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Speciated Volatile Organic Compound Emissions from Residential Biomass Combustion Appliances

International Emissions Inventory Conference – September 28, 2023

Nina Warren[1], Ingrid George[2], Angelina Brashear[3], Aranya Ahmed[1], Larry Virtaranta[2], Edgar Thompson[2], Peter Kariher[2], Joseph Martin[2], Michael Hays[2], Tiffany Yelverton[2], Amara Holder[2]

[1]National Student Services Contractor, Oak Ridge Associated Universities, Oak Ridge, TN. [2]U.S. EPA, Office of Research and Development, Center for Environmental Measurement and Modeling, Research Triangle Park, NC. [3]U.S. EPA, Office of Air Quality, Planning, and Standards, Air Quality Assessment Division, Research Triangle Park, NC

Overview / Agenda

1. Study Objectives
2. Experimental Design
3. Measurement Methods
4. Results
5. Summary

Study Objectives

- Quantify woodstove and pellet stove speciated particulate matter (PM), volatile organic compounds (VOCs), and semi-VOC (SVOCs) emissions.

- Test the variability of stove operation and fuel type to accurately characterize the emissions of harmful pollutants found in residential wood combustion (RWC).

- Generate accurate emissions data for incorporation into the EPA's SPECIATE database.

Speciate Database link: https://www.epa.gov/air-emissions-modeling/speciate

Overview of Office of Research and Development (ORD) Woodstove Facility

- ORD woodstove facility located in Research Triangle Park, NC
- Large hood, multistage dilution tunnel, and exhaust system
  - Measure in the flue, dilution tunnel, and a tertiary dilution manifold to meet requirements for multiple instruments
  - Platform scale measures mass loss to calculate burn rates
  - Continuous emission monitoring systems (CEMS) and Measurement capabilities:
    - CO_2, CO, CH_4, Total Hydrocarbons (THC), NO_x,
    - FTIR: NO_2, NH_3, C_2H_2, C_2H_4, C_2OH, C_2H_5OH, CH_2O_2, CH_3COOH (on some tests)
    - TO-15: VOCs
    - PM filters: mass concentration, elemental carbon, organic carbon, elements
    - Sorbent tube: volatility distribution
    - Black carbon, light scattering/absorption
    - Particle size distributions

Residential Wood Appliances

- The Blaze King (woodstove) was chosen based on previous studies that analyzed the most used residential wood burning appliances within the Fairbanks, Alaskan region.
- The England's Stove Works (pellet stove) was chosen due to availability within everyday hardware/appliance stores and manufacturers.

Tested: 2020-2021

Stove: Blaze King Princess Catalytic Stove

- Rated 37,587 – 40,836 Btu/hr
- Approximate burn rate of 2.42 g/hr
- 2.9 ft^3 fire box
- EPA 2020 certified

Tested: 2022

Stove: England's Stove Works 25-CBEP

- Rated 7,918 – 15,318 Btu/hr
  (2.32– 4.49 kW)
- Approximate burn rate of 3.7 lb/hr
  - (1.7 kg/hr)
- Hopper capacity of 45 lb
- EPA 2020 certified

Testing Parameters

Woodstove: 2020-2021

Fuel

Spruce and Birch

Sourced from an Alaskan firewood supplier

Moisture content approx. 15-20% wet basis

Replication

N=3

Test Method

Modified ASTM 3053

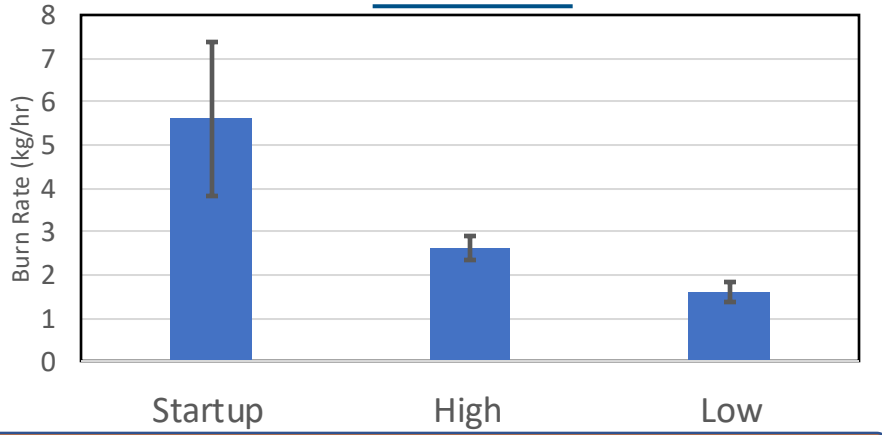
Test Phase Duration

Start Up: 18-30 minutes

High Fire: 200-289 minutes

Low Fire: 407-507 minutes

Burn Rate



Pellet-stove: 2022

Fuel

Hardwood low ash pellets

Sourced from American wood fibers (AWF)

Pellet Fuel Institute (PFI) certified

Replication

N=3

Test Method

ASTM E2779-10

Test Phase Duration

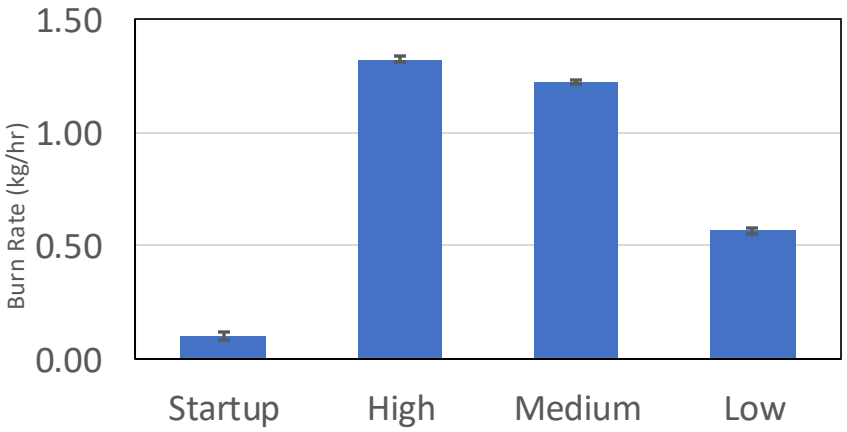
Start Up: 20 minutes

High Fire: 80 minutes

Mid Fire: 200 minutes

Low Fire: 380 minutes

Burn Rate



Sampling Methods

Measurements of various analytes were taken from different flow points.

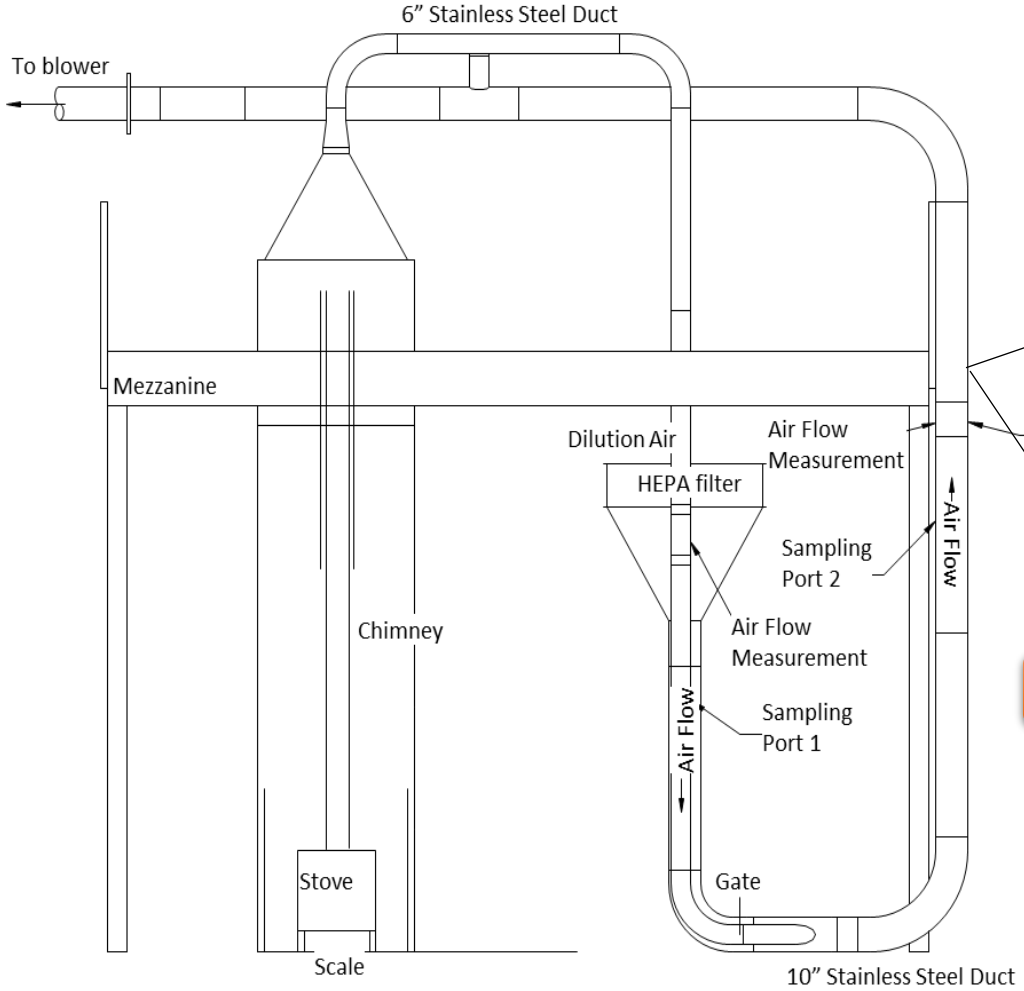


Diagram 1: Dilution Tunnel system RTP,NC

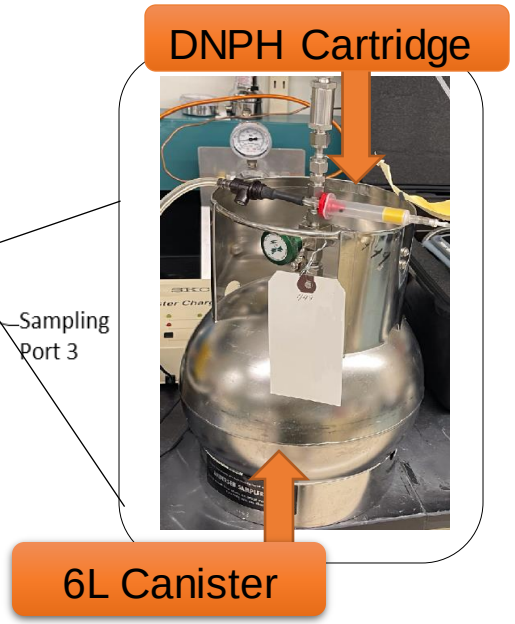
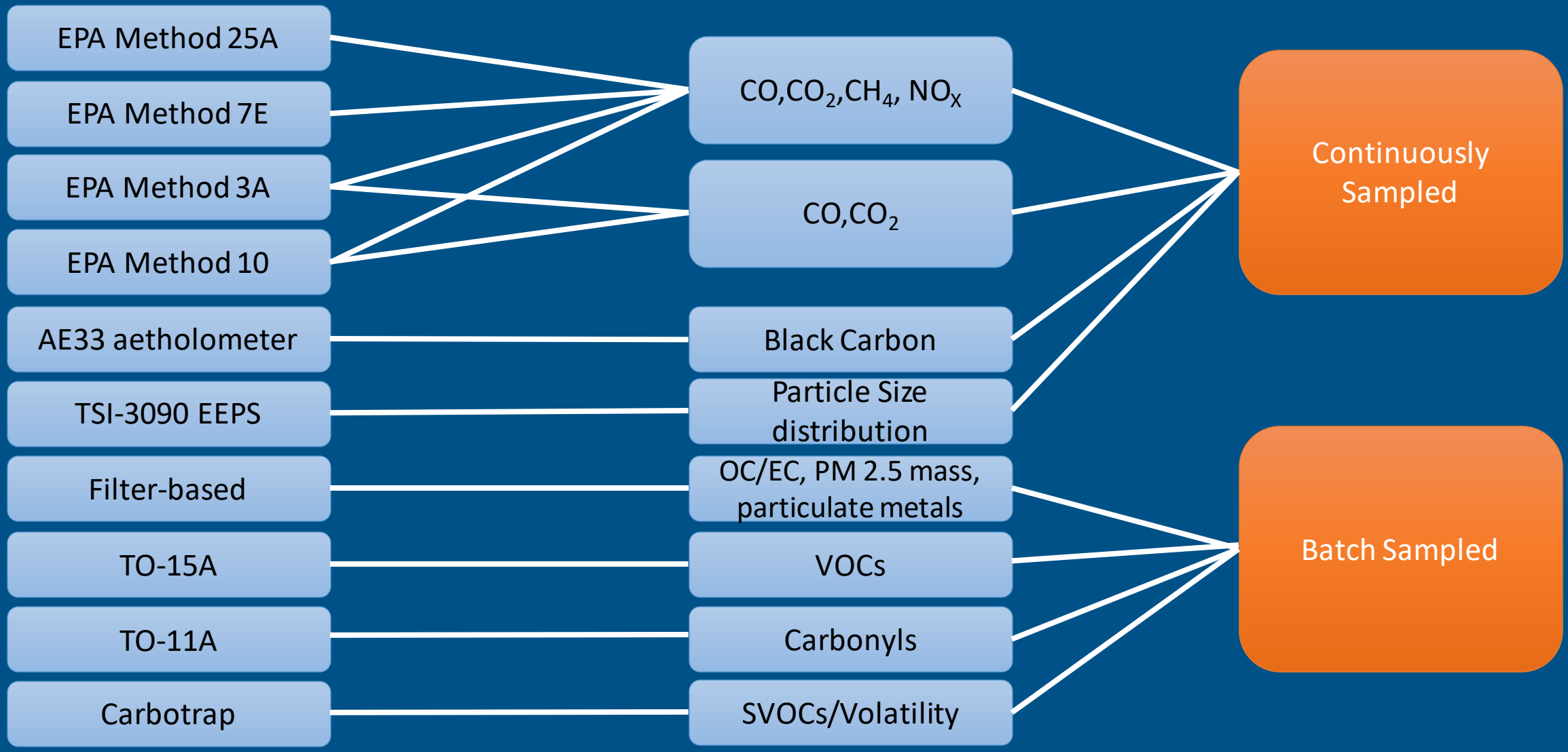


Diagram 2: Sampling methods for VOCs

- Chimney: CO, CO_2
- Sampling Port 2: PM concentration/composition
- Sampling Port 3: CO, CO_2, CH_4,NO_x, VOCs, Carbonyls Organic compound volatility
- Dilution Manifold from Port 3: Black Carbon, Particle size distribution, organic compound volatility

Sampling Methods



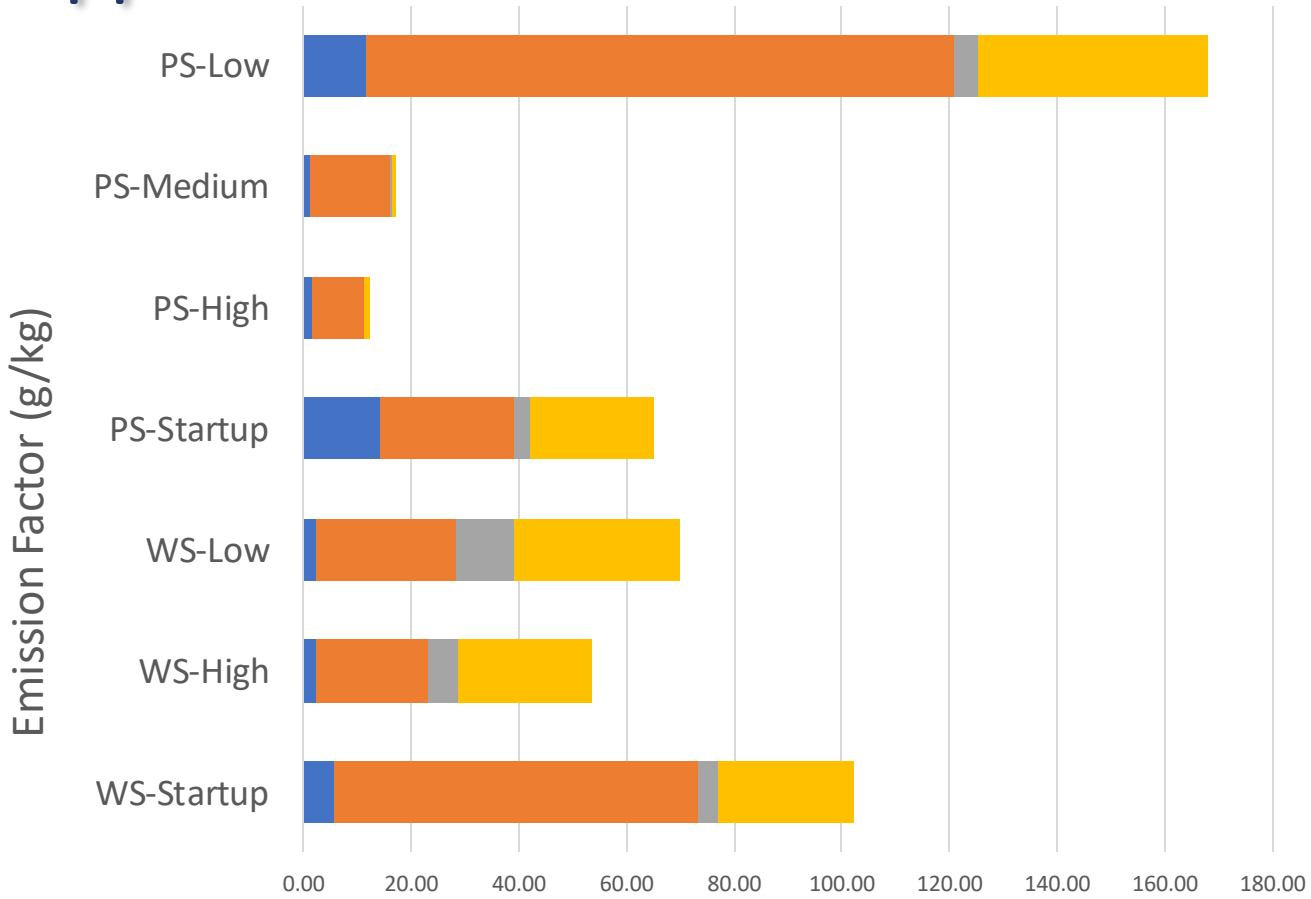
Speciation Results

This study generated a vast scope of data to characterize the emissions of RWC.

Focus of presentation:

Combustion Efficiency	Particulate Matter Speciation	Volatile Organic Compounds	SPECIATE
The comparison between CO and CO_2	Comparison between PM, OC, and EC	Comparison between VOCs and THC	Comparison between studies and fuel sources

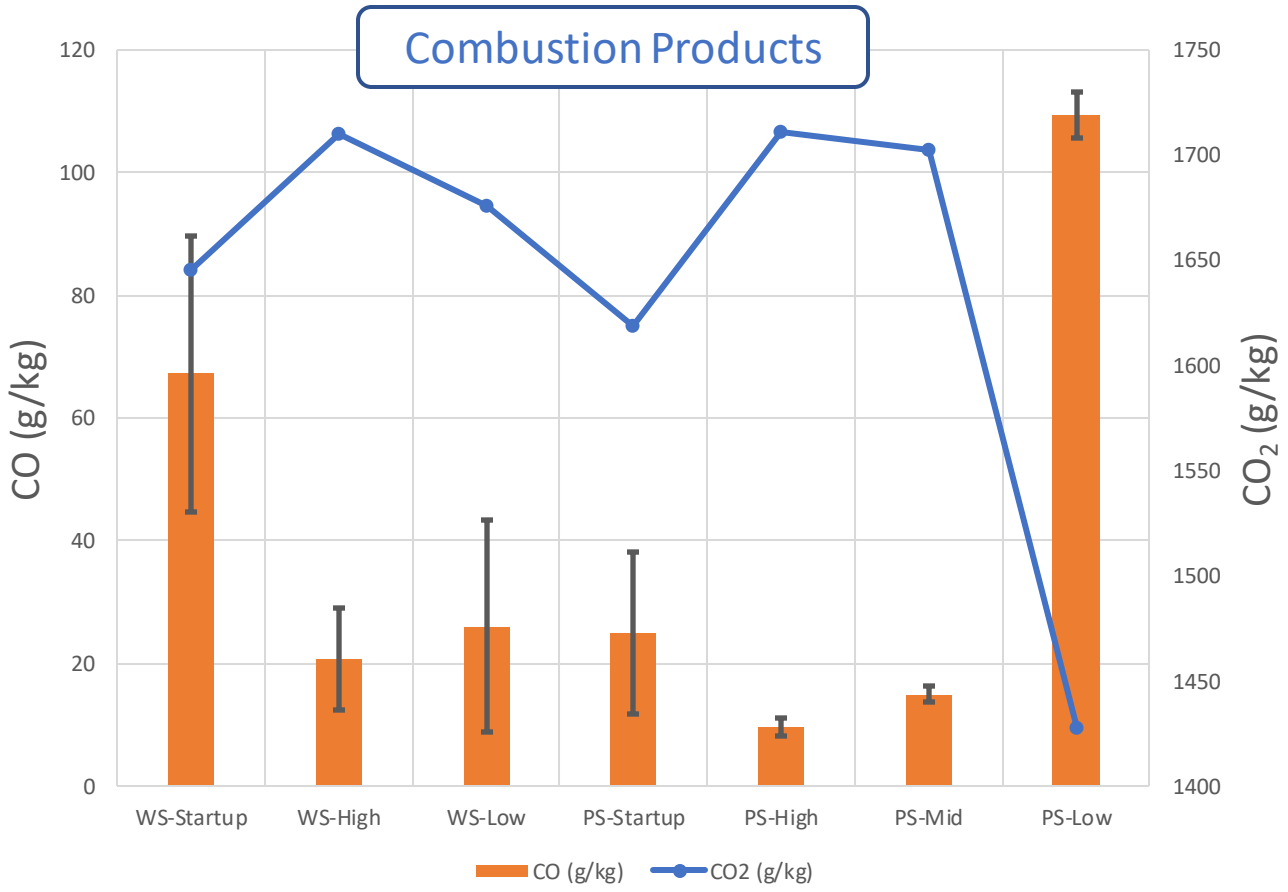
Gas and PM Emission Factors by Appliance and Phase



	WS-Startup	WS-High	WS-Low	PS-Startup	PS-High	PS-Medium	PS-Low
PM	5.76	2.32	2.16	14.20	1.61	1.18	11.47
CO 10"	67.34	20.70	26.06	25.01	9.59	15.03	109.41
CH4 10"	3.94	5.65	10.76	2.69	0.07	0.09	4.50
THC	25.38	24.81	30.90	23.13	1.01	1.00	42.66

- The start up and low fire phase produced the highest emissions of Carbon Monoxide.
- Emission factors were calculated using the carbon balance method and woodstove emissions were averaged across both fuels.

Combustion Efficiency



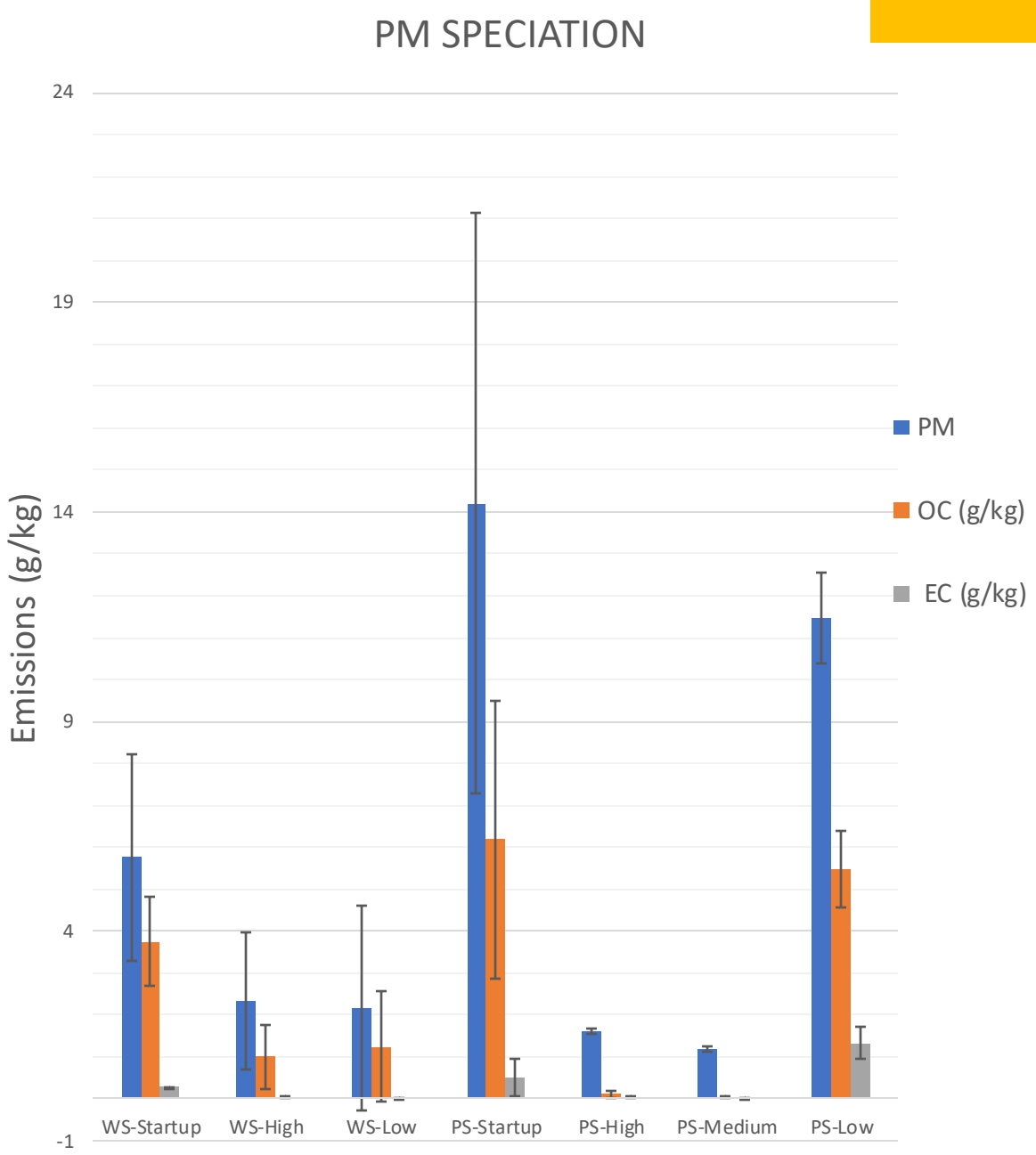
- The higher the CO_2 the more complete the combustion.
- High fire both in wood and pellet stoves as well as mid fire in pellet stove have more efficient combustion compared to the remainder of the phases.

Particulate Matter Emissions

- For both wood burning appliances, the Start Up phase contained the highest emission of PM species.
- The pellet stove emitted more PM compared to the catalytic wood burning stove.

Phase	PM (g/kg)	OC (g/kg)	EC (g/kg)
WS-Startup	5.76	3.75	0.29
WS-High	2.32	1.00	0.06
WS-Low	2.16	1.24	0.03
PS-Startup	14.20	6.19	0.52
PS-High	1.61	0.11	0.05
PS-Medium	1.18	0.04	0.03
PS-Low	11.47	5.49	1.33

Particulate Matter (PM), Organic Carbon (OC), Elemental Carbon (EC)

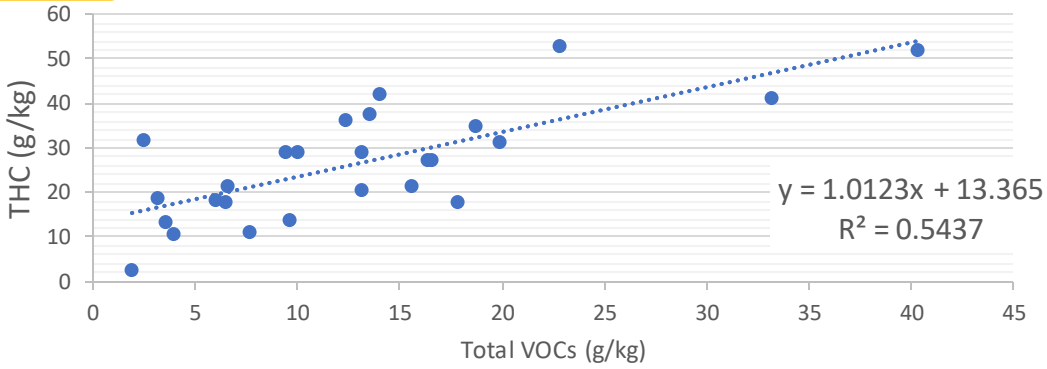


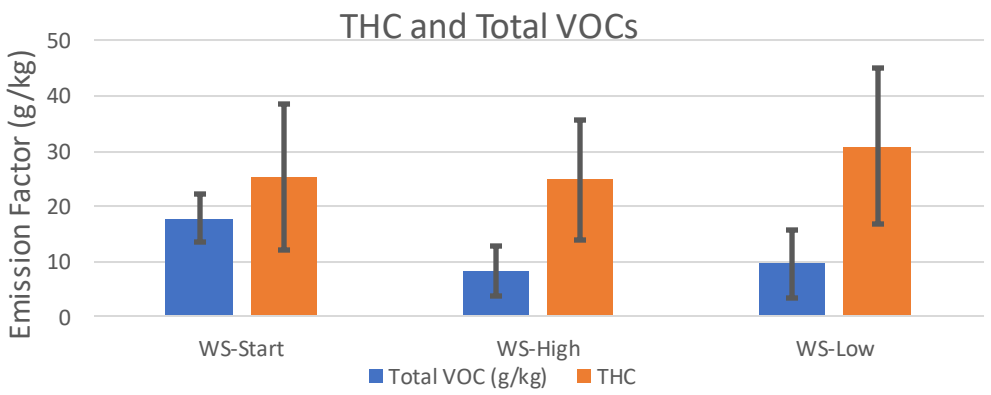
Comparison of Total VOCs with THC

The comparison between THC and Total VOCs (sum of measured speciated VOCs) allows correlation between methods used during sampling to account for accurate representation of a trend in the data.

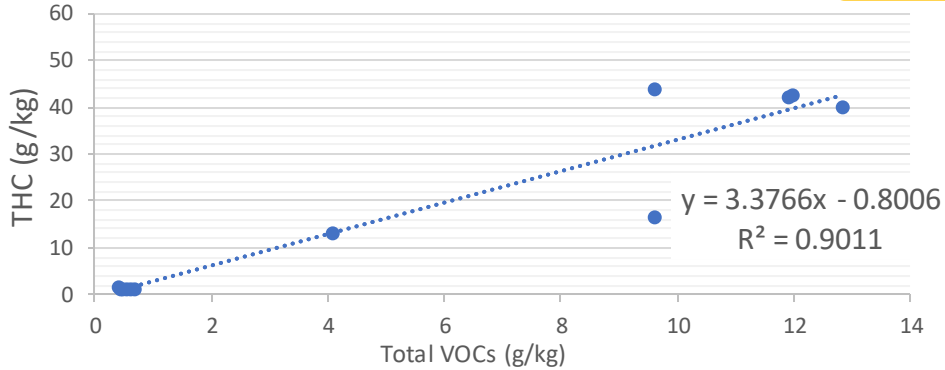
1. Woodstoves have a 1 to 1 ratio but a higher overall variance when compared.
2. Pellet stoves have a 1 to 3 ratio but a limited overall variance in comparison to one another as well as when compared with woodstoves.

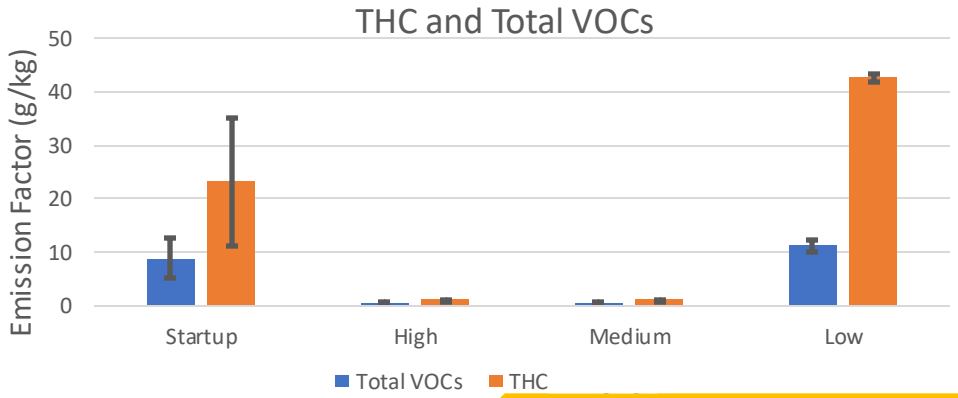
Woodstove





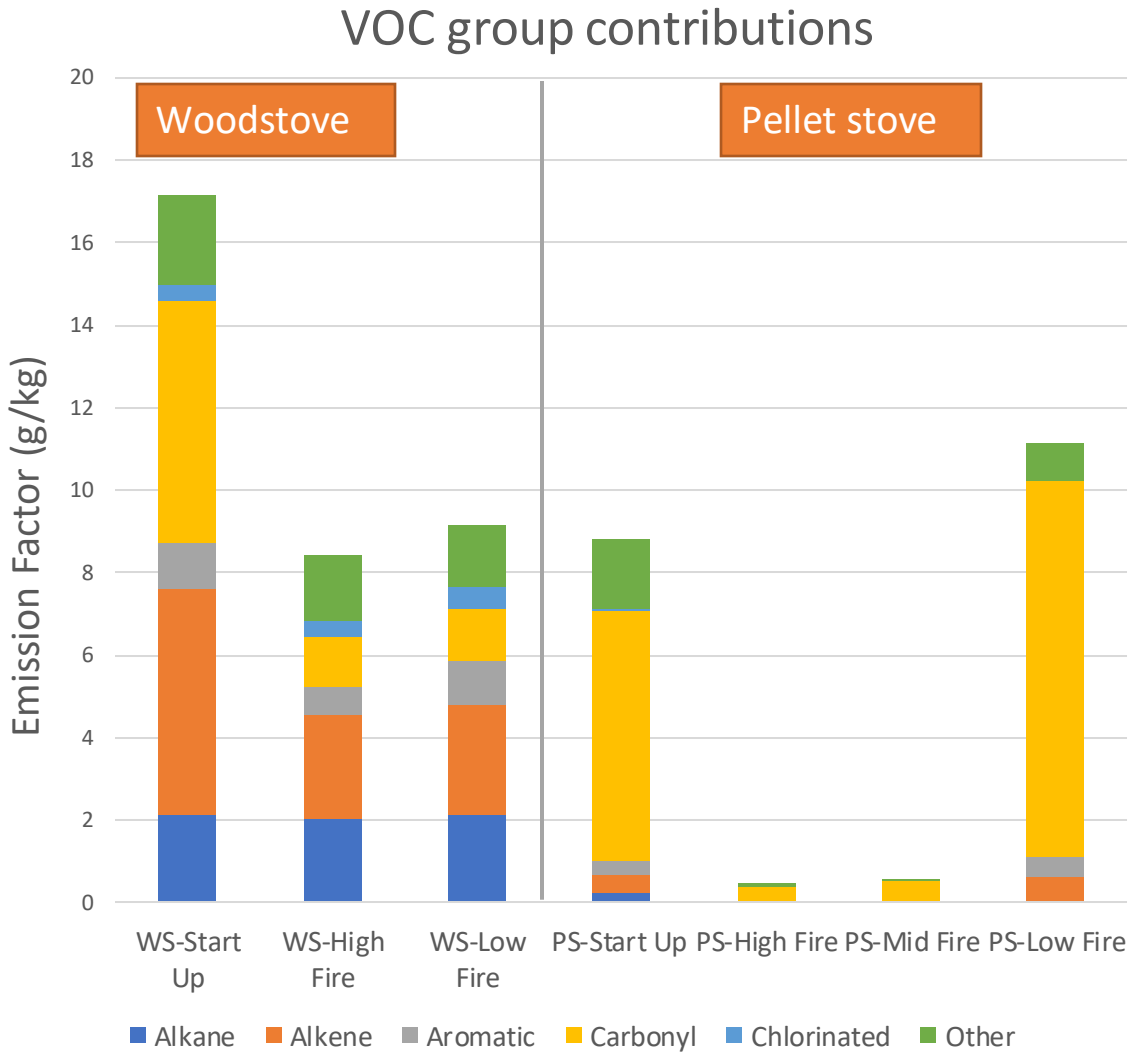
Pellet stove





VOC Emissions by Chemical Group

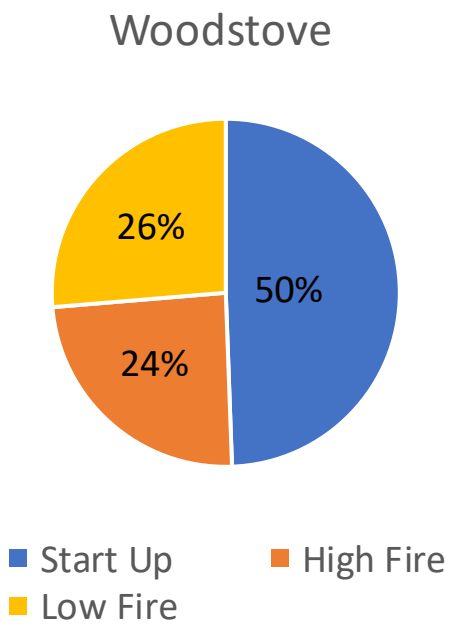
- Carbonyls made up the largest fraction of the total VOC emissions for all four phases of the pellet stove tests and for the woodstove start up phase.
- The woodstove emitted a relatively higher fraction of alkenes to total VOCs across its three phases as compared to pellet stove emissions.
- The highest total VOC emissions produced were observed in the start up and low fire phase for both appliances.

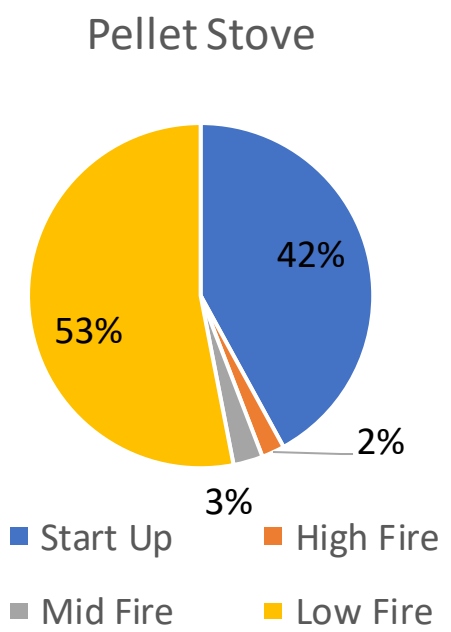


VOC Emissions by Phase

Each burn phase was used to model consumer utilization of wood and pellet burning appliances.

The Start Up phase produced the highest VOC emissions when comparing by phase.



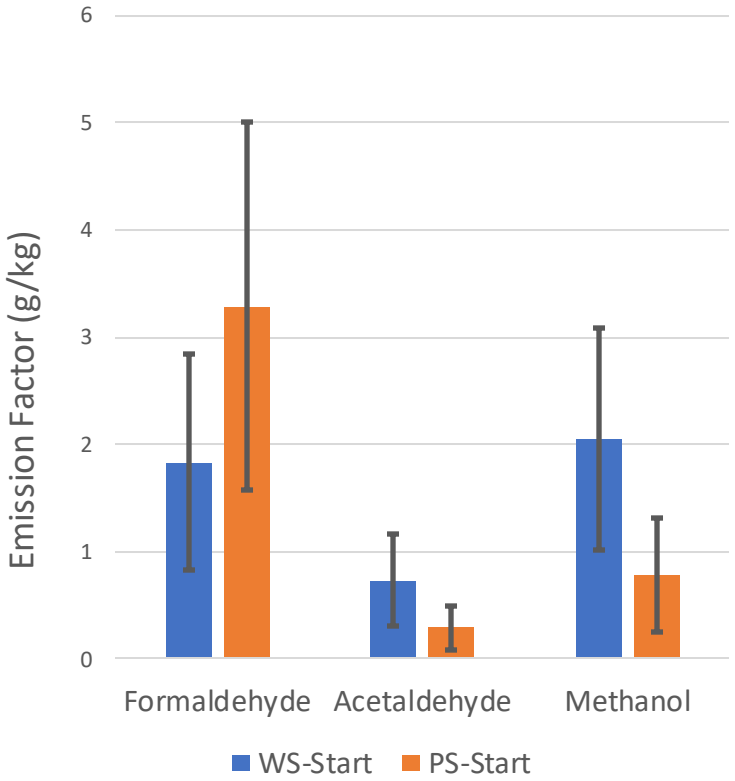


The low Fire phase of the pellet stove study contained the highest emissions of VOCs.

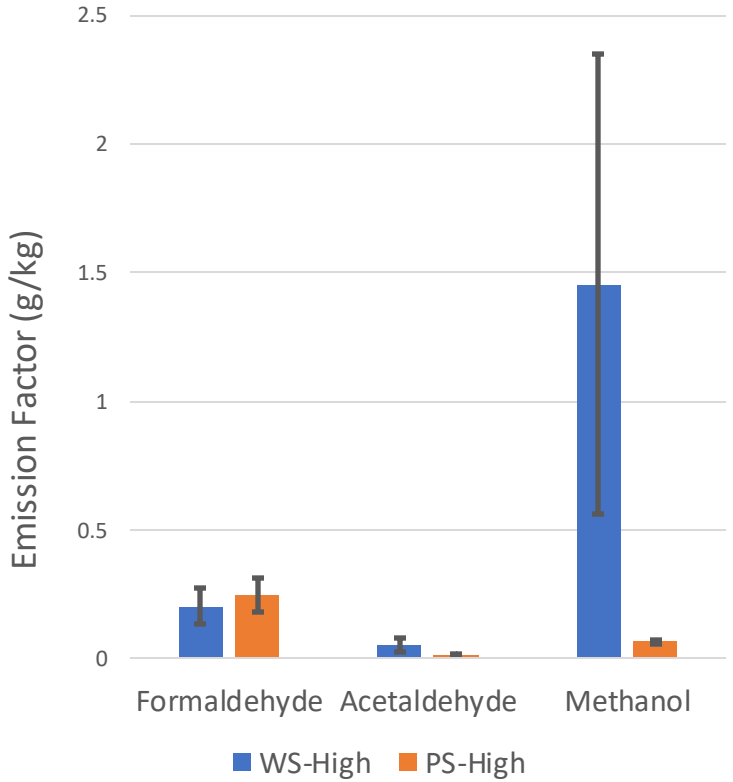
Select HAP Emissions by Appliance

The three compounds that contributed the largest fraction of the total VOCs emitted in both wood and pellet stoves are: Formaldehyde, Acetaldehyde, and Methanol.

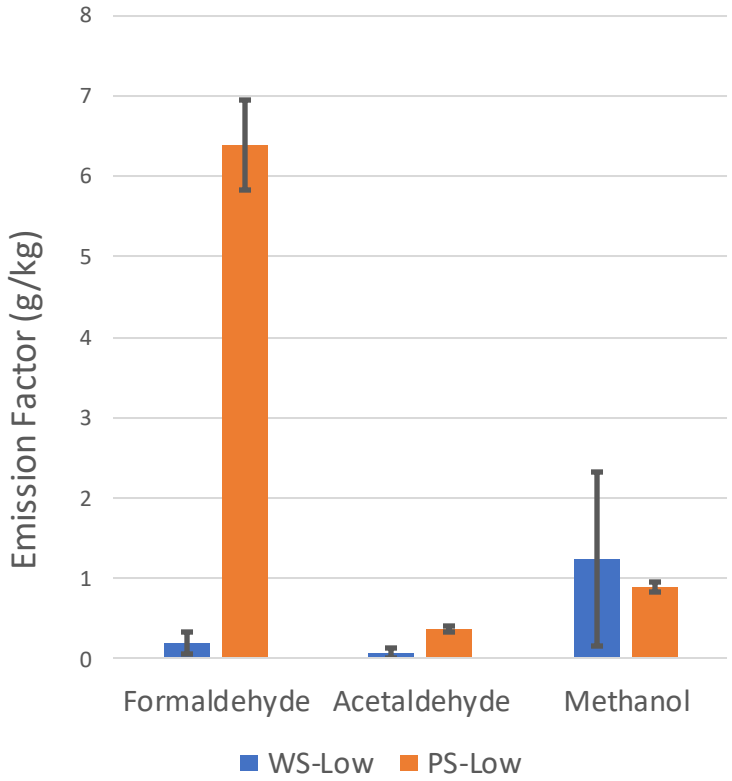
Start Up



High Fire



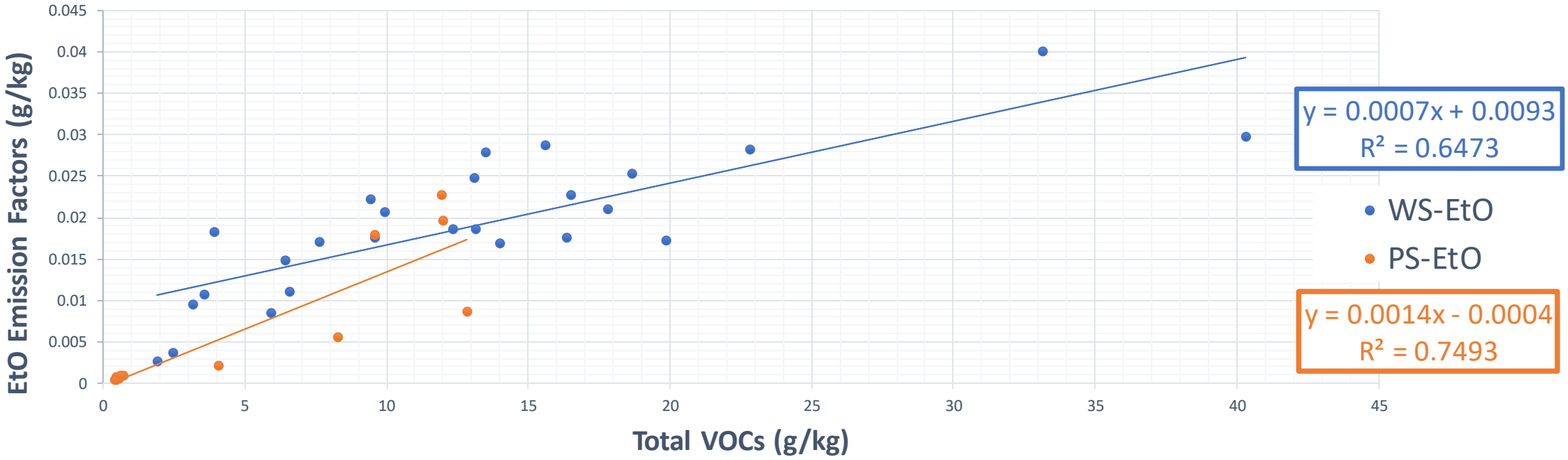
Low Fire



Ethylene Oxide (EtO) Emissions

- Samples were collected into canisters for analysis using EPA's TO-15A to investigate the method's ability to quantify EtO emissions.
- EtO correlates reasonably well with total VOC concentrations measured in canister samples (i.e., $R^2 > 0.6$).

Note: Each point is an individual test

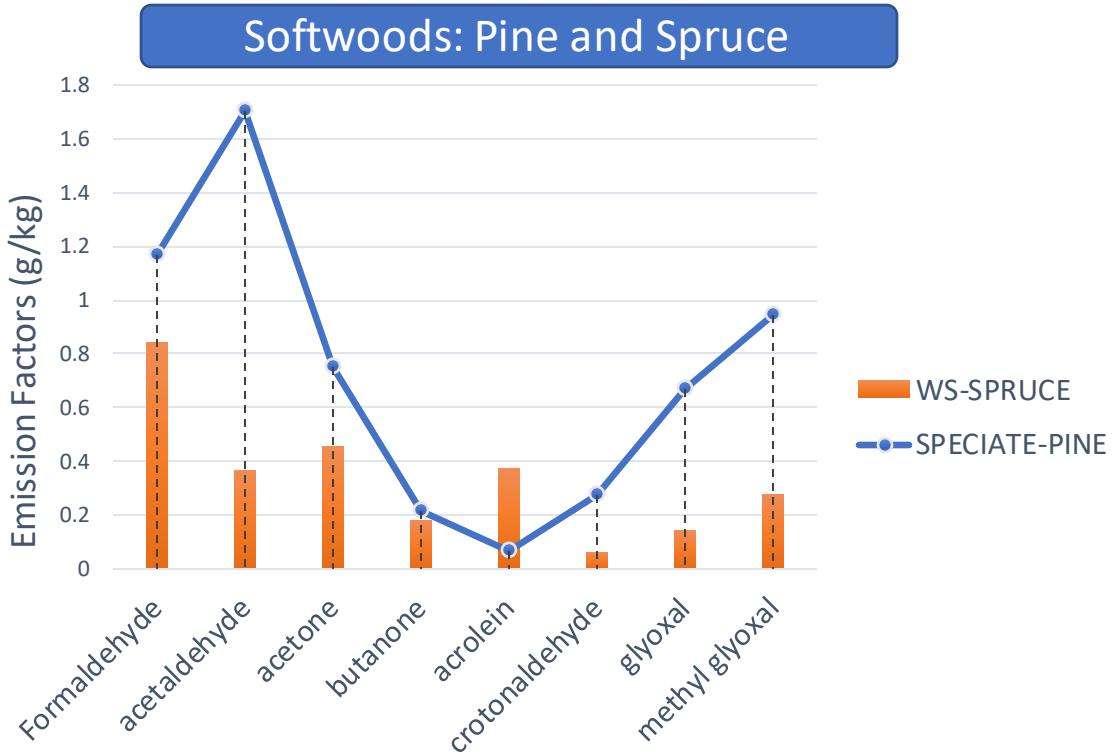


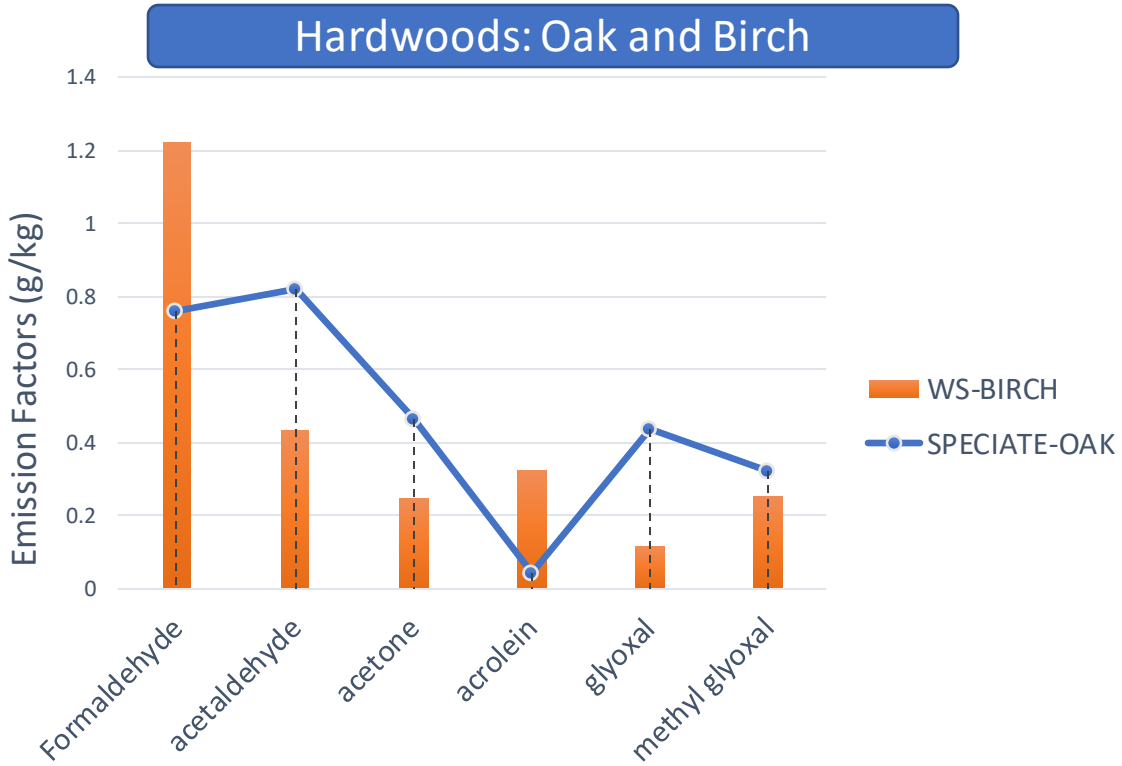
*Note: Further discussion of EtO measurements will be discussed during the 2023 AWMA Measurements conference.

SPECIATE

A key element of the study was to obtain speciated VOC emission factor data to update profile 4642 in the SPECIATE 5.2 database.

Emission Factors were averaged across the phases for each woodstove fuel type (spruce and birch) and common compounds were compared to the current SPECIATE profile.





Summary

This preliminary study quantified the emissions of various speciated compounds such as PM and VOCs that will be utilized in updating the SPECIATE database.

It was concluded that the differences in stove operation (i.e., phases and appliance type) had an impact on the quantity and composition of hazardous air pollutants emitted during residential wood combustion.

Emission factors for specific VOCs produced in this study agreed well with the current woodstove SPECIATE emissions data.

Future work will include additional RWC emissions testing to characterize HAPs and to better quantify EtO in other types of wood burning stoves (e.g., barrel stoves).

Disclaimer

Disclaimer: Although this presentation was reviewed by EPA and approved for presentation, it may not necessarily reflect official Agency policy.

Thanks!☺

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