Environmental, Energy Market, and Health Characterization of Four Wood-Fired Hydronic Heater Technologies

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Project Approach

- Test four OWHHs
  - Common, new, and multi-stage models
  - Fully characterize emissions, emission factors
  - 4/5 Fuel types
- Test under realistic, homeowner firing scenarios
  - 24 h, cordwood
- Health risk characterization
- Emission inventory projections for NY
- MARKAL technology assessment

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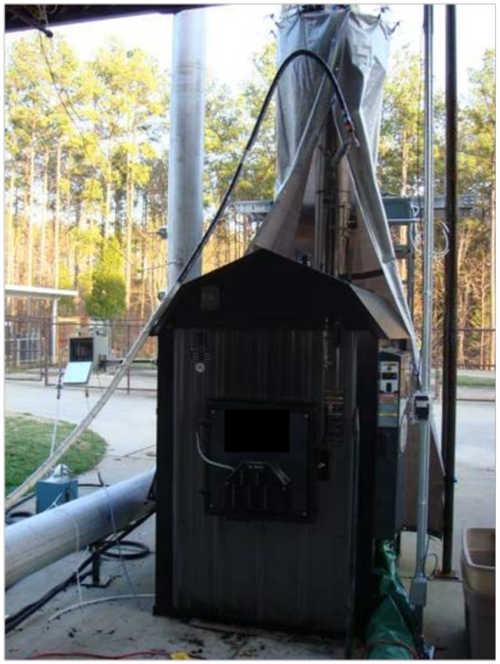
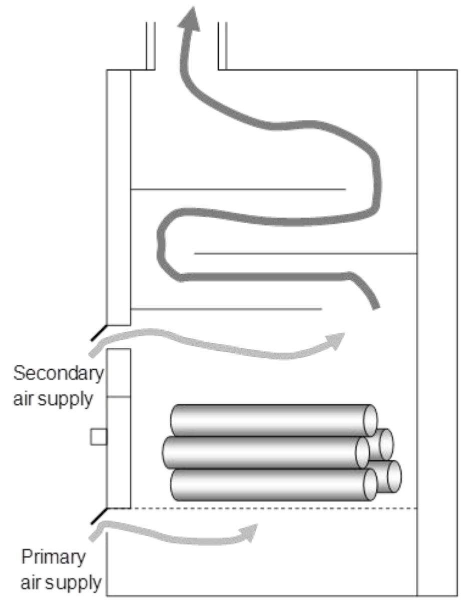
Conventional/Single Stage HH

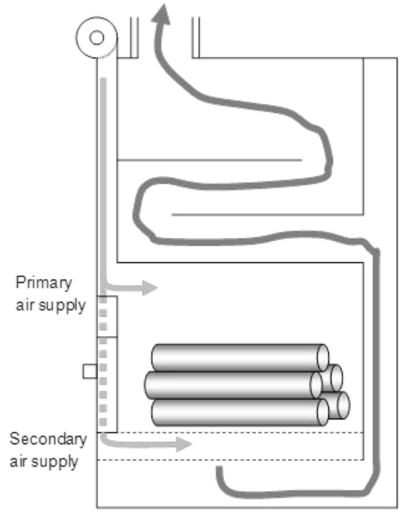




Up-draft combustion

Natural updraft, fan-assisted, single-stage combustion (250,000 BTU/h). Rectangular firebox surrounded by a high capacity water jacket. The gases are forced into a combustion chamber where additional super-heated air is added, increasing the gas temperature. Load demand satisfied by regulation of an air damper.

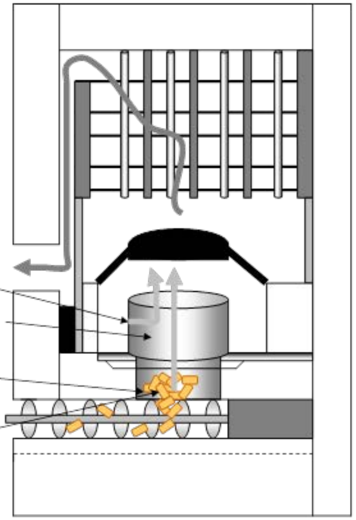
Three Stage HH



Down-draft combustion

Three-stage combustion process (160,000 BTU/h) in which wood is gasified in the primary combustion firebox. The hot gases are forced downward and mixed with super-heated air starting the secondary combustion. Final combustion occurs in a third, high temperature reaction chamber. Like the Conventional/Single Stage HH, this Three Stage HH is regulated by the opening and closing of a temperature controlled air damper.

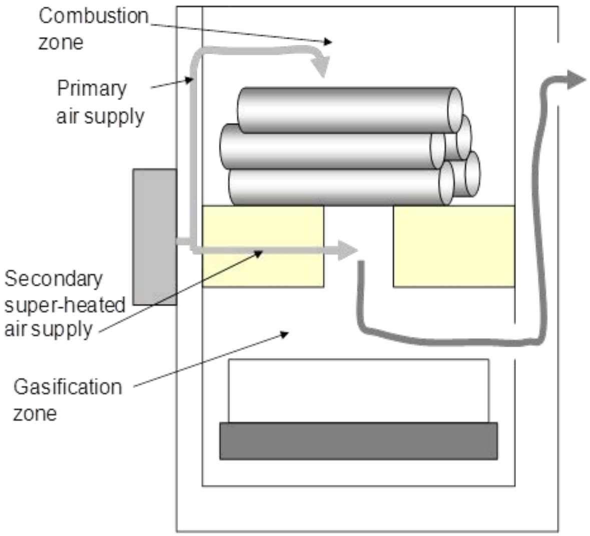
European Two-Stage Pellet Boiler



Bottom fed pellet burner

This unit is a pellet burning HH rated at 40 kW (137,000 Btu/hour). Combustion occurs on a round burner plate where primary air is supplied. Secondary air is introduced through a ring above the burner plate. Fuel is automatically screw-conveyed from the bottom. Operation of the screw feeder is regulated by a thermostat. During normal operation, the fan modulates based on the measured oxygen level in the exhaust gas, maintaining 8-10% oxygen

U.S. Two-Stage Downdraft Burner



Combustion and gasification

A two-stage heater (150,000 BTU/h) with both gasification and combustion chambers. Air is added to the firebox continuously and is blown downwards. A thermal storage unit was simulated with the addition of a water/air heat exchanger.

Fuels

Properties	Fuel		
	Pine	Red Oak	Pellets
Ash	0.44%	1.46%	0.52%
Loss on Drying (LOD)	9.68%	22.52%	7.24%
Volatile Matter	88.50%	84.23%	84.27%
Fixed Carbon	11.06%	14.31%	14.11%
C: Carbon	51.72%	48.70%	50.10%
Cl: Chlorine	36 ppm	38 ppm	44 ppm
H: Hydrogen	6.57%	5.96%	5.86%
N: Nitrogen	<0.5%	<0.5%	<0.5%
S: Sulfur	<0.05%	<0.05%	<0.5%

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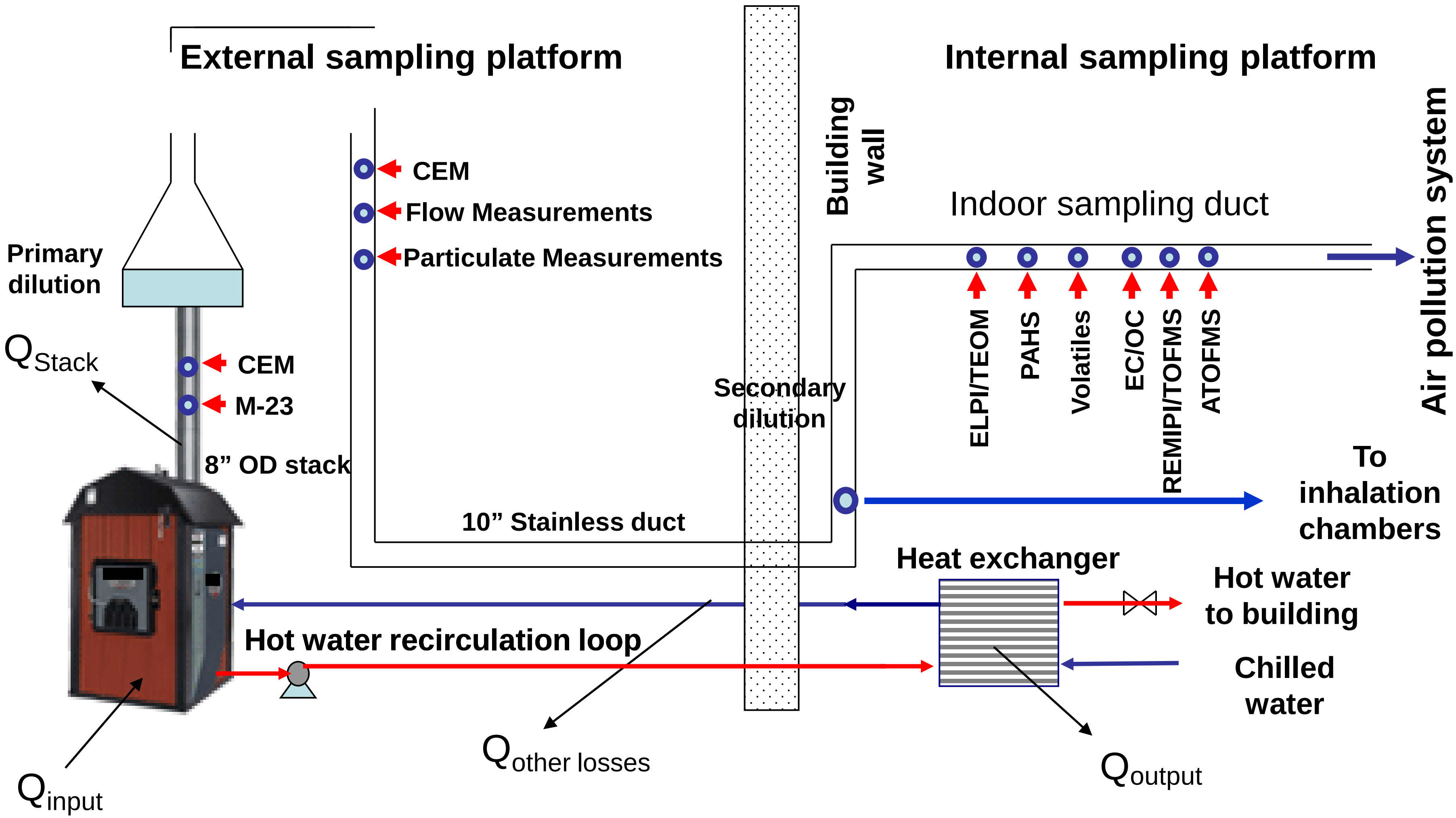
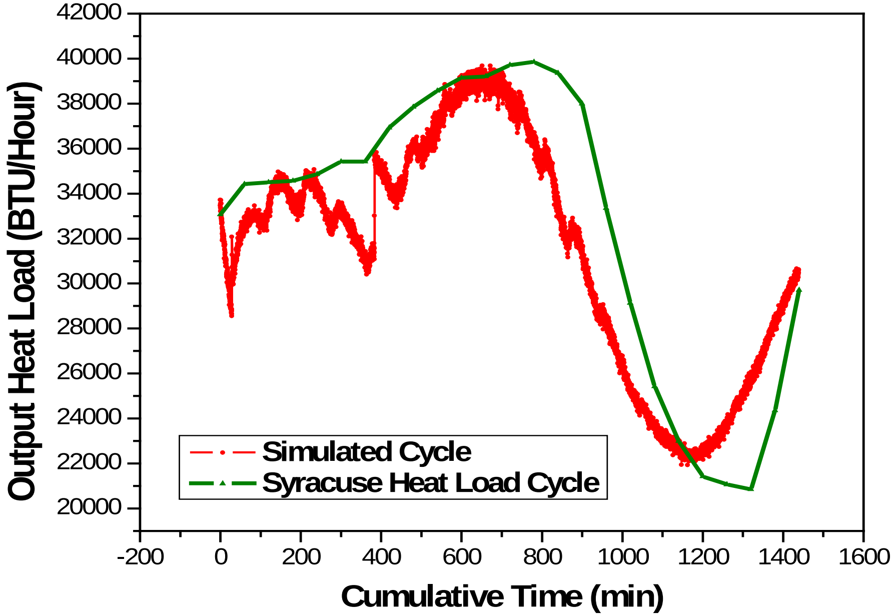
HH Sampling and Analytical Methods

Pollutant	Method(s)	Duration
Total PM	ASTM 2515M5G	Integrated run
PM mass and size	Dilution + TEOM, ASTM 2515 for tot for total mass and ELPI for size distributions, ELPI or SMPS	Real time & size distribution
CO	NDIR Method 10B	Real time
CO2	NDIR Method 3A	Real time
O2	Paramagnetic Method 3A	Real time
EC/OC	NIOSH 5040	Integrated run
PAHs, SVOCs	Method 0010, GC/MS	Integrated run
GaseousVOCs	Summa canister, TO15	Integrated run
Aromatics	REMPI-TOFMS	Real time
PCDD/F	Method 23	Integrated run
THC	FID Method 25A	Real time
CH4	FID with reduction catalyst	Real time
N2O	GC	Integrated run

HH test facility



Appliance Heat Load Profile



- The heat load profile used throughout the testing program (non-exposure tests) was derived from Tom Butcher's Energy-10 simulation for a 2500 sq-ft area home in Syracuse, New York.
- This heat load profile was calculated using an average hour per hour heat load for the first two weeks of January.

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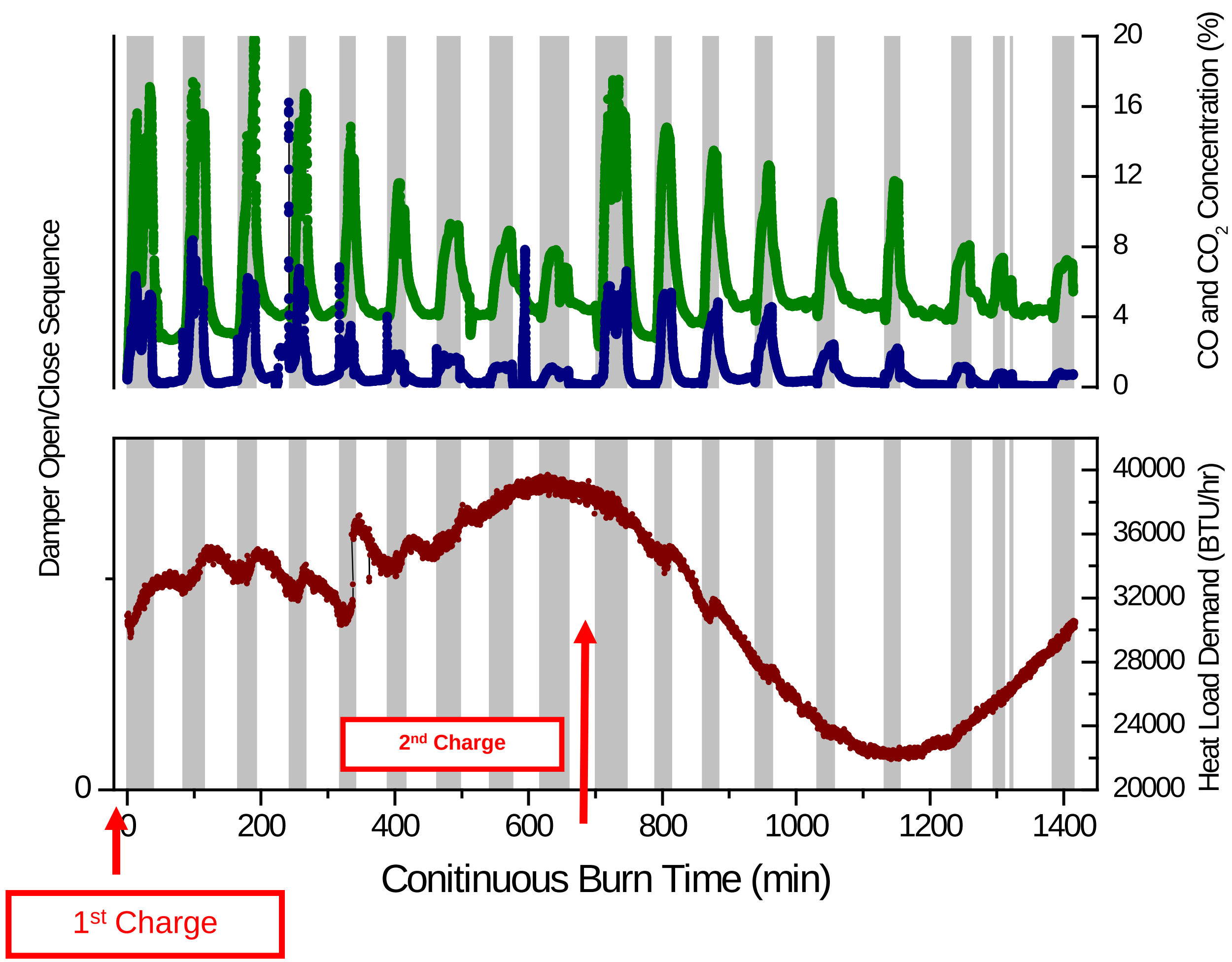
CO and CO_2 Emissions as a function of Syracuse Heat Load Demand, 24 h test Conventional/Single Stage HH, Red Oak

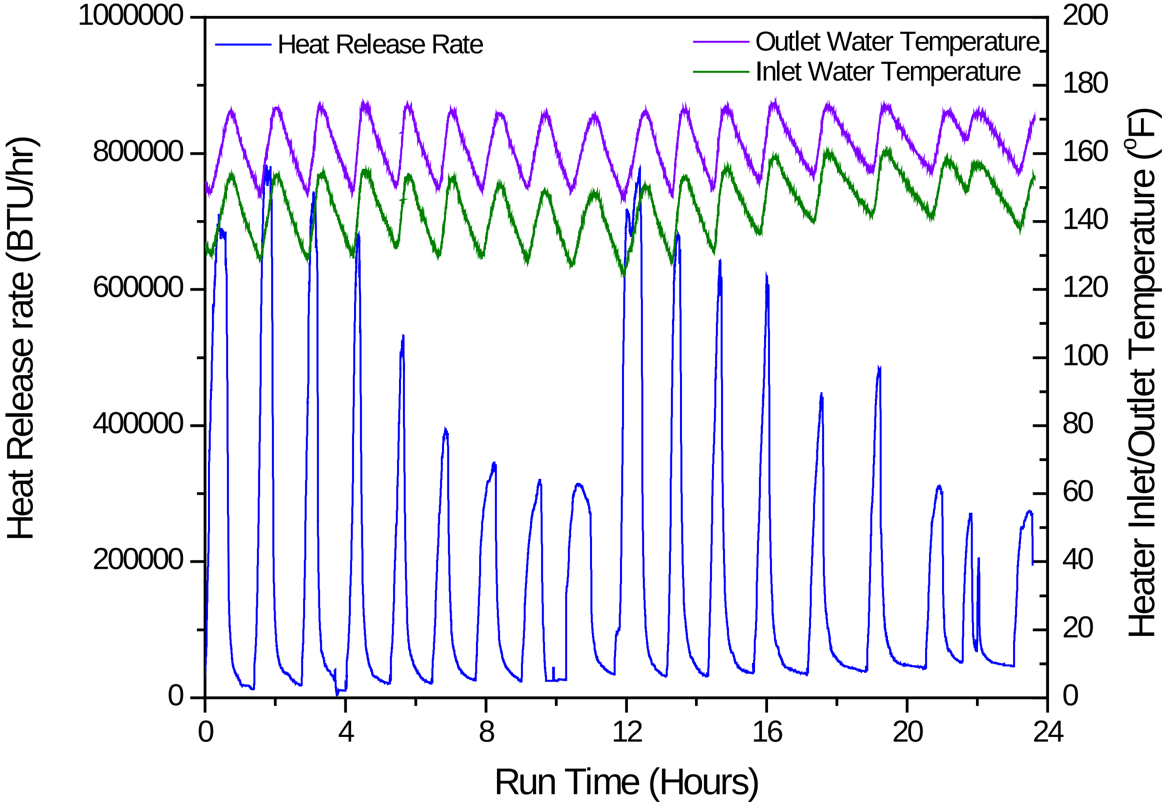


The emission profiles are ~ independent of the heat load. Rather they appear to be primarily related to the fuel charging cycle under our conditions.

Damper Close = Open
Damper Open = Gray
Green = CO2
Blue = CO

Heat Release Rate

Representative Run

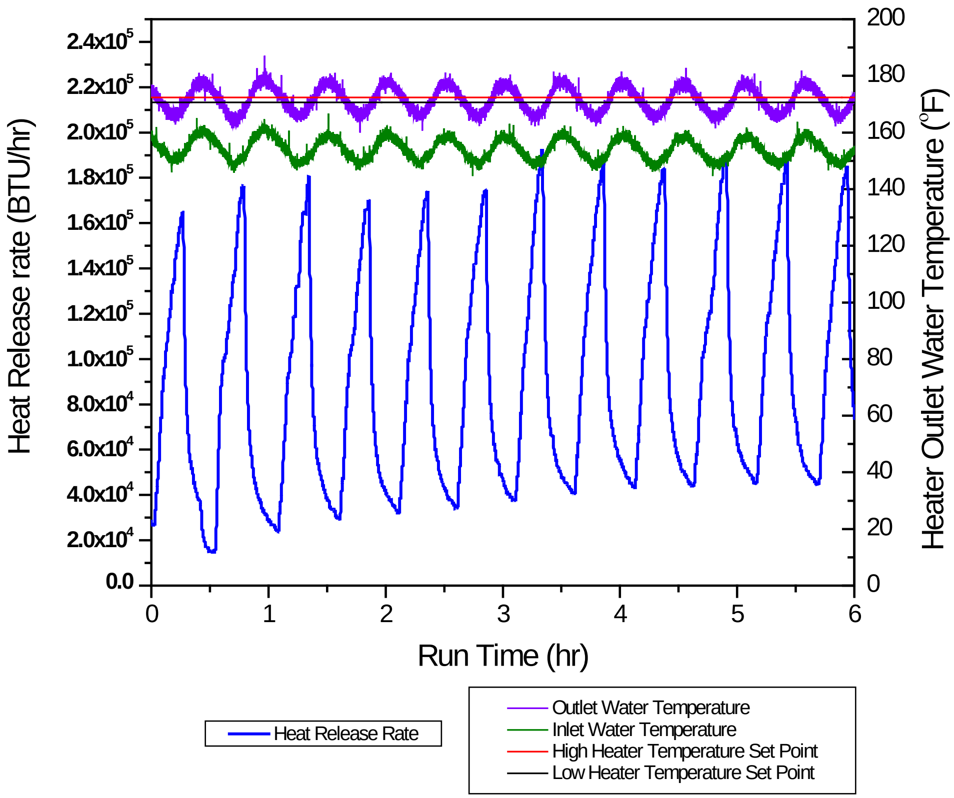


Heat release during damper openings

Conventional/Single Stage HH, Red Oak

Heat Release Rate

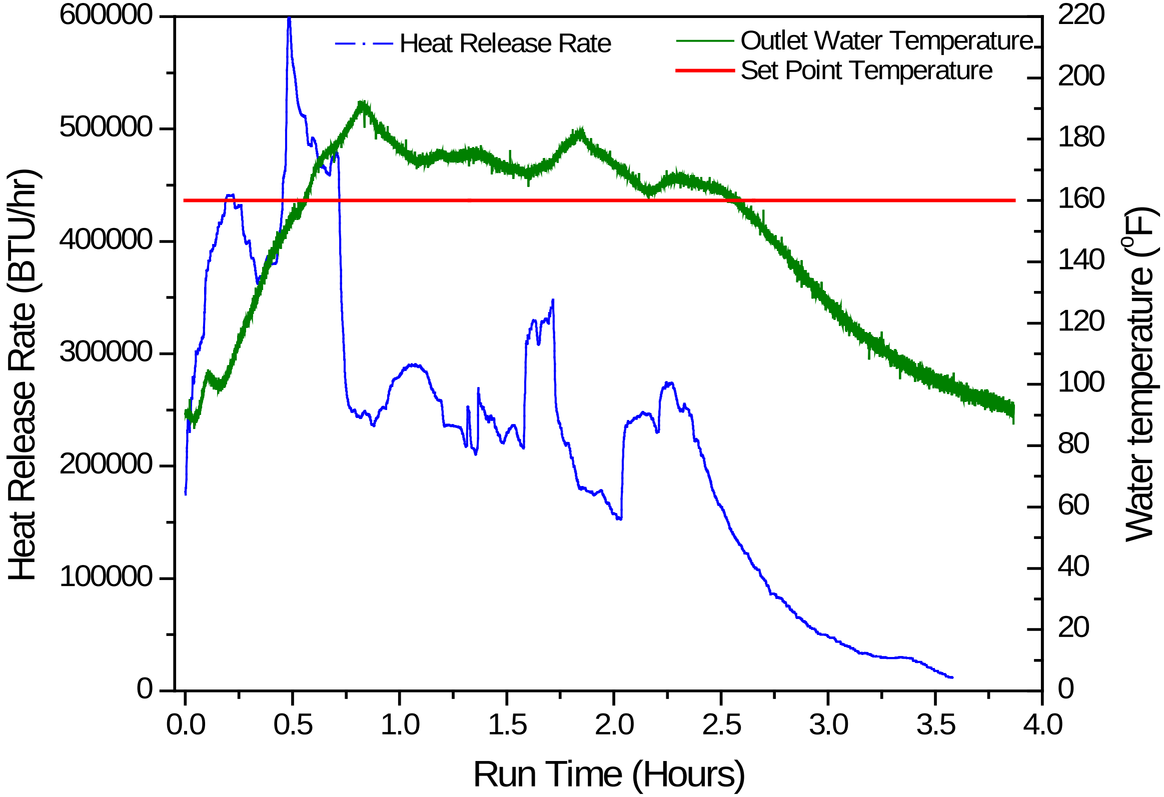
Representative Run



European 2-Stage Pellet Burner

Heat Release Rate

Representative Run



U.S. 2-Stage Downdraft Burner with Thermal Storage

Unit with simulated heat storage has non-cyclical heat release.

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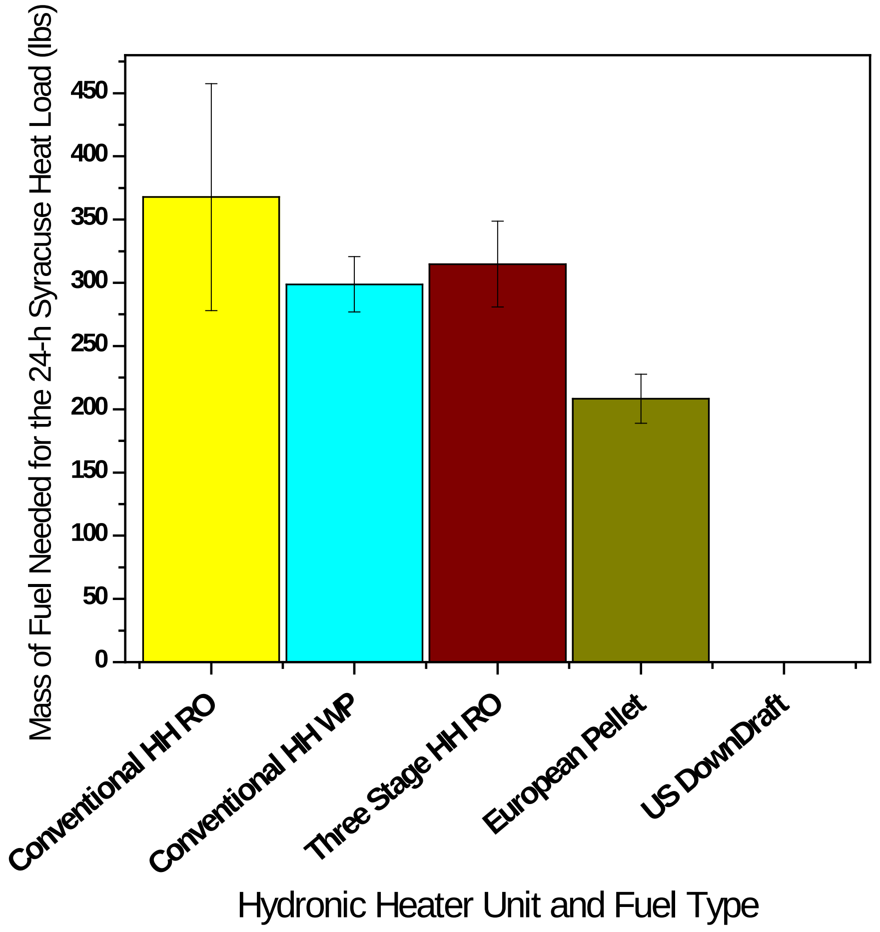
Efficiencies

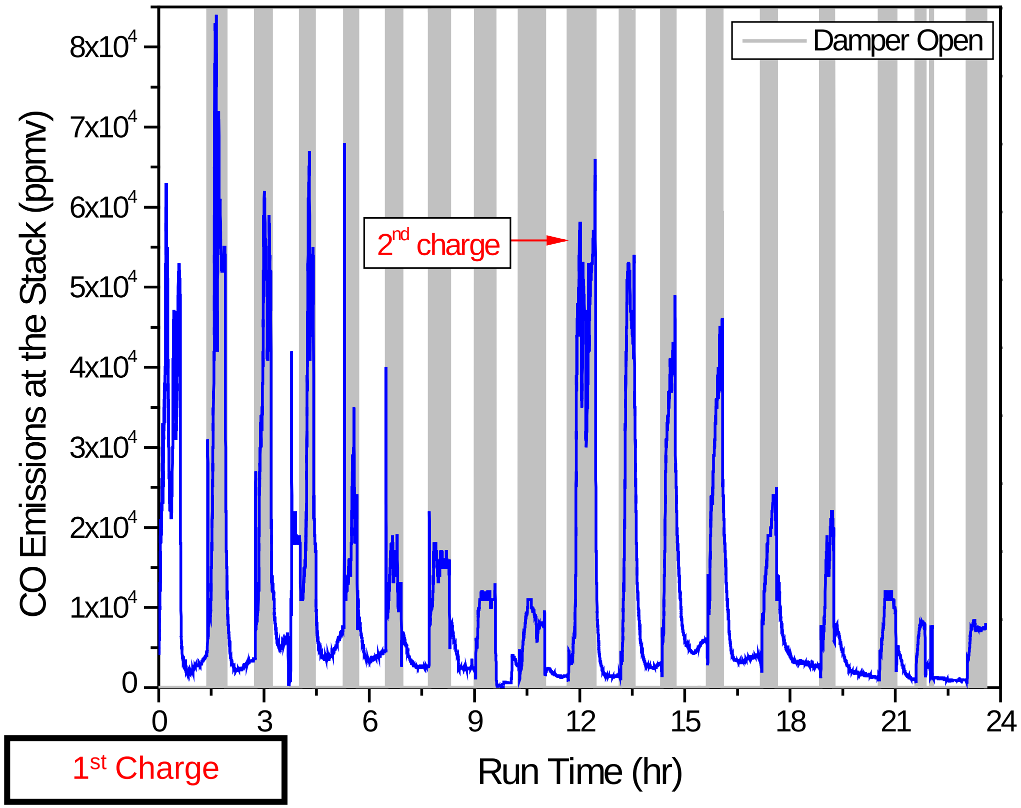
Units	Thermal Efficiency (%)		Boiler Efficiency	Combustion Efficiency
Conventional/Single Stage HH/Red Oak	Average	**22**	NC	74
	STDV	5		3.0
Conventional/Single Stage HH/Red Oak and refuse	Average	**31**	NC	87
	STDV	2.2		3.4
Conventional/Single Stage HH/White Pine	Average	**29**	NC	82
	STDV	1.8		3.2
Three Stage HH/Red Oak	Average	**30**	NC	86
	STDV	3.2		1.8
European 2-Stage Pellet Burner	Average	**44**	86	98
	STDV	4.1	3.5	0.16
U.S. 2-Stage Downdraft Burner Red Oak	Average	IM	83	90
	STDV		0.71	0.79

NC = Not calculated. IM = Insufficient measurements taken for this calculation

Mass of Fuel Needed for a 24 Hour Syracuse Heat Load

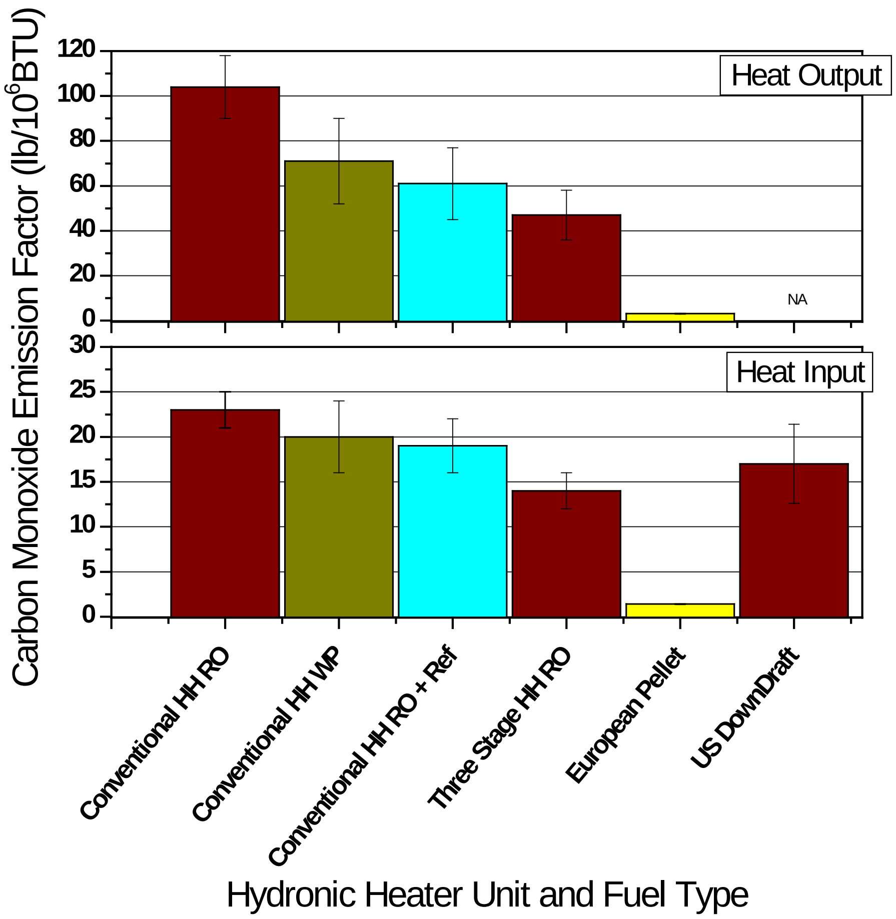


CO Stack Concentration as a Function of Damper Opening and Time of Fuel Charging, Conventional/Single Stage HH.

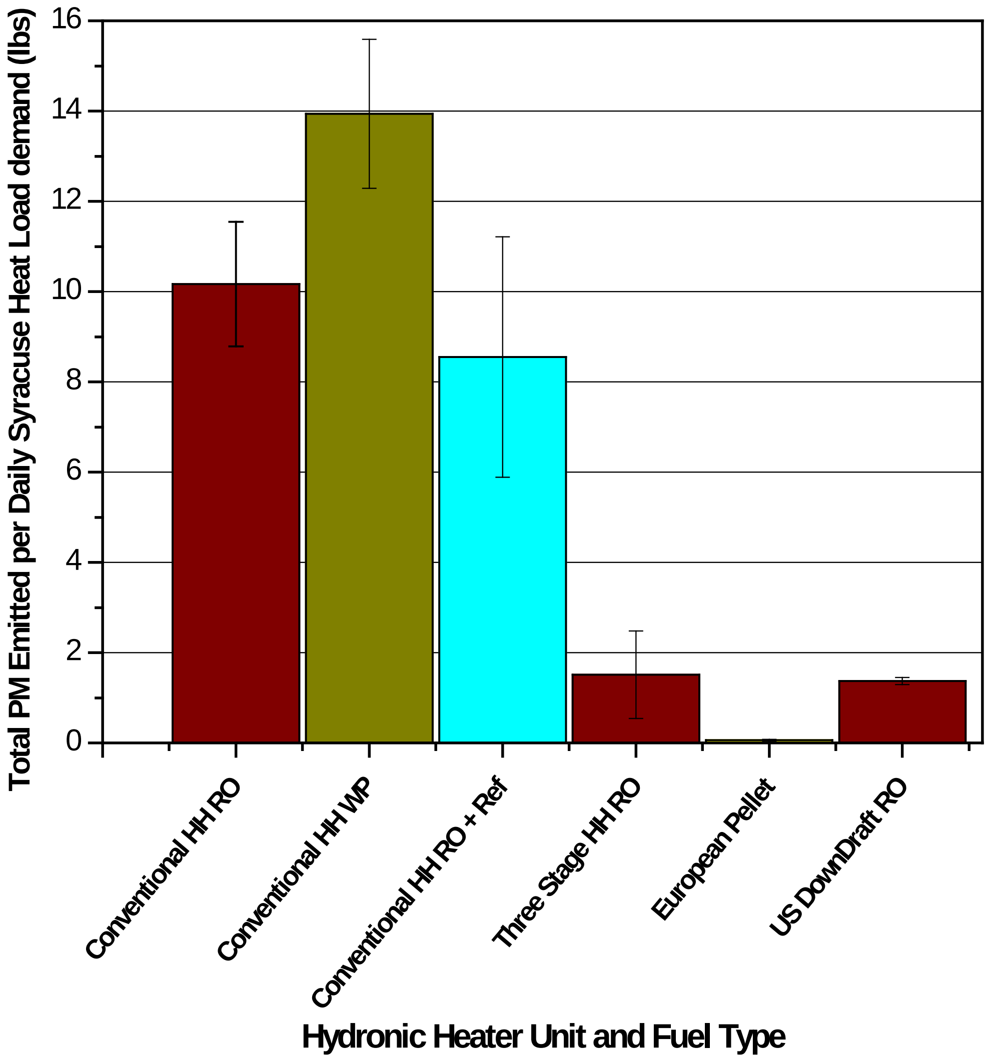


Emissions are primarily related to time-since-charging rather than heat load demand.

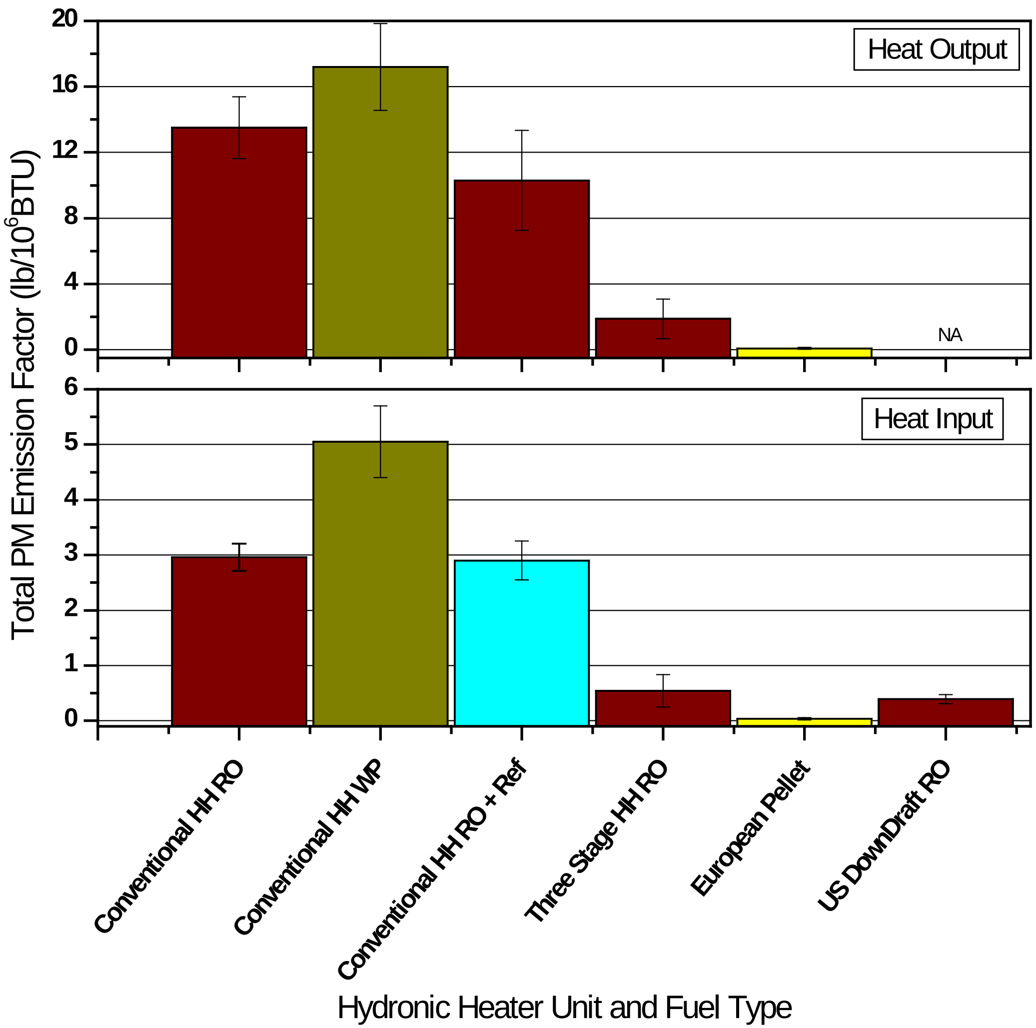
Carbon Monoxide Emission Factors



PM Generated per Syracuse Day for All Six Unit/Fuel Combinations

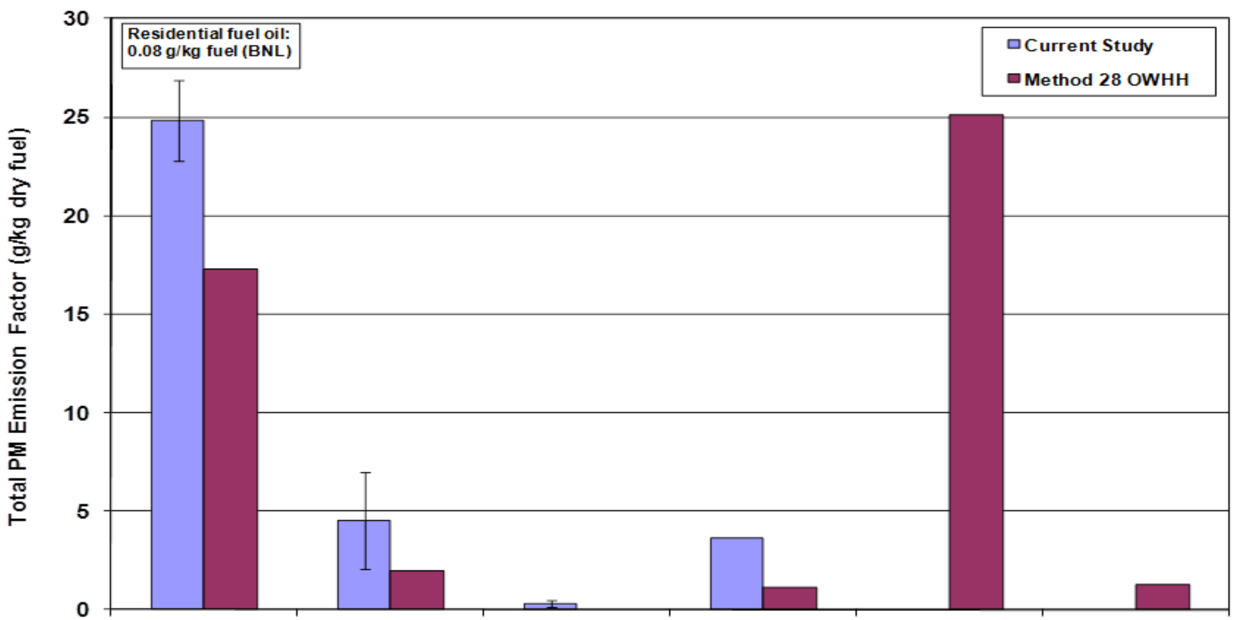


PM Emission Factors



PM. Comparison of Current Data to EPA Method 28 OWHH

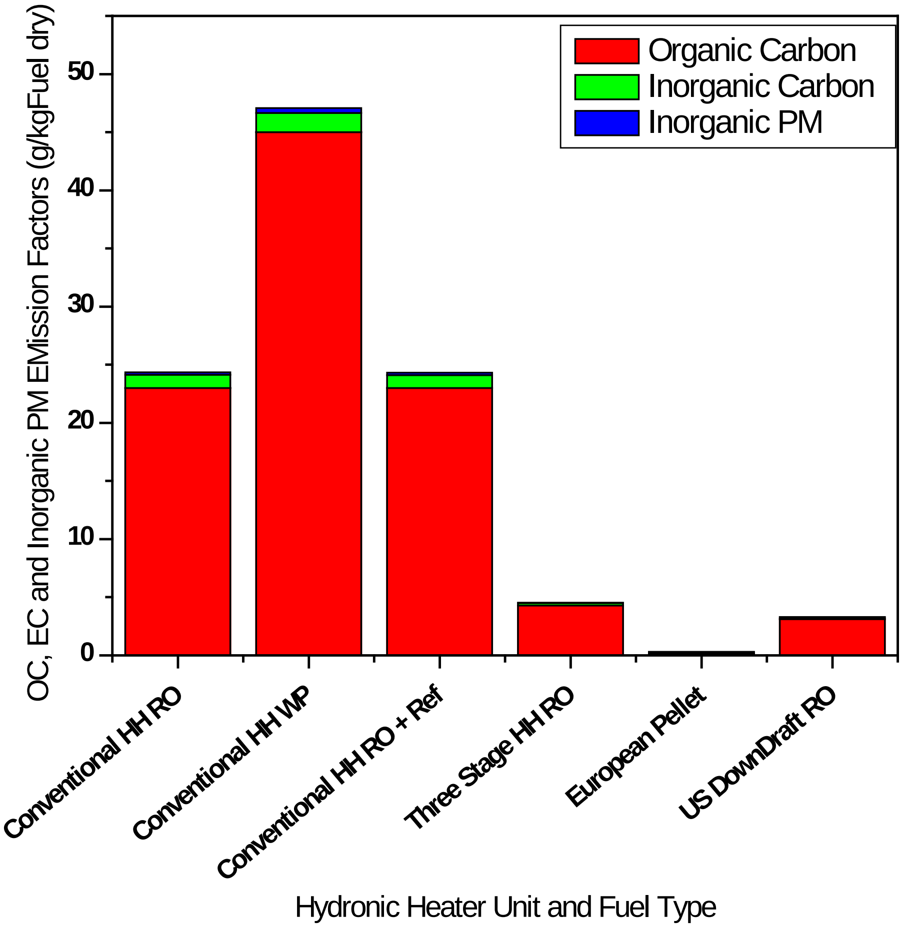
This project | Others' work, EPA Method 28



Conventional HH RO	Three Stage HH	European 2-Stage Pellet	U.S. 2-Stage Downdraft	Other Conventional HH	Multistage HH

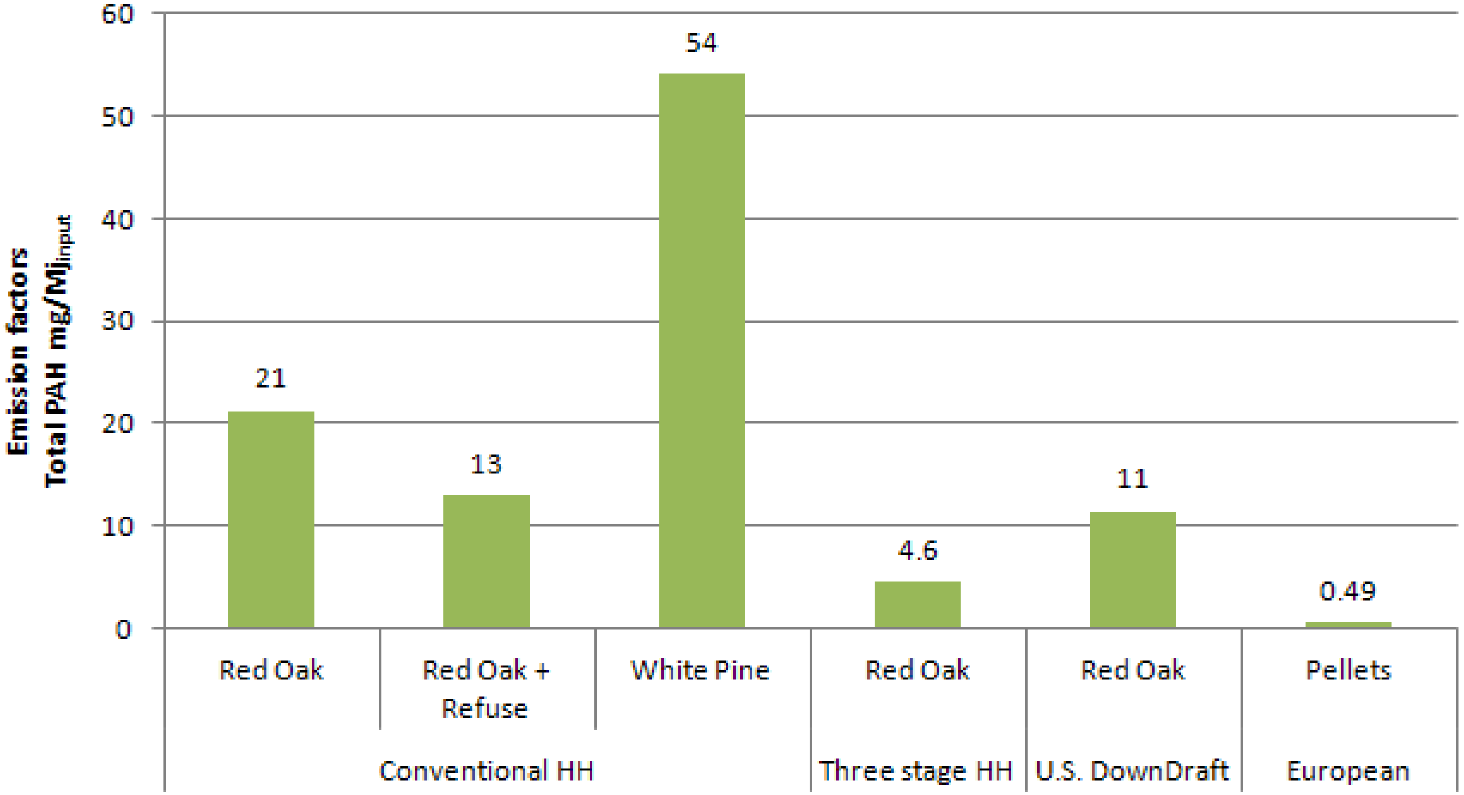
Large variation in PM emissions from different technologies

OC/EC Emission Factors



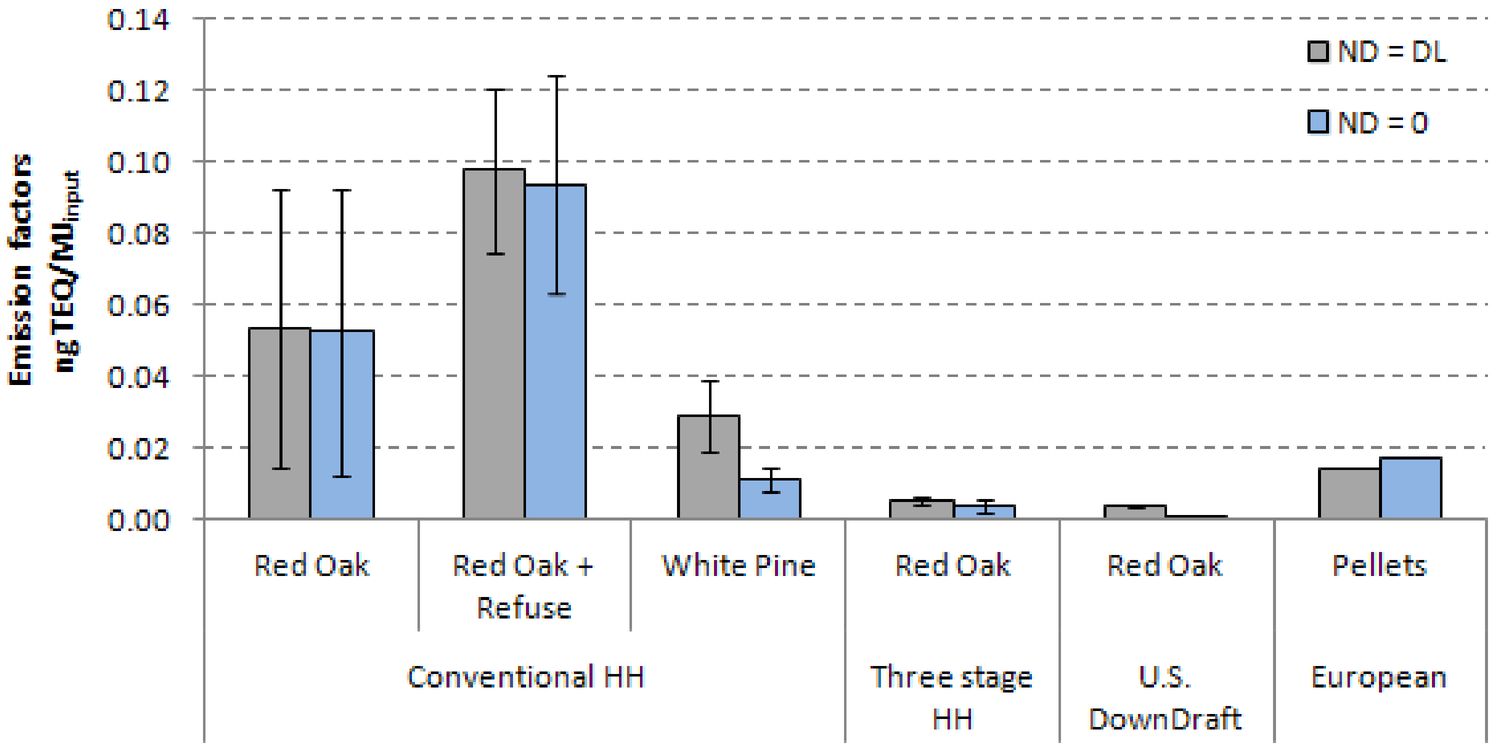
Significant organic carbon contribution with emission factor a function of technology type.

Total PAH Emission Factors



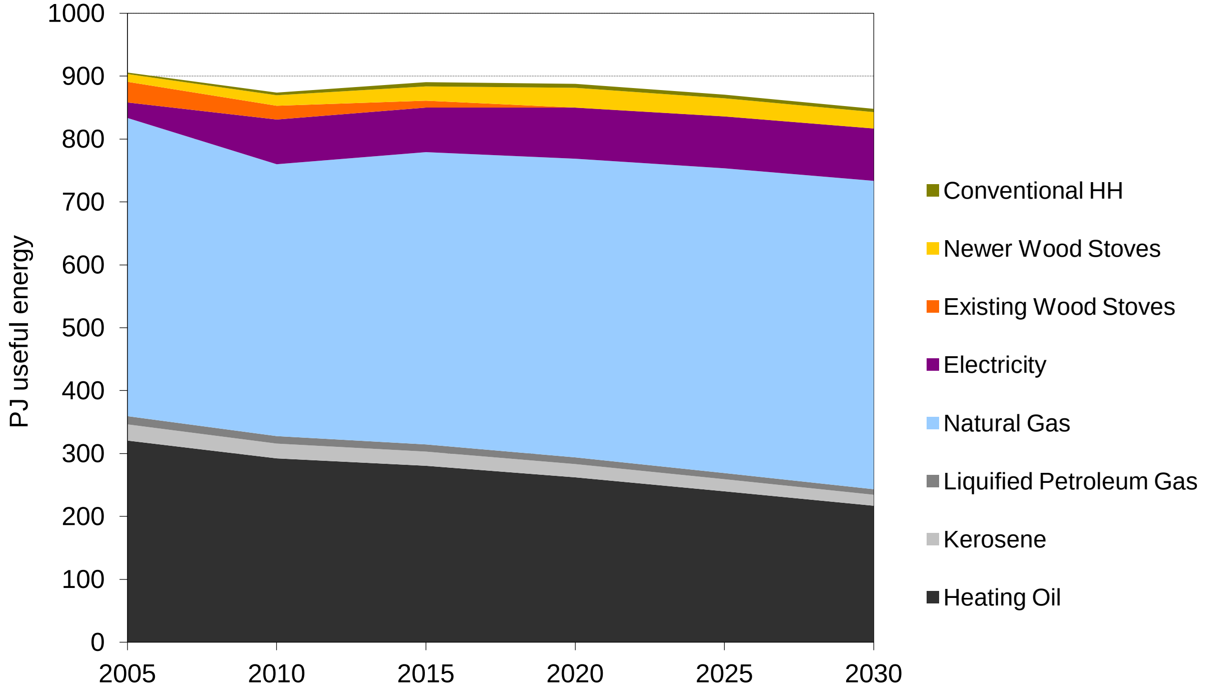
Higher PAHs from White Pine

PCDD/PCDF (Dioxin)



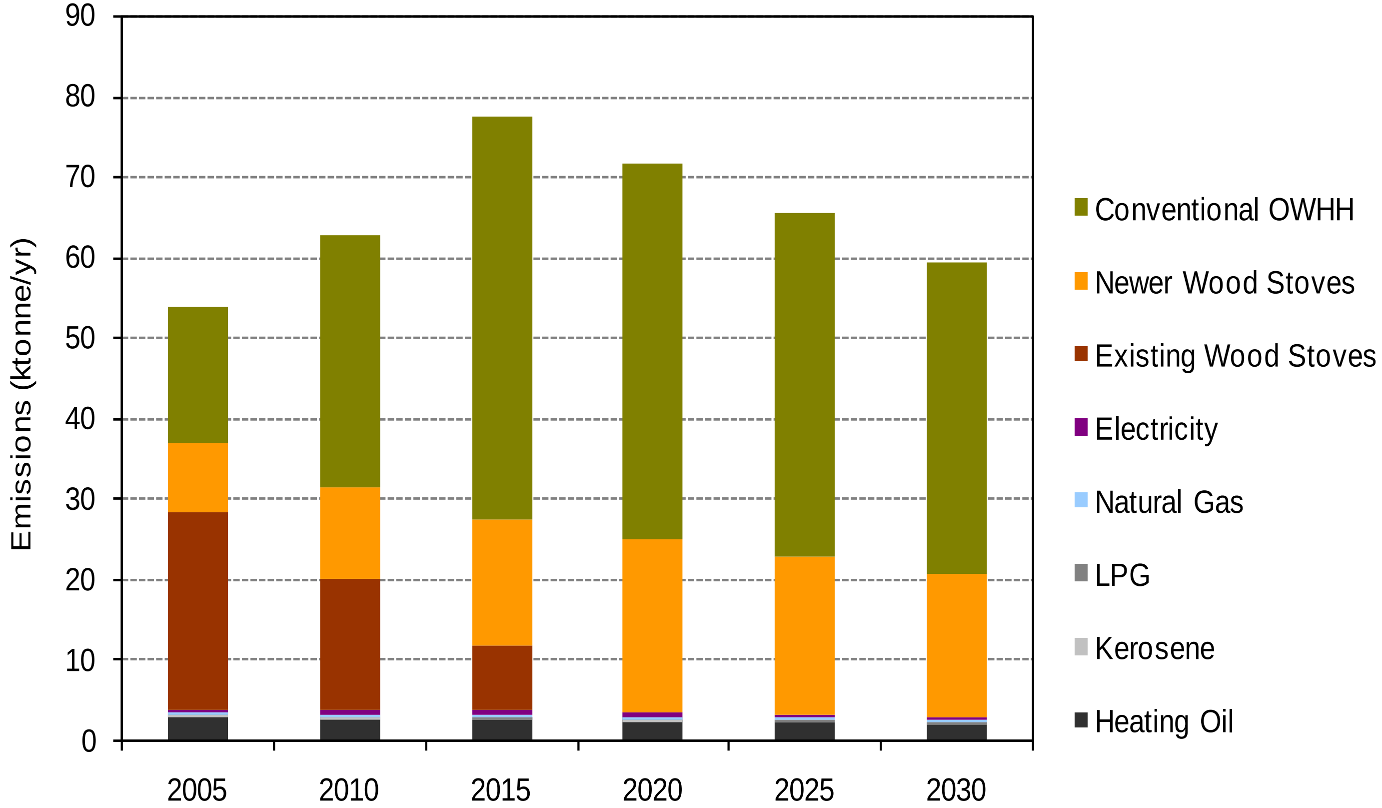
Fuel and technology-induced variations in Dioxin emissions.

Market for Residential Space Heating for "Baseline" Optimization Scenario



In the Mid-Atlantic region (including New York, New Jersey, and Pennsylvania), optimization based solely on costs and technology efficiency predicts that wood heat is likely to remain a relatively small market share of total residential space heating demands.

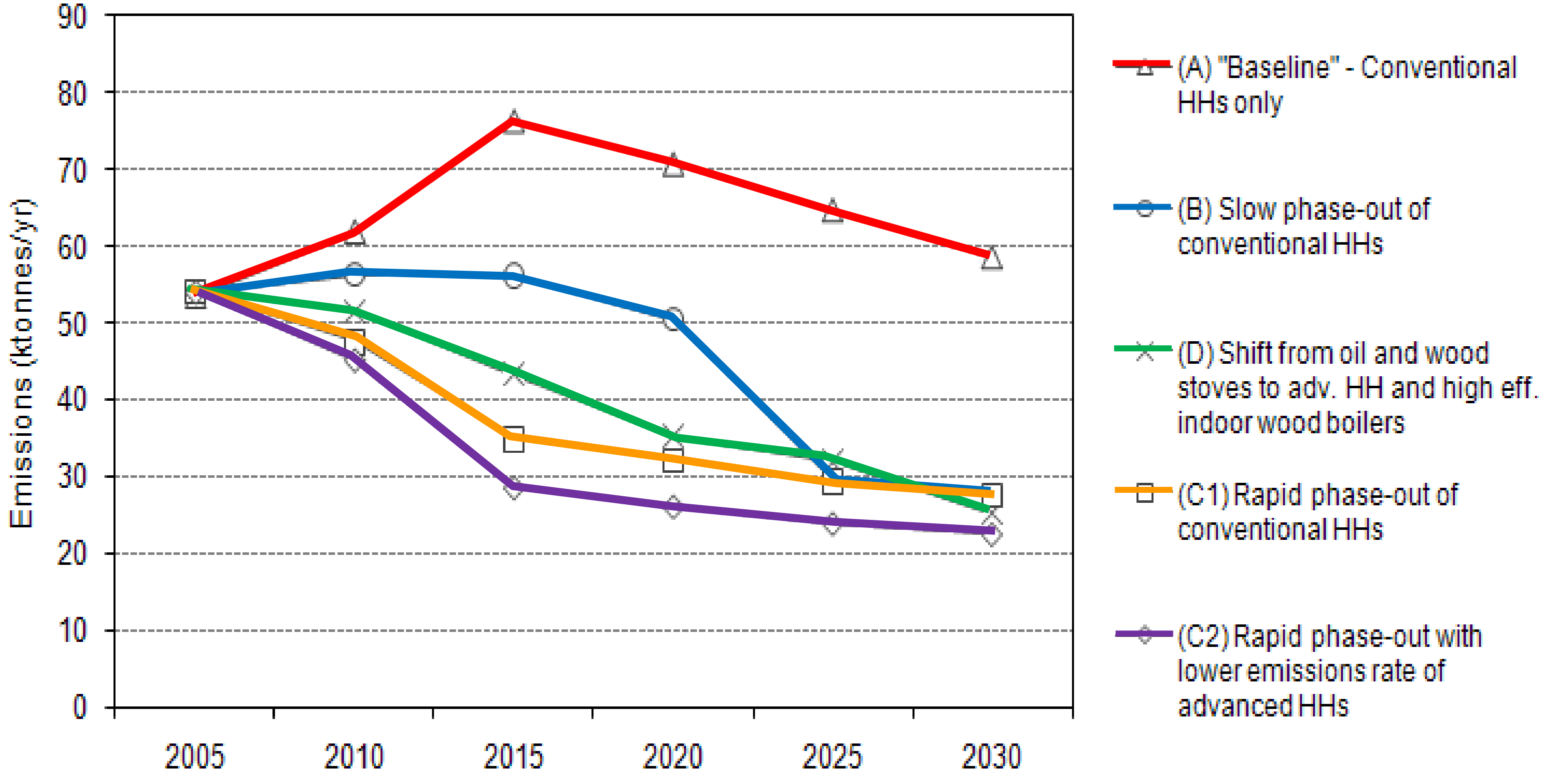
PM Emissions for Total Residential Energy Use for "Baseline" Optimization Scenario



In the scenarios analyzed, wood heat units had a limited impact on the broader market for residential fuels and electricity

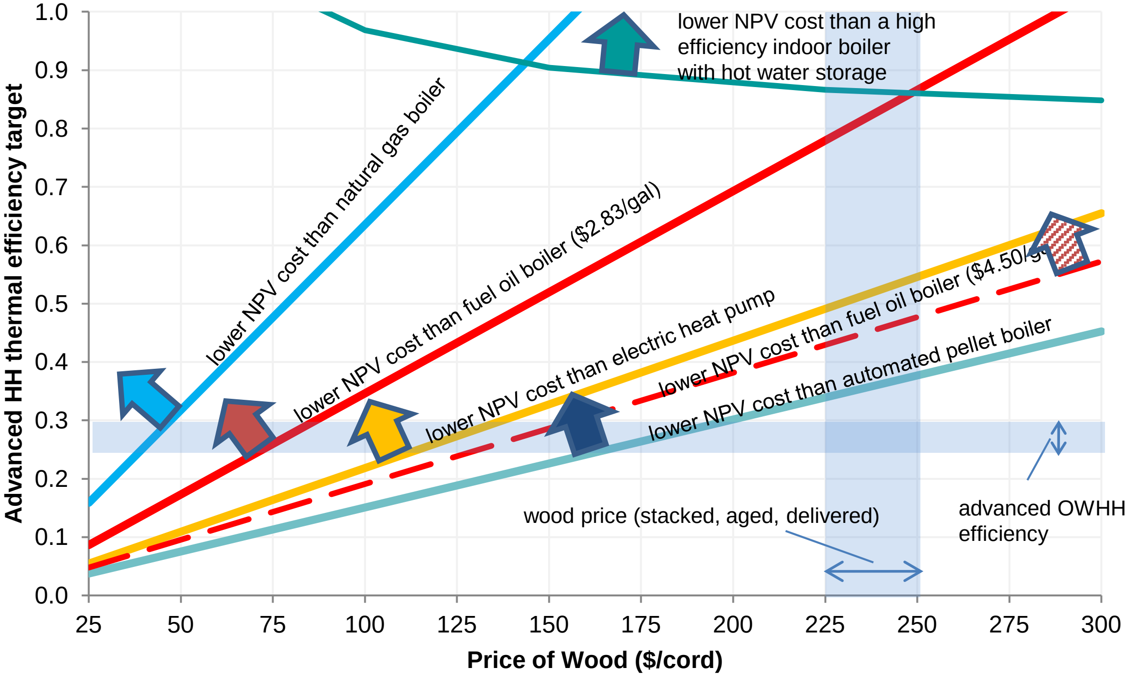
However, wood heat emissions dominated the total PM emissions from total residential energy usage over all scenarios

Total Residential PM Emissions "Baseline" and Four Alternative Scenarios



The evolution of the technology mix within the market for wood heat will have a major impact on both residential PM emissions and, consequently, total PM emissions. Depending on the rate of changeover from less efficient, higher emitting units and emissions performance of newer units, residential PM emissions could increase substantially, peaking in the next 5-10 years, or drop by nearly half.

Comparative Technology Costs



* At typical HH efficiencies and cord wood prices, an HH has a higher lifetime cost than competing technologies
* Fuel price and device efficiency are the primary components of heating costs, not the capital cost of equipment
* The low efficiency of HHs contributes to their high relative lifetime cost
* A free or very low cost wood supply can tilt the lifetime cost balance in favor of HHs
* Under these conditions, HHs are considerably more expensive than high efficiency indoor boilers with hot water storage, however

Emission Conclusions

- In general, over a 20-fold variation in emissions was observed between these four technologies.
- Thermal efficiencies (heat delivered/heat input) varied by 2-fold, depending on technology.
- Emissions are highly cyclic for the units that respond to heat demand with damper openings.
- For these same units, nuisance odor was significant despite use of the building's air cleaning system.
- The magnitude of emissions depend on the amount of time passage after charging the appliance with fuel rather than on the heat load.

Emission Conclusions

- White pine had the highest total PM and PAH mass emissions.
- The identified and quantified SVOCs account for 9% w/w of the PM emitted, of which ~25% was levoglucosan
- CH_4 is about 10% of the THC emissions.
- CO concentrations on the order of 1-8% were observed

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