flow calculated stopwatch timing of 1/4-foot dial of gas meter (n=2 per burn). Firing rate calculated from measured 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 92. Environmental conditions1 for experiments with CT07.

Exp.	Fuel	T (°C)	RH (%)
L131	PG&E	21.3 ± 0.3	49 ± 0
L132	3C	21.4 ± 0.3	49 ± 1
L133	1C	21.4 ± 0.3	40 ± 1
L134	PG&E	21.5 ± 0.3	38 ± 1

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

Table 93. Sampling system conditions for experiments with cooktop CT07.

Exp.	Sample Location T (°C)[1]		Dilution Ratio[2]	
	Burn 1	Burn 2	Burn 1	Burn 2
L131	70 ± 1	70 ± 1	29	30
L132	74 ± 1	73 ± 1	30	31
L133	73 ± 1	76 ± 1	32	32
L134	73 ± 1	72 ± 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 94.Gas sampling manifold temperature and RH.

Exp.	Sample Manifold T (°C)[1]		Sample Manifold RH (%)[1]	
	Burn 1	Burn 2	Burn 1	Burn 2
L131	18.6 ± 0	18.6 ± 0	69 ± 1	70 ± 1
L132	18.7 ± 0	18.7 ± 0	71 ± 1	70 ± 1
L133	18.7 ± 0	18.9 ± 0	62 ± 1	59 ± 1
L134	19.1 ± 0	19.3 ± 0	58 ± 1	56 ± 1

Table 95. Formaldehyde (HCHO) and acetaldehyde samples for experiments with cooktop CT07.

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/m³)	Acet. air conc.[1] (μg/m³)
Bkg	Lab air	12/19/08	9:10	15:19	0.92	340	0.605	0.213	4	1
L131a	Collection hood outlet	12/19/08	9:10	10:04	1.12	60	1.526	0.186	51	6
L131b			9:10	10:04	1.22	66	1.716	0.202	52	6
L132			10:24	11:18	1.19	64	2.633	0.305	82	10
L133			13:06	14:00	1.21	65	2.332	0.223	72	7
L134			14:25	15:19	1.19	64	1.544	0.168	48	5

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

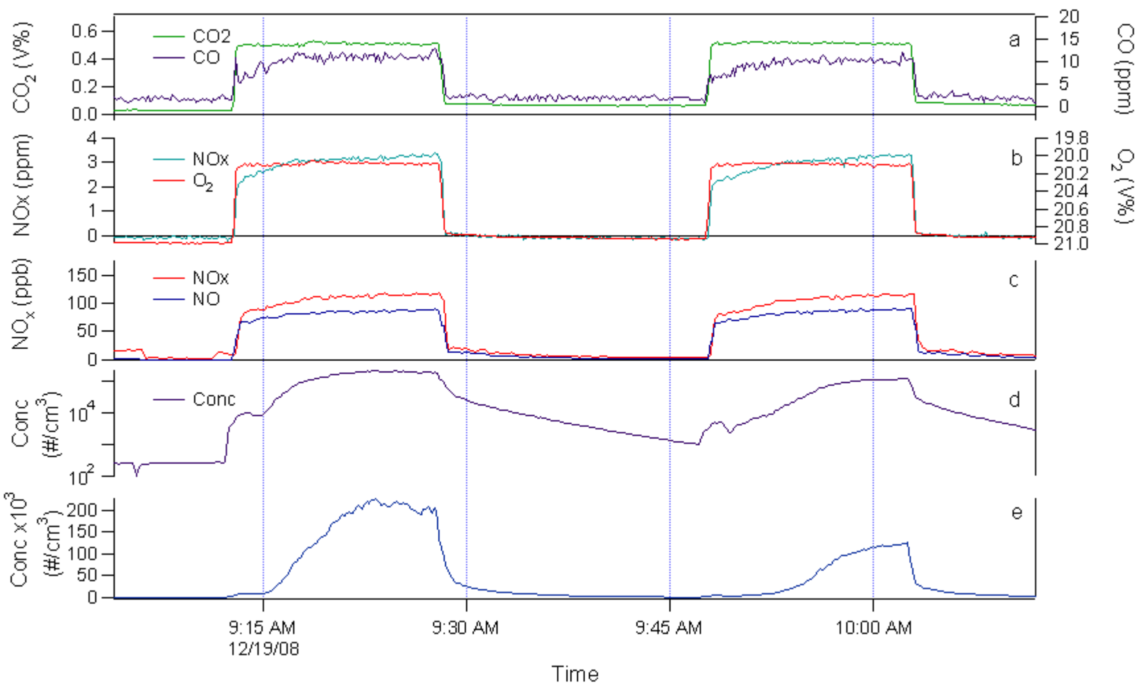

Figure 68. Measured analyte concentrations for cooktop CT07 with PG&E line gas (L131).

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.

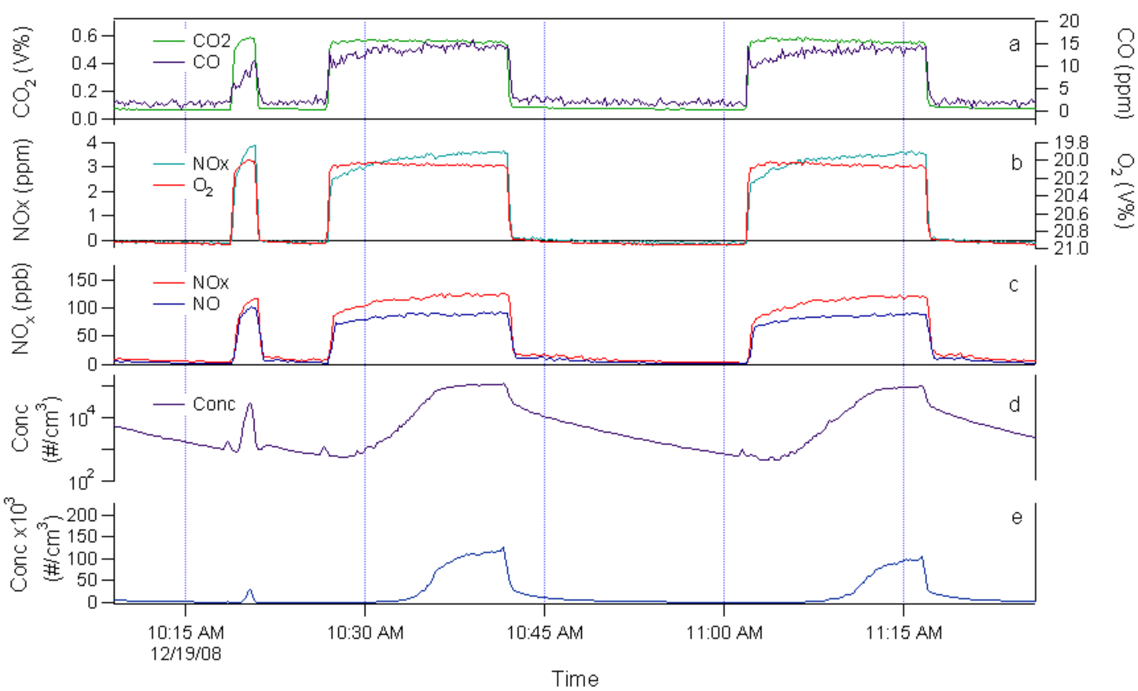

Figure 69. Measured analyte concentrations for cooktop CT07 with fuel 3C (L132).

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.

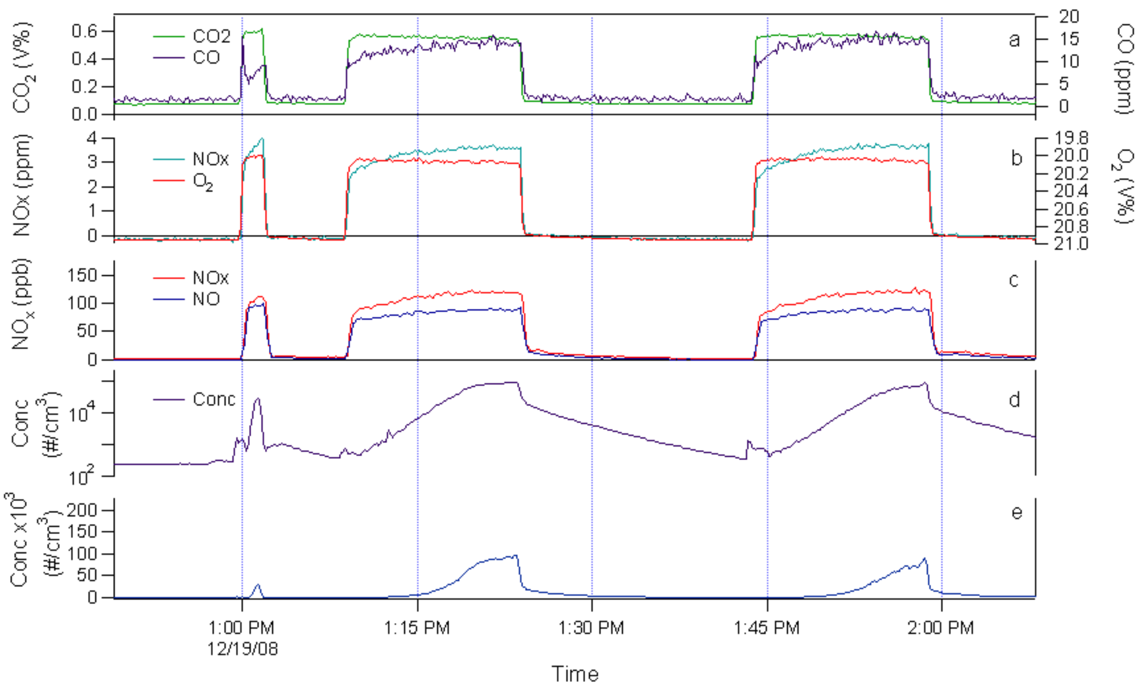

Figure 70. Measured analyte concentrations for cooktop CT07 with fuel 1C (L133).

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.

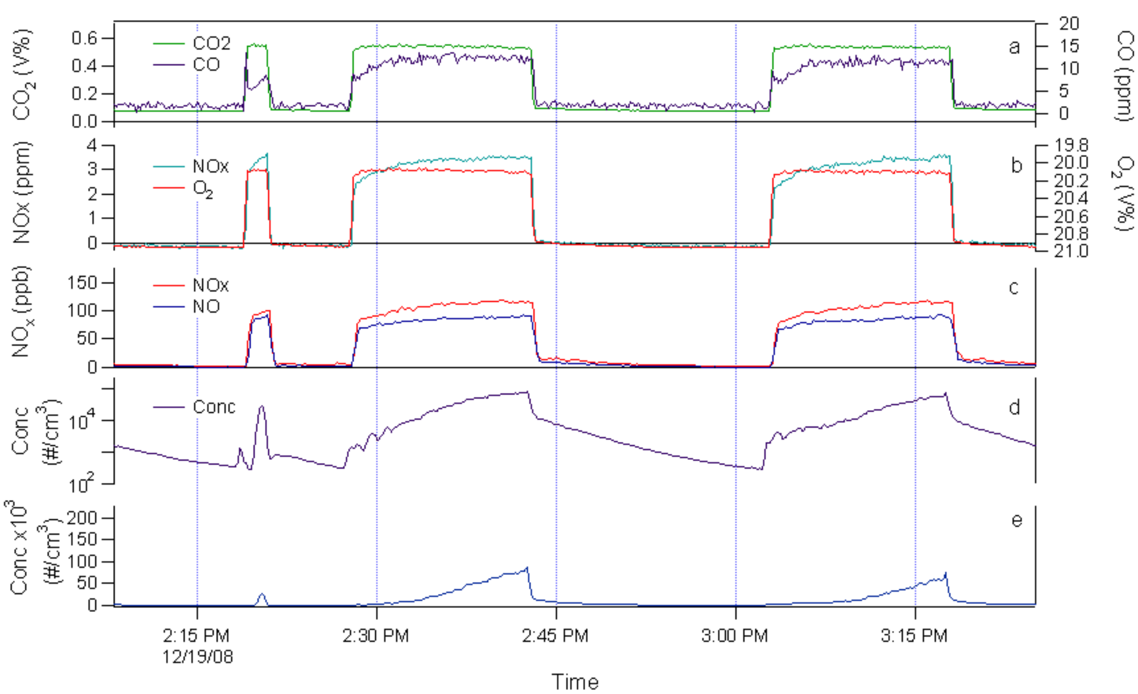

Figure 71. Measured analyte concentrations for cooktop CT07 with PG&E line gas (L134).

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 96. Calculated air-free concentrations (using CO_2) over last 5 min of each burn, cooktop CT07.

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
L131	PG&E	1334	241	217	85	84	65	66	20.2	18.5	1600	790
L132	3C	1419	300	290	86	85	63	63	23	22.4	710	530
L133	1C	1390	294	308	87	87	65	64	22	22.8	520	360
L134	PG&E	1334	259	239	86	85	66	66	19.6	19.1	450	300

Table 97. Calculated emission rates over entirety of each burn, cooktop CT07.

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	
L131	PG&E	1334	60	53	35	33	27	27	7.9	6.7	2300	920	0.47, 0.49
L132	3C	1419	76	72	35	34	26	26	8.7	8.4	740	550	0.73
L133	1C	1390	72	76	35	35	27	27	8.5	8.4	560	390	0.62
L134	PG&E	1334	65	59	35	34	27	27	7.4	7.0	530	380	0.41