the Energy to Lead

LNG Interchangeability–– Residential Field Studies and Sensitive Industrial Burner Tests

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Interchangeability Defined

- The ability to substitute one gaseous fuel for another in a combustion application without materially changing operational safety or performance and without materially increasing air pollutant emissions

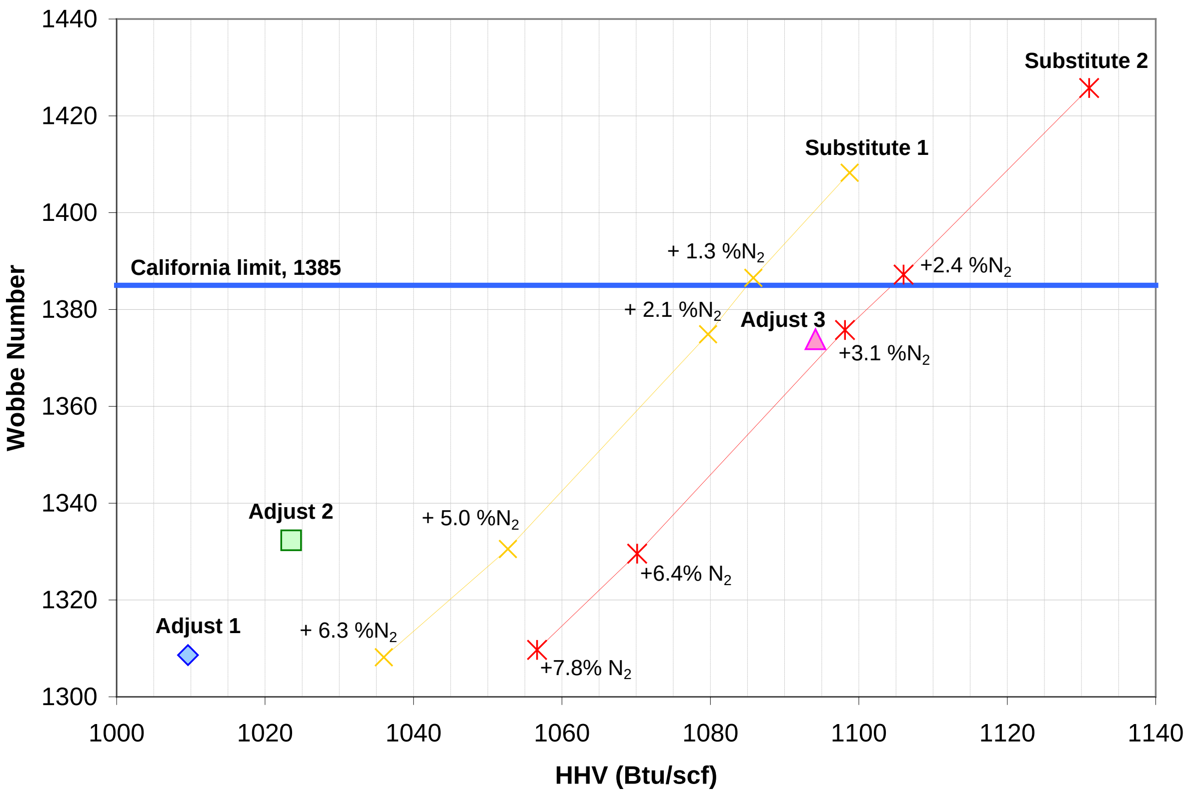
Source – NGC+ Working Group on Interchangeability White Paper presented to FERC, Feb. 2005

Program Objective

- To provide information to policymakers, regulators and industry such as on the potential safety, performance and air quality impacts of increased variability in the California natural gas supply, and specifically related to the use of LNG
- Combustion systems studied include:
  - Industrial combustion systems
  - Commercial cooking appliances
  - Residential appliances

Industrial Burner and Cooking Appliance Test Gases

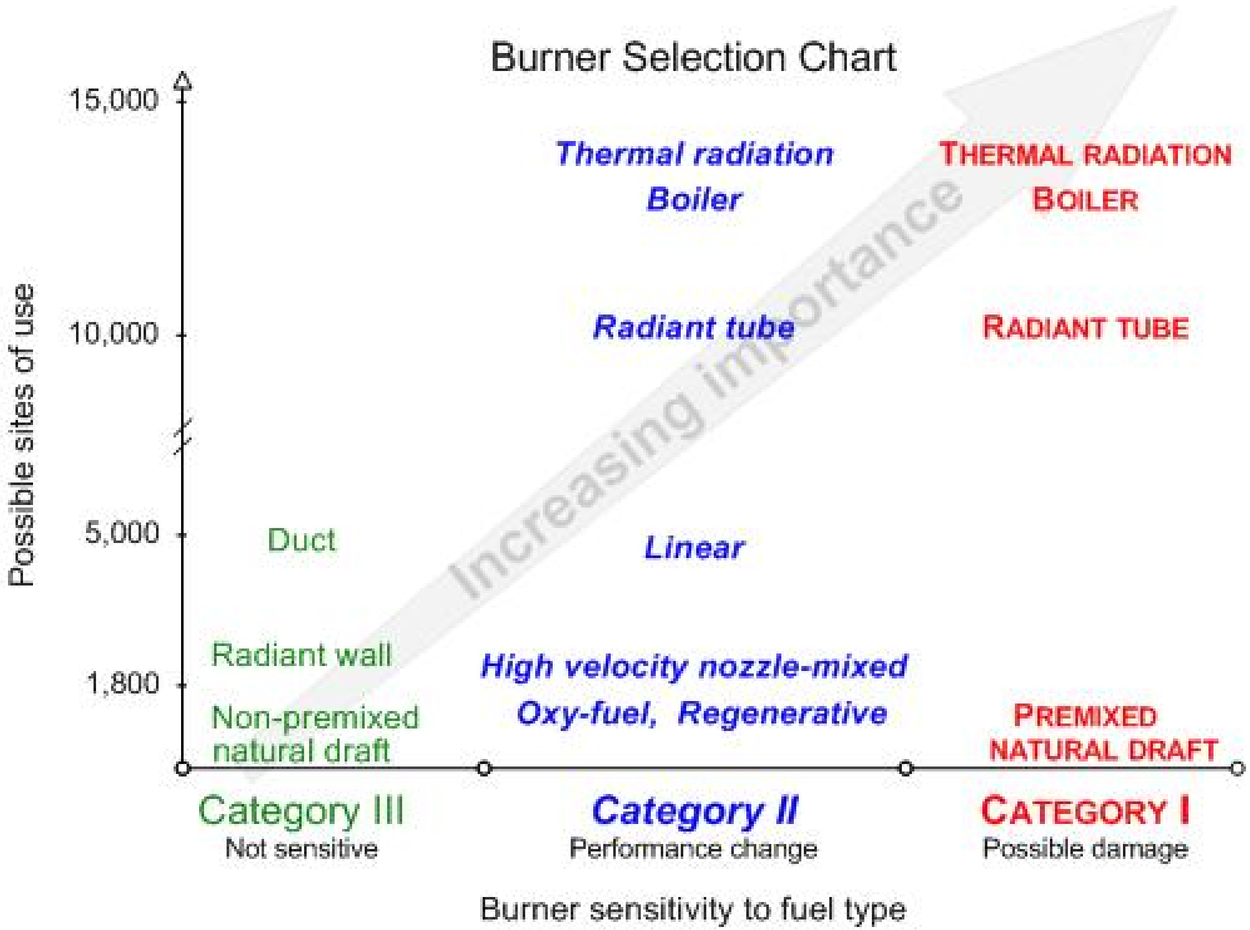
- > Adjust gases are California natural gas average compositions
- > Substitute gases are representative Pacific Basin LNG compositions



Organizing the Many Industrial Burners

Operating Characteristics	Types and Applications
Mixing method	Radiant Burners
Fuel	High Velocity Burners
Oxidant (air, O_2, etc.)	Regenerative Burners
Draft type	Natural Draft Burners
Heating type	Boiler Burners
Burner Geometry	Linear Grid/In-Duct Burners
	O_2 and O_2-Enriched Air Burners
	Flare Burners

Burner Classes and Sensitivity



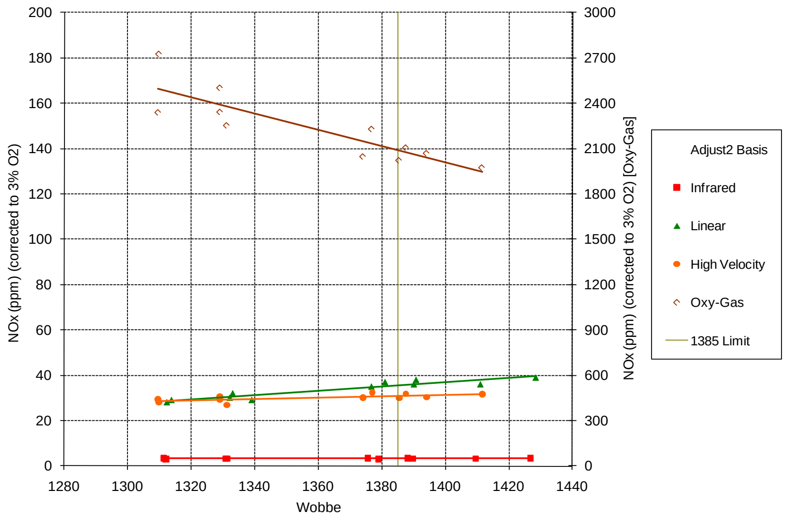
Burners Selected for Testing

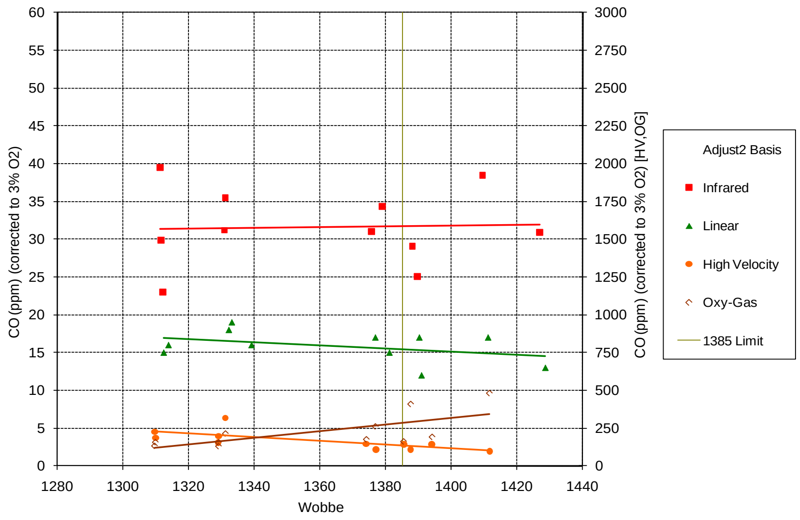
Lab Testing
Field Testing

Manufacturer	Model Name	Comment	Control	Capacity, MMBtu/hr
Radiant Burners				
North American	Evenglow	Radiant Tube	Modulating +Pressure Balance	0.02-0.5
Maxon	Radmax	Radiant Panel	On/Off + Venturi mixer	0.025 per head
Bloom Engineering	2320	Recuperative	Modulating	0.4 - 0.5
Boiler Burners				
Powerflame	C1-G-12	Turndown 10:1	Cam linkage + O_2 Trim	2-14.7
Cleaver-Brooks	SB-200-080-150	Low NOx Packaged System		80HP
LAARS	Mighty Term II	Hydronic Boiler	Staged Control	0.5 – 2.0
Linear/Grid/Duct Burners				
Flynn Burner	Pipe	Linear Burner (baking)	Modulating +Venturi mixer	0.04 per inch
Oxygen Enhanced Combustion				
Eclipse	PrimeFire 300	High Luminosity	On/Off + Pressure Balance	0.5 – 8.0
Regenerative Burners				
Bloom Engineering	1150	Nozzle-Mixed type	Modulating +Pressure Balance	To be tested
Nozzle Mixed Burners				
Eclipse Combustion	ThermJet	High Velocity	Modulating +Pressure Balance	0.15 - 20

All relevant types are covered; top sellers–by market presence

Emissions for Industrial Burners

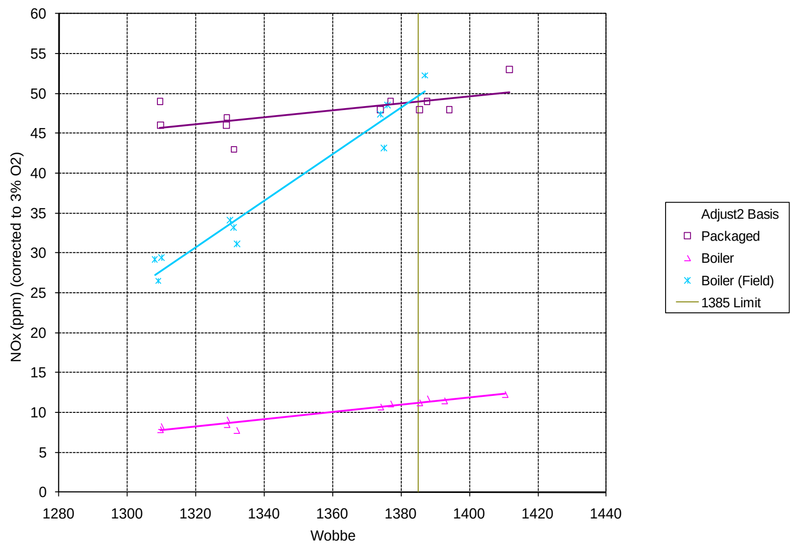


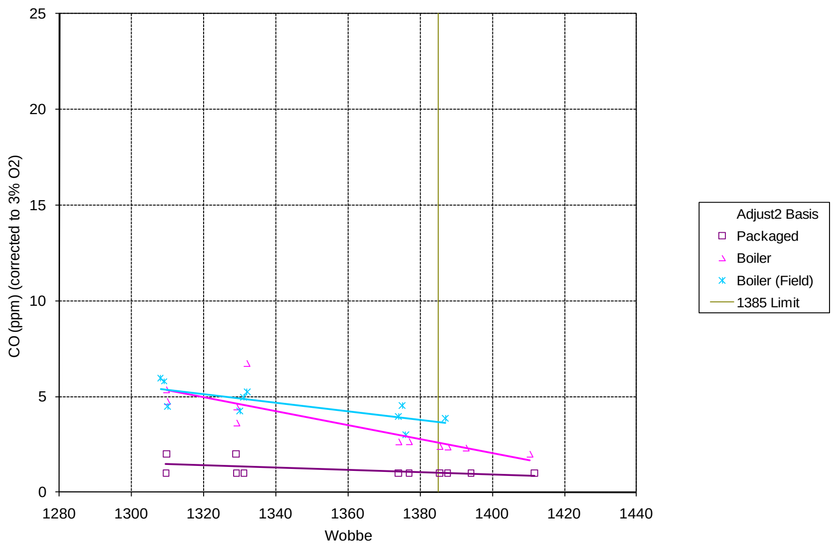


> Burners tuned to Adjust Gas 2 at 1332 Wobbe, then fired with different adjust and substitute gases

> Emissions vary widely and changes in emissions with Wobbe differ between different burners

Emissions for Boiler Burners



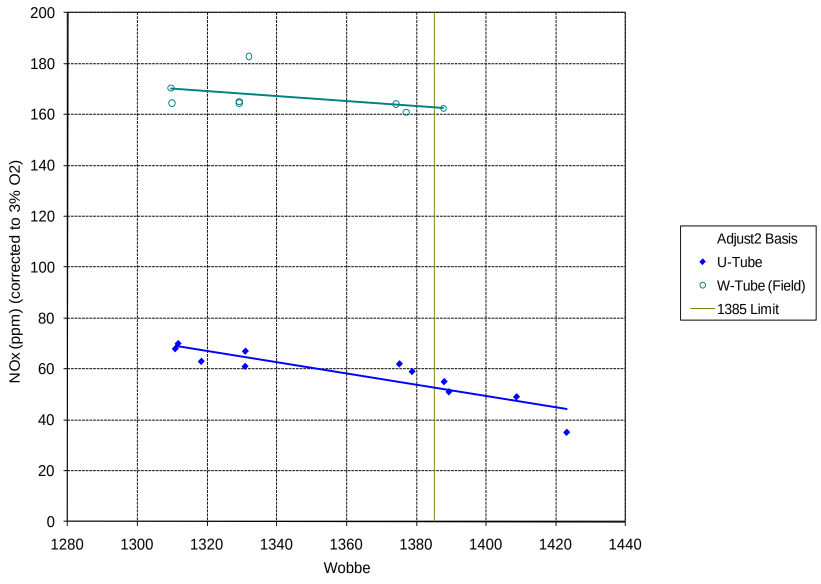


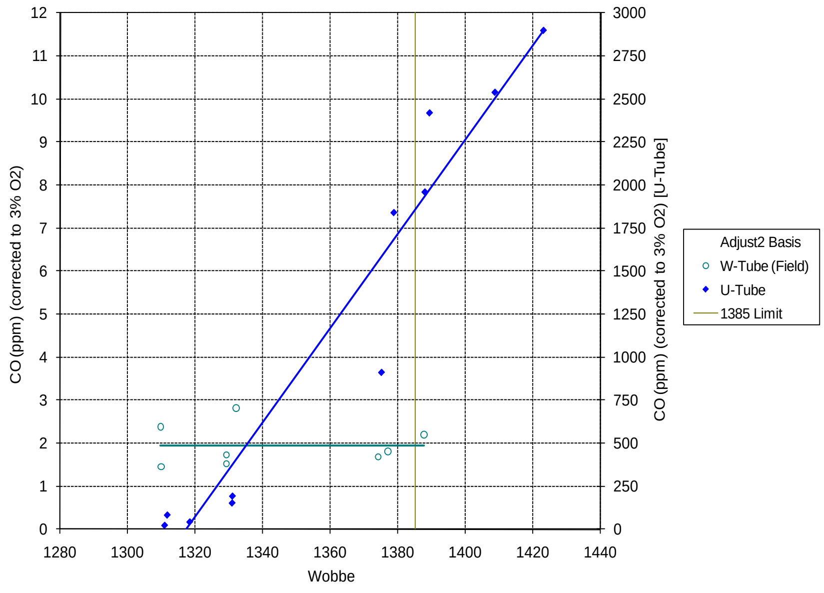
> Burners tuned to Adjust Gas 2 at 1332 Wobbe, then fired with different adjust and substitute gases

> NO_x varies widely based on burner type

> CO is low for all boiler burners and decreases at higher Wobbe

Emissions for Radiant Tube Burners





> Burners tuned to Adjust Gas 2 at 1332 Wobbe, then fired with different adjust and substitute gases

> NO_x varies widely and decreases with higher Wobbe

> CO can increase exponentially at low excess air levels

Conclusions: Industrial Burners

- No industrial burners had ignition problems over the range of gases studied (1308-1425 W)
- Emissions (NO_x, CO) can increase, decrease, or be unchanged for burners
- With proper tuning NO_x for all burners at 1385 W can be equal to or lower than NO_x when burner is tuned to 1332 W
- For burners using low oxidant to fuel ratios (radiant tubes, oxygen burners, low NO_x boilers) higher W gas requires increased oxidant to avoid exponential increases in CO
- Many burners require no adjustments for NO_x, CO
- Advanced controls can do needed tuning for many burners
- Data suggests simplified protocols can be devised for the remaining burners of concern

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Commercial Cooking Unit Selection

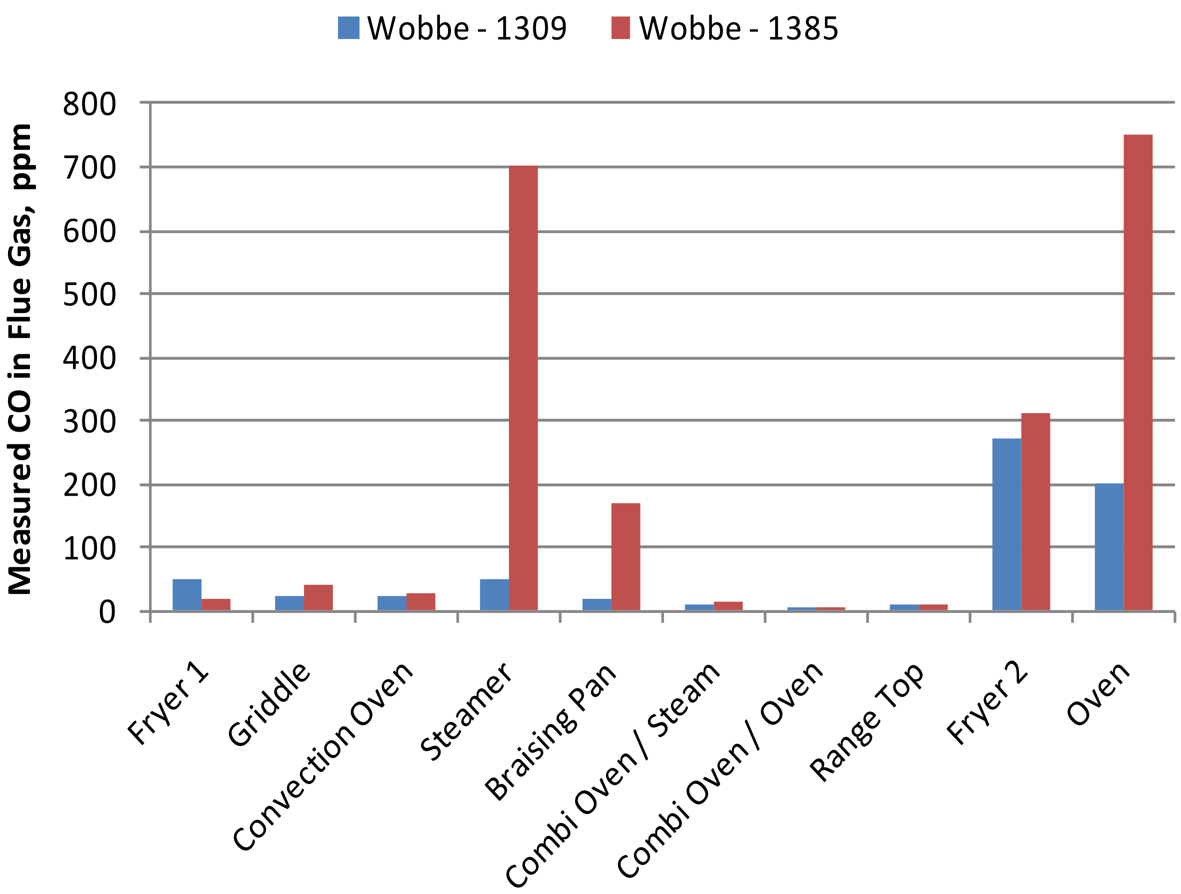
- GTI enlisted Carl Suchovsky, President of Gas Consultants, Inc. and Don Fisher of Fisher-Nickel, Inc. to help select the commercial foodservice appliances
- Selected appliances were representative of equipment currently sold in California
- Appliances represented technology commonly found in restaurants
- Choices covered the burner types found in food service equipment (atmospheric, infrared, powered and fan-assisted burners)

Commercial Cooking Appliances Selected

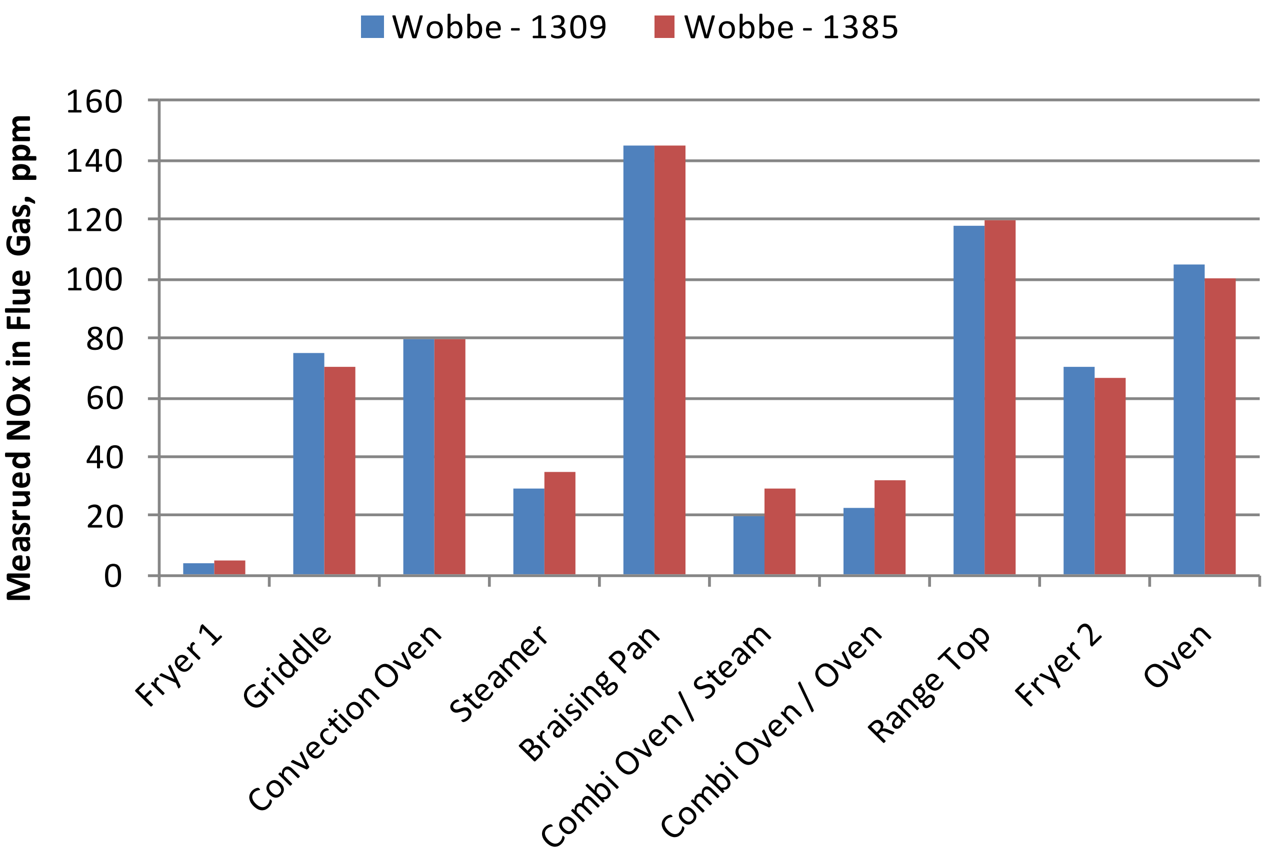
Appliance	Manufacturer	Model	Notes
Fryer	Frymaster	FH155	Infrared burner, exhaust fan
Fryer	Pitco	SG-14 or SSH55	Atmospheric burner
Convection Oven	Blodgett	DFG-100Xcel	Atmospheric burner, exhaust blower
Combi Oven	Cleveland	OGB-6.20	Dual premixed powered burners
Griddle	Vulcan	36RRG	Atmospheric U-shaped burners
Griddle	Jade	JSO315	Blue flame burner (cast iron open burners)
Range	Garland	G36-6R	33,000 Btu/h top burner
Steamer	AccumTemp	N6	Stainless steel powered burner

Appliance Test Facility

CO in Flue Over Wobbe Range of Gases



NO_x in Flue Over Wobbe Range of Gases



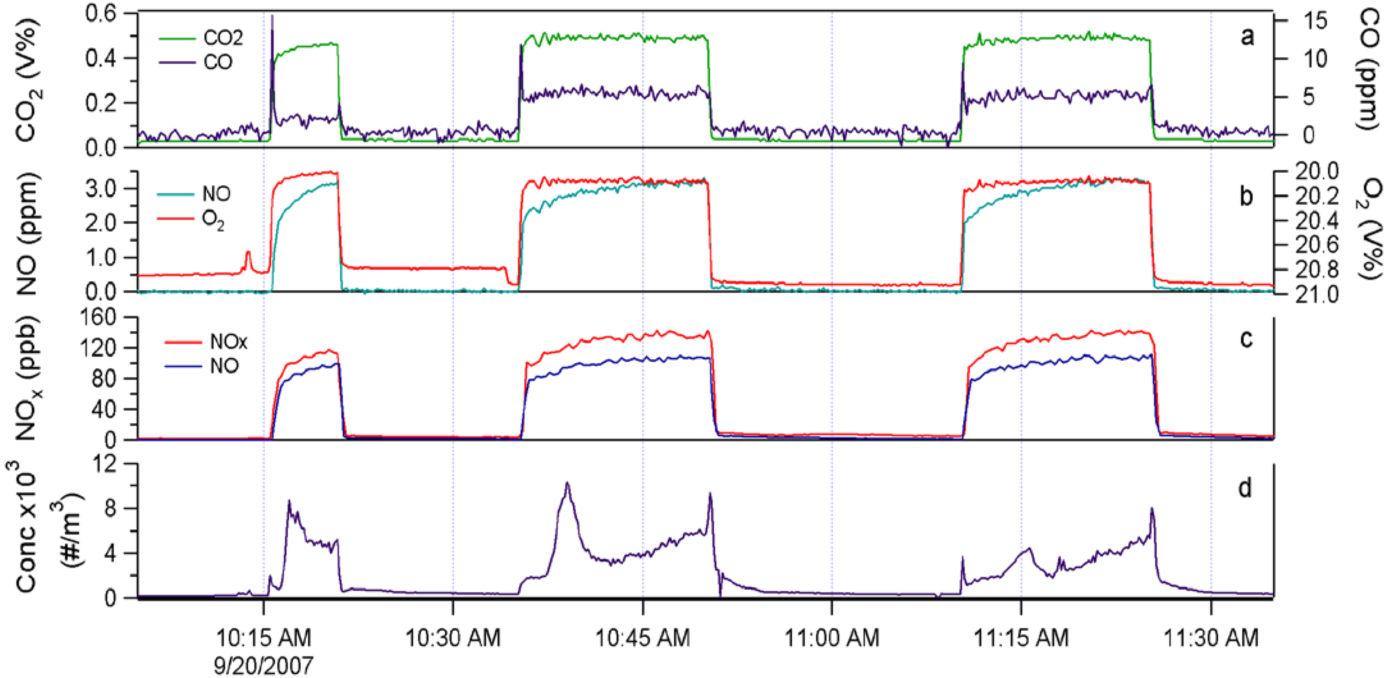
Food Service Appliance Summary

- No issues with ignition or operation of equipment tested
- Based on NO_x and CO emissions appliances can have none, some, or significant interchangeability concerns
  - Some minor concerns with NO_x at high Wobbe
  - CO rises to high levels for some appliances at high Wobbe
- Testing of excess O_2 in the flue is a good indicator of high CO and an appliance needing adjustment
- Appliances must be either adjusted by manufacturer or by trained service technician for low emission operation with high Wobbe gas

Appliance Burner Experiments

- **Cooking:** 13 cooktops, 12 ovens, 5 broilers
- **Vented:** 5 storage water heaters, 6 tankless , 5 furnaces
- **Fuels:**
  - Northern CA line gas: 1330-1340 WN
  - Simulated LNG: 1390, 1420 WN (some 1360 WN)
- **Experimental Approach:**
  - Operating cycles to capture transient emission events
  - Duplicate burns for cooktops, ovens, furnaces, storage WHs
  - Varied operation for oven (temp) and tankless (flow)
  - Calculated emission factors for full-burn, end-of-burn
  - Univariate: emissions by burner and fuel
  - Bivariate: emissions related to fuel WN
  - Multivariate: included other effects
  - Changes in emission factor were related to increase in Wobbe Number

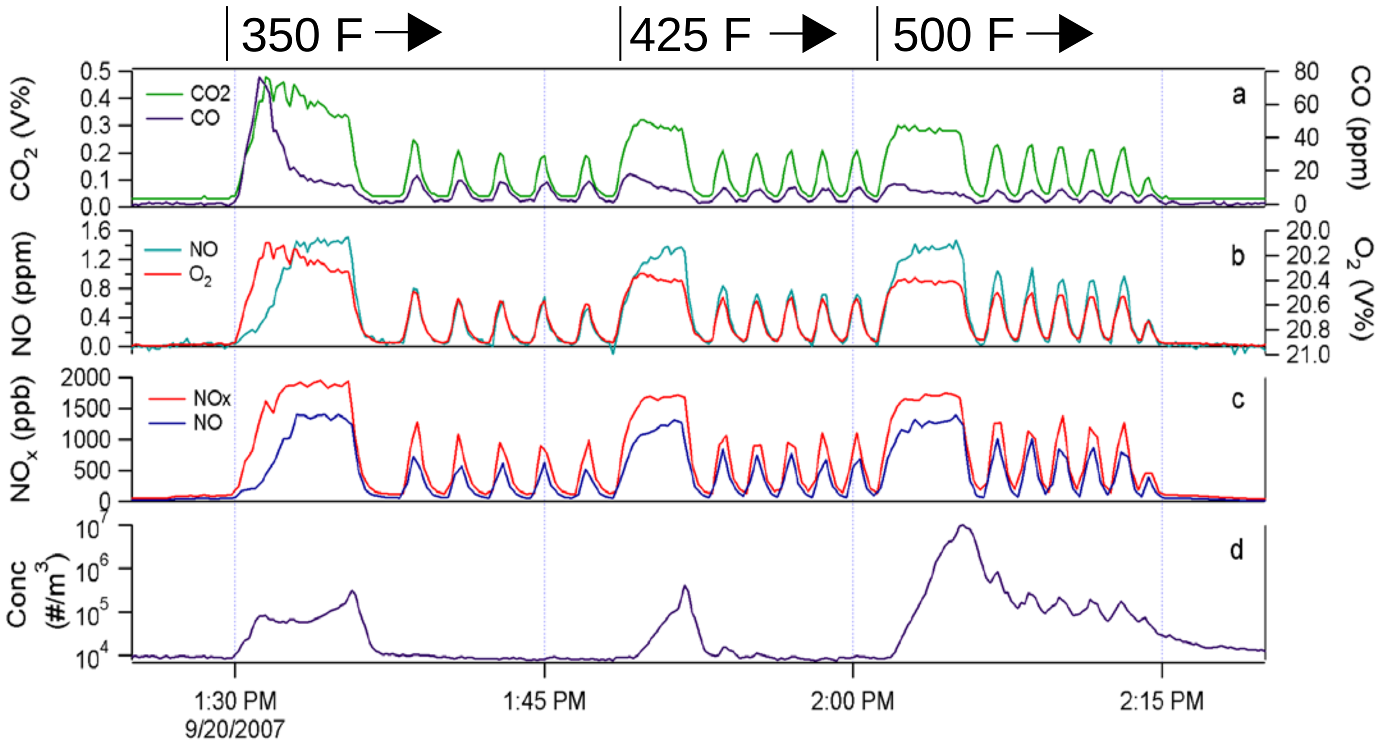
Example Data From Cooktop Experiment



> Pot + 4 L H_2O on each corner burner, all at highest firing rates; 15 minute burns

> Cooling period varied in early experiments, then consistent at 15 minutes (CT02, fuel 3A+N_2)

Example Data From Oven Experiment



> Subsequent experiments used 2-3 maintenance cycles per T setting (OV02, fuel 3A)

Interpretation of Results

Cooking/Unvented Burners

- Indoor exposures
- Concern: impacts for individual burners
- Focus on primary pollutants
  - CO, NO_2, PN, HCHO
  - Small contribution to ambient air quality
- Sample includes common technologies, varied ages
- Sample not large enough to reliably assess outliers

Vented Burners

- Ambient air quality
- Concern: impacts on total emissions from population
- Focus on regulated pollutants
  - NO_X effect on O_3, $PM_{2.5}$
  - CO small effect on ozone
  - HCHO is Hazardous Air Pollutant
  - NO_2 primary pollutant
- Most common technologies sampled; results consistent with other studies

Baseline Emissions* by Appliance Group

	CO (ng J^{-1})	NO_2 (ng J^{-1})	HCHO (ng J^{-1})	PN* (10_4 J^{-1})	NO_X (ng J^{-1})
Cooktops	7 – 823	5.0 – 17.7	0.1 – 4.7	183 – 9200	25 – 47
Ovens	16 – 528	3.8 – 13.9	0.3 – 5.5	10 – 6300	27 – 41
Broilers	29 – 178	2.8 – 13.0	0.1 – 0.9	107 – 2650	17 – 37
Furnaces	<1 – 31	<1 – 9.7	0.2 , 0.4	<1 – 46	22 – 34
Storage WH	<0 – 2	0.3 – 2.2	<0.1	3 – 51	24 – 32
Tankless WH	19 – 434	4.0 – 8.9	0.2 – 2.4	<1 – 27	9 – 31

* Range of mean emissions across burners; PN is range of maxima across burners.

Key Findings: Cooktops

> **CO:** Increases in most cooktops
  - Significant increases in 11 of 13 cooktops
  - ↑6-40% for 4 cooktops with CO > 100 ng/J

> **NO_2:** Increases in half of the cooktops
  - Significant increases in 7 of 13 cooktops; ↑5-20%
  - All had NO_2 > 5 ng/J

> **HCHO:** Important impacts for some cooktops
  - No change for most burners including highest emitter
  - Next two highest had one increase 62%, one decrease 28%

> **PN:** varies much more with operation than fuel

Effects are change in emission factors (ng/J) per 50 Btu/scf increase in WN

Key Findings: Ovens and Broilers

- **CO:** Increases in most
  - Increases in 16 of 17 burners
  - ↑5-40% for 7 of 9 with CO ≥ 100 ng/J
  - ↓5-14% for 2 of 9 with CO ≥ 100 ng/J
- **NO_2:** Increase in half of the burners
  - Increases in 9 burners: ↑10-38% for NO_2 > 5 ng/J
  - Decrease of 7% in 1 burner
- **HCHO:** Some impacts
  - Increases of 8-20% in 6 burners; decrease of 21% in 1 burner
  - No change in 8; no data for 2 burners
- **PN** varies much more with operation than fuel

Effects are change in emission factors (ng/J) per 50 Btu/scf increase in WN

Key Findings: Water Heaters I

- Standard storage WHs have low CO and NO_2, appear to have low HCHO; negligible fuel effects
- Tankless had higher CO, NO_2, HCHO, PN
- Tankless:
  - CO increase for group dominated by unit with bad regulator
  - Frequency of this problem in population is unknown
  - NO_2 ↑3-19% for 5 burners; ↓3% for 1 burner
  - HCHO ↓2-11% for 5 burners; no change for 1 burner

Effects are change in emission factors (ng/J) per 50 Btu/scf increase in WN

Key Findings: Water Heaters II

- Storage to tankless switch has much larger impact than LNG on CO, NO_2, HCHO
  - Baseline emissions much higher
  - CO and NO2 increase with LNG
  - HCHO decreases with LNG (but higher than storage)
- Baseline NO_X lower in tankless water heaters, but more sensitive to fuel WN
  - With LNG, NO_X from tankless likely still lower than from conventional storage WHs
  - Given tankless NO_X variability, need market analysis
- Effect of fuel WN on ultra-low-NO_X storage WHs and next generation tankless?
  - TBD in CEC-funded Healthy Homes study

Key Findings: Furnaces

- **CO:**
  - Generally low emission rates
  - ↓26% in 2 furnaces, mixed or no change in others
- **NO_X:**
  - ↑3-7% in 3 furnaces, no change in other 2
- **NO_2:**
  - ↓14% in 1 furnace; no change in others
- **HCHO:**
  - Data for only 2 of 5 furnaces tested
  - Relatively low baseline; ↓24-34% with increasing fuel WN

Effects are change in emission factors (ng/J) per 50 Btu/scf increase in WN

Appliance Findings: Summary

> **Appliance Operation**

– Consistent with other studies, we found no substantial operational issues related to LNG use in residential appliances

> **Pollutant Emissions**

– Small, if any increase in emissions from forced air furnaces and storage water heaters

– Tankless water heaters have higher emissions and LNG impacts compared to storage WHs

– Cooking burners can have substantial baseline emissions and sensitivity to LNG

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