Measurement of Space-Heating Emissions

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1. Introduction

OMNI-Test Laboratories, Inc. (OMNI) was contracted by Fairbanks North Star Borough (FNSB) to measure specific emissions from home heating appliances believed to be contributing to elevated levels of particulate matter smaller than 2.5 microns ($PM_{2.5}$). The objective of the study was to determine real-world emissions produced by devices commonly used in the borough's $PM_{2.5}$ nonattainment area, to use such data to develop source profiles and emission factors which can be used to model air quality within the nonattainment area, to evaluate possible $PM_{2.5}$ mitigation programs for emissions benefits, and to improve overall knowledge about local sources and source apportionment. To that end, nine heating appliances were selected and operated in a normal fashion during testing. This included: (1) tests with both hardwood and softwood cordwood, (2) tests with coal of varying moisture content, (3) tests with heating oils of differing composition, and (4) tests with both higher and lower burn rates. To provide insight into the possible range of emissions produced in the nonattainment area, a variety of appliances, with and without U.S. EPA certification and utilizing different fuels, were selected for the study.

All fuel samples were provided by FNSB and received in good condition. Testing was conducted at OMNI's facilities in Portland, Oregon by Mike Eisele, Lyrik Pitzman, Sebastian Button, Jeremy Clark, and Aaron Kravitz between March 8 and August 18, 2011.

Emissions of total particles (PM), particles with aerodynamic diameters of less than 2.5 microns ($PM_{2.5}$), nitrogen oxides (NO_x), carbon monoxide (CO), total volatile organic compounds (VOC), sulfur dioxide (SO_2), and ammonia (NH_3) were measured. In addition carbon dioxide (CO2), oxygen (O2), temperatures (chimney, room, meter boxes, particulate filters and dilution tunnel), fuel mass, and air and sample flow were measured to support the emission calculations. Moisture, elemental composition, and energy content were also measured for each fuel type. Standard methods were used to the extent feasible for all testing.

A detailed description of the testing program is provided as Section 2. The results of the testing are provided and discussed in Section 3. A summary is provided as Section 4. Real time graphs and analytical laboratory reports are provided as appendices.

2. Testing Program

2.1 Measurements

Measurements deemed appropriate for this study were selected based on consultations between OMNI and Fairbanks North Star Borough staff. Standard sampling methods were used to collect and monitor all parameters. Table 1 lists the methods used and the pollutants measured. Air emission samples were collected from a dilution tunnel. Supporting measurements were made in the heater chimney (stack) and in the surrounding laboratory. Selected background samples were collected from laboratory air. The pollutants measured included:

- Total particulate matter (PM) measured from the dilution tunnel
- Particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) measured from the dilution tunnel
- Nitrogen oxides (NO_x, reported as NO_2) measured from the dilution tunnel
- Carbon monoxide (CO) measured from the dilution tunnel
- Carbon monoxide (CO) measured from the stack
- Oxygen (O2) measured from the stack
- Carbon dioxide (CO_2) measured from the stack
- Sulfur dioxide (SO2) measured from the dilution tunnel
- Ammonia (NH_3) measured from the dilution tunnel
- Total volatile organic compounds (VOC) measured from the dilution tunnel. The total VOC emission factor was collected with a real-time gas analyzer incorporating a flame ionization detector (FID). This value includes methane and most non-methane VOCs, reported as carbon.

Table 1. Compounds, Parameters, Sampling and Monitoring Methods, Collection and Monitoring Devices, Analytical Laboratories, and Analytical Methods

Group	Analytical Compounds	Sampling Method	Collection Device	Analytical Laboratory	Analytical Method*
Particles	Particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$)	EPA Other Test Method 27 (In accordance with EPA proposed changes to method 201A)	47 mm Glass Fibre A/E Filter, Teflon coated glass A/E	Research Triangle Institute	Determined by RTI
Gases	Nitrogen Oxides (NO_x)	EPA Method 7E	Chemiluminescent gas analyzer	N/A	N/A
	Carbon Monoxide (CO)	EPA Method 10	Gas filter correlation analyzer	N/A	N/A
	Oxygen (O_2)	EPA Method 3A	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Carbon Dioxide(CO_2)	EPA Method 3A	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Sulfur Dioxide (SO_2)	EPA Method 6	Pulsed florescence UV analyzer	N/A	N/A
	Ammonia (NH_3)	EPA Conditional Test Method 27	Sulfuric acid-filled impinger series	Columbia Analytical Services, Inc.	EPA Method 350.1
	Total Volatile Organic Compounds (VOC's)	EPA Method 25A	Total hydrocarbon analyzer with flame ionizing detector (FID)	N/A	N/A
Efficiency	Flue Gas CO, CO_2, O_2	CSA B415.1-10	Non-dispersive infrared analyzer (NDIR)	N/A	N/A

*See appropriate laboratory reports in the appendices for modifications to analytical method

2.2 Standardized Methods

ASTM E 2515-07 further specifies the determination of TPM emissions collected in a dilution tunnel and includes specifications concerning the flow rate of the sampling equipment, the construction and proper operation of the dilution tunnel, and calculations for determining the total particulate emissions during a test.

EPA Method 201A pertains to the equipment, preparation, and analysis necessary to measure filterable particulate matter emissions equal to or less than 2.5 micrometers ($PM_{2.5}$).

EPA Method 28 pertains to the certification and auditing of wood heaters. This method prescribes the fueling protocol, conditions, and procedures for determining the particulate emissions and burn rate of a burn event.

EPA Method 28 OWHH concerns the measurement of particulate emissions and heating efficiency of wood-fired hydronic heating devices. The method provides specifications for fueling, test facility conditions, and procedures for determining heat output rates and particulate emission rates, and for reducing data.

EPA Method 25A is used in the determination of the total gaseous organic concentration of vapors (i.e., VOCs) which are primarily composed of arenes, alkanes and/or alkenes. This method contains specifications for the type of analyzer to be used, the temperature of the heated sample line carrying gases from the source to the analyzer, the proper location for sampling, the appropriate concentrations for calibration gases, and calculations for determining the average organic concentration in terms of ppm_v as propane.

EPA Method 7E specifies the determination of the concentrations of nitrogen oxides emitted from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of NO_x.

EPA Method 10 is likewise used in the determination of the concentration of carbon monoxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of CO.

EPA Method 3A is concerned with the determination of oxygen and carbon dioxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentrations of O_2 and CO_2.

EPA Method 6 prescribes the measurement of sulfur dioxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of SO_2.

EPA Conditional Test Method 27 (CTM-027) addresses the collection of ammonia samples and, in conjunction with EPA Method 17, dictates the assembly and operation of the sample train and metering system as well as procedures for sample recovery.

CSA B415.1-10 specifies requirements for performance testing of solid-fuel-burning heating appliances, including appliance efficiencies via the stack-loss method.

2.3 Sampling Notes

2.3.1 Particulate Sampling

Particulate sampling was carried out in accordance with applicable portions of EPA method 201A. The particulate sampling system relied on a cyclone head attachment on the sample probe in order to sample only particulate smaller than 2.5 microns in diameter ($PM_{2.5}$). The cyclone head was placed in the dilution tunnel and the sample flow was split into 5 branches, each with a filter. The flow rate in each branch was individually controlled. One filter was composed of Teflon, three were quartz, and one was glass fiber. The Teflon filter and one quartz filter were sent to RTI for analysis, one quartz filter was sent to the University of Montana for analysis, and the final quartz filter was retained for OMNI's archive.

The glass fiber filter was used purely for bypass flow. In order to effectively separate particulate matter, a cyclone must be operated within a range of flow rates governed by sample temperature. The Teflon and quartz filters were set to their optimum sample rate and the flow through the glass filter was adjusted to achieve the proper cumulative sample flow.

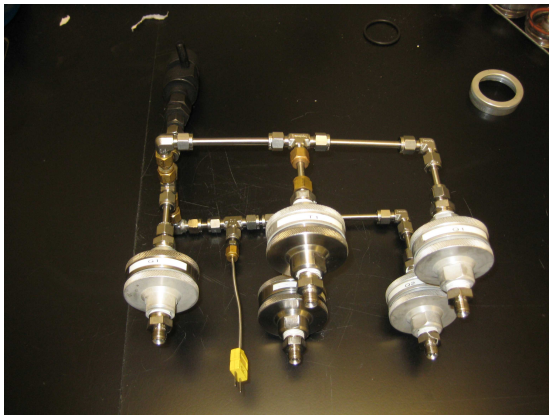


Figure 1. Cyclone and Filter Assembly

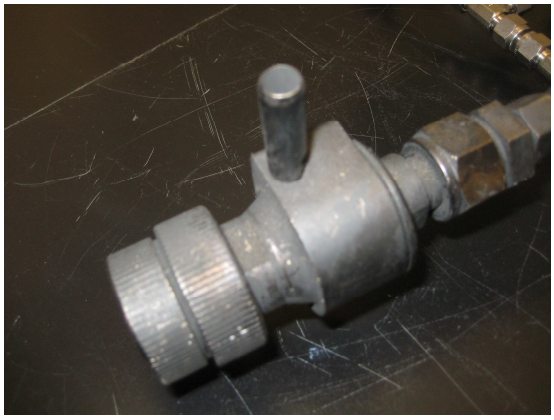


Figure 2. Cyclone Head Detail

2.3.2 Ammonia Sampling

Ammonia sampling was carried out in accordance with EPA CTM 27. The sampling system employed a glass impinger train behind a heated glass fiber particulate filter. The sample was collected in the first two impingers, which were each filled with 100 mL of 0.1 molar sulfuric acid prior to every test run. The sample rate was kept constant and proportional to the dilution tunnel flow throughout testing. Sample recovery was carried out by draining the impingers and rinsing with deionized water. The rinse water was then added to the sample, diluting each impinger's 100 mL to 250 mL.

Figure 3. Ammonia Sampling Probe and Impinger Train

2.3.3 Gas Sampling

Gas sampling system was divided into two trains: one used to measure CO, SO_2, NO, NO_2, and NO_x, and one dedicated solely to VOCs. Each train consisted of a ¼-inch stainless steel probe and a stainless steel 2-micron pore size in-line filter attached to a sample line heated to 215 °F to prevent gas condensation. Air samples for $CO/SO_2/NO_x$ analysis were pumped through a sample conditioner capable of removing water vapor without removing water soluble fractions from the gas sample, resulting in a dry gas sample which has the same composition on a dry basis before and after passing through the conditioner. The dried air was then conveyed to the respective analyzers at pressures dictated by their nominal operating conditions. The VOC analyzer, being an FID detector, required neither an external pump nor a cool, dry gas sample.

The in-line sample filters were replaced as needed, indicated by a drop in sample flow rate to the analyzers.

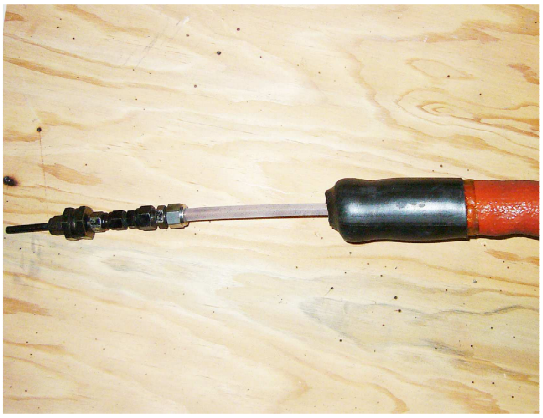


Figure 4. Probe, In-Line Filter, Heated Sample Line

Figure 5. In-Line Filter Detail

2.4 Operation and Run Notes

Testing adhered as closely as possible to the procedures found in standard EPA methods but for many of the units tested portions of those procedures were not applicable. Therefore, in many instances customized procedures were developed in order to generate repeatable, comparable results while still adhering to the intent of the methods. Table 2 presents a summary of all test runs. A unit-by-unit summary of the testing follows; it covers the operation procedures and deviations from the sample methods used for each run.

Table 2. Summary of Test Runs

Run	Appliance	Fuel Type	Burn Rate	Hot/Cold Start
1	Pellet Stove	Pellets	Single	Hot
2	EPA Certified Wood Stove	Birch Cordwood	High	Hot
3	EPA Certified Wood Stove	Spruce Cordwood	High	Hot
5	EPA Certified Wood Stove	Birch Cordwood	Low	Hot
6	EPA Certified Wood Stove	Spruce Cordwood	Low	Hot
8	EPA Phase II OWHH	Birch Cordwood	High	Hot
9	EPA Phase II OWHH	Birch Cordwood	Low	Hot
10	EPA Phase II OWHH	Spruce Cordwood	High	Hot
11	EPA Phase II OWHH	Spruce Cordwood	Low	Hot
12	Conventional Wood Stove	Spruce Cordwood	High	Hot
13	Conventional Wood Stove	Birch Cordwood	High	Hot
14	Conventional Wood Stove	Spruce Cordwood	Low	Hot
15	Conventional Wood Stove	Birch Cordwood	Low	Hot
17	Oil Furnace	No. 2 Heating Oil	Single	Hot
18	Waste Oil Furnace	Waste Oil	Single	Hot
20	Coal Stove	Dry Stoker Coal	High	Hot
21	Coal Stove	Dry Stoker Coal	Low	Hot
23	Coal Stove	Wet Stoker Coal	Low	Hot
25	Non-Qualified OWHH	Spruce Cordwood	High	Hot
26	Non-Qualified OWHH	Wet Stoker Coal	Single	Hot
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Cold
28	Auger-Fed Coal HH	Wet Stoker Coal	Single	Cold
29	Auger-Fed Coal HH	Wet Stoker Coal	Single	Hot
30	Non-Qualified OWHH	Spruce Cordwood	Low	Hot
31	Non-Qualified OWHH	Birch Cordwood	High	Hot
32	Non-Qualified OWHH	Birch Cordwood	Low	Hot
33	Non-Qualified OWHH	Birch Cordwood	Low	Cold
34	EPA Phase II OWHH, Catalyst	Birch Cordwood	Low	Hot
35	Coal Stove	Wet Stoker Coal	High	Hot
36	Coal Stove	Wet Lump Coal	Low	Cold
37	Coal Stove	Wet Lump Coal	Low	Hot
38	Coal Stove	Dry Lump Coal	Low	Hot
39	Coal Stove	Wet Stoker Coal	Low	Cold
40	Oil Furnace	No. 1 Heating Oil	Single	Hot
41	EPA Certified Wood Stove	Birch Cordwood	Low	Cold

2.4.1 Pellet Stove

Operation of the pellet stove was carried out in accordance with EPA Method 28. A single run was completed, and no deviations from either Method 28 or any of the proscribed sampling methods were necessary.

Table 3. Pellet Stove Burn Characteristics

Fuel	Run	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Alaskan Pellets	1	6.60	120	2.23	10.5

2.4.2 EPA Certified Wood Stove

EPA Method 28 was used in the testing of the EPA Certified stove. The only deviation occurred in the fuel loads which, while of appropriate weight and length, were not dimensional Douglas fir but rather spruce and birch cordwood, as specified in the proposal. A summary of the fuel and burn rate can be found in Table 3. Otherwise, the firing procedures (e.g. preburn length, data collected) adhered to the method. Sampling, likewise, adhered to the methods and procedures specified in Section 2.3.

Table 4. EPA Certified Wood Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	3	High	23.75	90	4.27	16.4
Spruce	6	Low	17.90	210	1.77	16.1
Birch	2	High	17.83	110	3.76	16.6
Birch	5	Low	16.70	250	1.50	15.9
Birch	41	Low, Cold Start	17.30	288	3.13	6.0 Kindling, 16.5 Preburn, 16.4 Test

2.4.3 EPA Phase II Qualified Outdoor Wood-Fired Hydronic Heater

As with the EPA stove, an applicable method was in place for operation of the Phase II outdoor wood-fired hydronic heater (OWHH). Again, this method was followed with the exception of the fuel requirements- the Alaskan fuels were used instead of the specified oak lumber.

In addition to the four high/low runs with birch and spruce, a fifth test was performed with a retrofit catalyst device, which consists of a catalyst and heating element, put on the exhaust gas stack while performing a low burn setting test with birch.

Table 5. EPA Phase II OWHH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	10	High	20.78	237	13.31	140.0
Spruce	11	Low	20.32	582	5.48	141.0
Birch	8	High	18.11	243	13.29	140.2
Birch	9	Low	16.40	620	5.29	140.2
Birch	34	Low, with retrofit catalyst	27.90	534	4.98	125.0

2.4.4 Conventional Wood Stove

EPA Method 28 was applicable for the operation of the conventional wood stove tested. Testing was conducted in much the same fashion as with the EPA certified unit, however, controlling the burn rate was problematic. Despite performing high burns at the highest air setting, and low burns at the lowest air setting, very little difference in burn rate was observed. This is likely due to the age of the stove – over time many air leaks developed in the firebox, resulting in uncontrolled air supply to the fire. However, as any non-certified unit still in use in the field would be at least as old as the tested unit, the poorly-controlled air supply was considered typical for a unit of this type, and the data considered acceptable.

Otherwise, sampling was straightforward and as specified.

Table 6. Conventional Wood Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	12	High	17.38	53	6.47	14.8
Spruce	14	Low	17.70	60	6.24	14.3
Birch	13	High	16.67	40	8.69	14.9
Birch	15	Low	13.95	50	7.26	14.9

2.4.5 Oil Furnace

No EPA standard is in place for oil-burning central air furnaces so the manufacturer's instructions were relied upon for operation. Test duration was dictated by the amount of time needed to acquire a measurable amount of particulate matter on the filters. No modifications to the sampling system or procedures were necessary.

Table 7. Oil Furnace Burn Characteristics

Fuel	Run	Fuel Heating Value (BTU/lb)	Duration (min)	Fuel Usage (lb)
No. 1 Fuel Oil	40	19721	886	61.6
No. 2 Fuel Oil	17	19613	520	40.8

2.4.6 Waste Oil Furnace

Testing of the waste oil furnace was conducted in an identical manner to that of the conventional oil furnace. The furnace was run at its single output rate until sufficient particulate had been acquired by each of the sample filters.

Table 8. Waste Oil Furnace Burn Characteristics

Fuel	Run	Fuel Heating Value (BTU/lb)	Duration (min)	Fuel Usage (lb)
Waste Oil	18	19237	170	26.5

2.4.7 Coal Stove

Due to the lack of an EPA method for coal stove operation, the manufacturer's instructions were used to determine fuel loads and operation procedures.

Table 9. Coal Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Stoker Coal	35	High	33.50	220	2.46	25.0
Stoker Coal	23	Low	33.50	294	1.62	22.1
Dried Stoker Coal	20	High	11.20	208	2.64	22.4
Dried Stoker Coal	21	Low	11.20	391	1.50	24.0
Lump Coal	36	Low, Cold Start	25.40	497	2.23	4.0 Birch Kindling, 25.0 Preburn, 25.0 Test
Lump Coal	37	Low	25.40	393	1.38	25.0
Dried Lump Coal	38	Low	19.00	369	1.55	25.0
Stoker Coal	39	Low, Cold Start	33.50	448	2.28	6.0 Birch Kindling, 26.5 Preburn, 25.0 Test

2.4.8 Non-Qualified Outdoor Wood Fired Hydronic Heater

The non-qualified OWHH used for testing required substantially modified procedures in order to generate meaningful results. This unit produced an extreme amount of particulate matter and heat in the flue. Combined with a low dilution factor, this resulted in excessively high particulate concentrations and temperatures in the dilution tunnel – far beyond the capabilities of the sampling systems described in Section 2.3.

All of the sampling systems rely on filters for sample collection or conditioning, and all of the filters would become clogged almost immediately after test start. In addition to the high particulate concentrations, the elevated temperatures produced in the dilution tunnel caused large amounts of water to condense on the cooler filters. Regardless of material, a wet filter will not allow airflow. Solving this problem for the particulate sampling system required a two-pronged approach. The filters were first heated to prevent condensation. The filter holders were placed in a temperature-controlled box featuring a hole for the protuberance of the cyclone head. To solve the particulate problem, a larger bypass filter was used. A 102mm glass bypass filter was employed in place of the 47mm filter, allowing much higher flow through the bypass. The revised filter train is shown in Figure 6. The flow through the sample collection filters was greatly reduced, thus reducing the amount of particulate collected. The air from the bypass filter was cooled using a glass impinger train immersed in an ice bath; silica gel dryers were sufficient for cooling and drying the air from the sample filters.

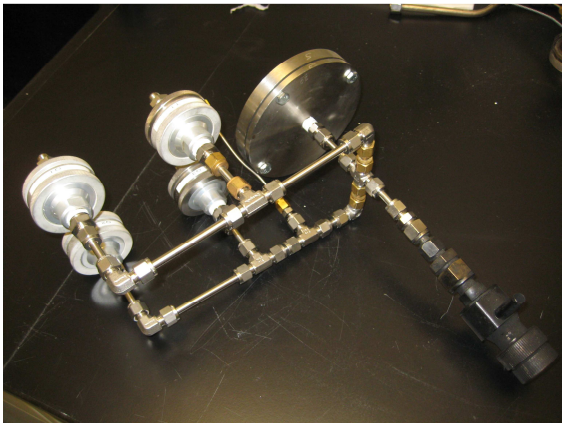


Figure 6. Cyclone and Filter Assembly with 102 mm Glass Filter

Despite this, multiple filter changes were needed for each run. Most frequently changed was the glass bypass filter. Fortunately the effects of these changes were relatively minor, resulting only in a brief (approximately 1 minute) alteration in sample rate.

The gas sampling systems also required adjustment. A dilution system was attempted to reduce flow through the filter while maintaining the required sample rates. However, due to the difficulty in achieving a precise and constant dilution rate throughout each test, it was determined that the most robust technique was not to dilute but to simply closely monitor sample rates and change filters when needed. In some instances gas concentrations exceeded the maximum detection limits of the analyzers. For such cases, data are reported as being greater than the amount measured.

Similar to the EPA qualified OWHH, an additional test was performed on this unit with a retrofit catalyst exhaust stack. This extra test was done burning coal fuel with a low burn setting.

Table 10. Non-Qualified OWHH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	25	High	16.91	118	23.89	121.1
Spruce	30	Low	14.00	116	14.24	69.2
Birch	31	High	18.04	115	20.13	100.4
Birch	32	Low	17.02	231	10.09	100.2
Stoker Coal	26	Low	33.50	123	10.89	62.0
Stoker Coal	27	Low, w/ Stack catalyst	33.50	196	6.45	62.0
Birch	33	Low, Cold Start	26.78	346	14.91	40.0 Kindling, 100.2 Preburn, 100.1 Test

2.4.9 Auger-Fed Coal Fired Hydronic Heater

The auger-fed coal burning hydronic heater was tested in accordance to Method 28 OWHH for pellet boilers. Two tests were performed with this unit at the same heat output rate, which was approximately 35% of the maximum achievable heat output. The first test was a "cold start", meaning sampling started prior to a fire being lit. A fire was started in the burn pot with newspaper and small kindling wood prior to activating the auger. The second test was identical to the first with regards to burn rate and fuel consumption; however, it was a standard "hot start" per Method 28 OWHH.

Table 11. Auger-Fed Coal HH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Wet Stoker Coal	28	Low – Cold Start	33.5	202	16.08	150.0
Wet Stoker Coal	29	Low – Hot Start	33.5	200	16.24	150.0

3. Testing Results

3.1 Particulate Sampling Results

Results from particulate sampling are shown in Appendix A. Speciation was performed on the Teflon filter from each run, generating data for both elemental and ionic emissions. These are reported both as total filter catch and overall gram per hour emissions. For every run, there was no detectable catch for several of the compounds. These are reported as zero. Carbon emissions data were generated from the quartz filter and are broken down into elemental and organic carbon. These data are also reported both as total filter catch and emission rate per hour.

3.2 Ammonia Sampling Results

Results from ammonia sampling are reported in Appendix B. Samples were analyzed for total ammonia catch as nitrogen. These values were used to calculate the volumetric concentration of ammonia gas in the stack as well as the emission rate of ammonia by weight for each run.

3.3 Gas Sampling Results

Tables 12 through 19 contain air emissions measurements derived from the gas analyzers. Tables 12 and 16 compare emission rates of SO_2, CO, VOCs (as C), NO, NO_2, and NO_x by appliance type and by fuel type, respectively. Tables 13 and 17 compare emission factors (in g/kg of dry fuel) of SO_2, CO, VOCs (as C), NO, NO_2, and NO_x by appliance type and by fuel type, respectively. Tables 14 and 18 compare emission factors (in g/MJ input) of SO_2, CO, VOCs (as C), NO, NO_2, and NO_x by appliance type and by fuel type, respectively. Tables 15 and 19 compare emission factors (in g/MJ output) of SO_2, CO, VOCs (as C), NO, NO_2, and NO_x by appliance type and by fuel type, respectively

Note that for the oil furnace burning fuel oil #1, CO concentration was below the detection limit.

Note also that for two of the non-qualified OWHH test runs – burning spruce on high and wet stoker coal on low – the CO analyzer was disconnected from the sampling train. Due to the fact that the filter for the analyzer was constantly plugging, and when it was not plugged the analyzer was far out of its calibration range, it was determined that no useful data could be collected for these runs.

Table 12. Emission Rate of Gas By-Products in g/hr, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Rate (g/hr)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.5681	11.09	1.986	5.050	0.1171	4.471	0.08029
3	EPA Wood Stove	Spruce	High	Hot	0.1113	70.36	9.269	2.889	0.7484	3.707	0.1158
6	EPA Wood Stove	Spruce	Low	Hot	0.02587	120.7	14.06	0.6780	0.1197	0.8919	0.1371
2	EPA Wood Stove	Birch	High	Hot	0.2107	108.7	6.613	3.095	1.082	4.556	0.1784
5	EPA Wood Stove	Birch	Low	Hot	0.05873	74.59	23.36	1.249	0.1808	1.544	0.2409
41	EPA Wood Stove	Birch	Low	Cold	0.07125	101.1	26.96	2.299	0.6377	3.368	0.2079
10	EPA OWHH	Spruce	High	Hot	0.002837	334.9	32.80	12.02	0.3301	12.51	0.3869
11	EPA OWHH	Spruce	Low	Hot	0.01611	230.9	77.30	3.320	0.7777	4.612	0.3078
8	EPA OWHH	Birch	High	Hot	0.1965	301.9	104.6	19.80	0.2983	20.23	1.547
9	EPA OWHH	Birch	Low	Hot	0.05227	207.5	75.77	6.042	0.6082	7.069	0.2916
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.1701	63.31	44.29	7.162	0.8584	8.534	0.3163
12	Conventional Wood Stove	Spruce	High	Hot	0.03949	89.52	23.08	4.468	0.7336	5.702	0.2774
14	Conventional Wood Stove	Spruce	Low	Hot	0.04720	359.3	125.8	2.267	0.9782	3.884	0.8025
13	Conventional Wood Stove	Birch	High	Hot	0.2504	470.5	353.1	3.524	3.931	9.989	3.244
15	Conventional Wood Stove	Birch	Low	Hot	0.1100	422.5	313.8	2.130	2.062	5.554	1.821
40	Oil Furnace	Oil #1	Single	Hot	2.361	0	2.129	3.808	2.137E-04	3.673	0.01994
17	Oil Furnace	Oil #2	Single	Hot	4.502	0.1259	2.832	2.957	0.1905	3.140	0.006887
18	Waste Oil Burner	Waste Oil	Single	Hot	21.06	7.078	1.989	29.84	0.005961	29.74	0.02072
35	Coal Stove	Wet Stoker Coal	High	Hot	3.835	105.5	17.41	4.847	0.8117	6.197	0.3149
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.3705	107.0	24.89	2.220	0.9022	3.653	1.239
39	Coal Stove	Wet Stoker Coal	Low	Cold	1.706	128.7	33.54	3.537	0.8999	5.038	1.583
20	Coal Stove	Dry Stoker Coal	High	Hot	2.955	82.66	22.49	3.949	0.8896	5.362	0.2209
21	Coal Stove	Dry Stoker Coal	Low	Hot	1.466	98.44	12.99	2.236	0.8425	3.523	0.9764
37	Coal Stove	Wet Lump Coal	Low	Hot	1.212	107.3	11.68	2.597	0.4249	3.292	0.9573
36	Coal Stove	Wet Lump Coal	Low	Cold	0.4983	118.1	42.96	3.147	0.9102	4.663	2.078
38	Coal Stove	Dry Lump Coal	Low	Hot	0.9417	76.59	29.00	2.834	0.5006	3.673	0.6132
25	Non-Qualified OWHH	Spruce	High	Hot	0.9604	N/A	285.2	6.076	3.854	12.38	1.662
30	Non-Qualified OWHH	Spruce	Low	Hot	0.6206	>345.8	>269.3	2.841	1.923	5.991	1.013
31	Non-Qualified OWHH	Birch	High	Hot	0.5069	>392.6	>281.0	8.812	7.582	21.20	4.279
32	Non-Qualified OWHH	Birch	Low	Hot	0.6068	>275.3	>231.3	3.046	4.077	9.761	1.880
33	Non-Qualified OWHH	Birch	Low	Cold	0.3818	314.8	283.4	4.615	5.370	13.45	3.531
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	1.998	N/A	126.4	6.055	4.501	13.39	5.933
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.3524	139.1	124.2	5.859	2.963	10.64	5.333
28	Auger-Fed HH	Wet Stoker Coal	Single	Cold	49.91	143.1	2.218	36.82	8.197	50.27	0.2014
29	Auger-Fed HH	Wet Stoker Coal	Single	Hot	50.74	114.7	1.219	35.61	7.804	48.39	0.03969

Table 13. Emission Factor of Gas By-Products in g/kg of Dry Fuel, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/kg dry fuel)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.2543	4.966	0.88910	2.260	0.05244	2.002	0.03594
3	EPA Wood Stove	Spruce	High	Hot	0.02560	16.19	2.133	0.6647	0.1722	0.8531	0.02666
6	EPA Wood Stove	Spruce	Low	Hot	1.462E-02	68.23	7.942	0.3831	0.06766	0.5040	0.07749
2	EPA Wood Stove	Birch	High	Hot	0.05551	28.64	1.742	0.8152	0.2851	1.200	0.04698
5	EPA Wood Stove	Birch	Low	Hot	0.03928	49.89	15.62	0.8356	0.1209	1.033	0.1611
41	EPA Wood Stove	Birch	Low	Cold	0.02272	32.24	8.598	0.7332	0.2034	1.074	0.06632
10	EPA OWHH	Spruce	High	Hot	2.132E-04	25.16	2.464	0.9028	0.02480	0.9400	0.02907
11	EPA OWHH	Spruce	Low	Hot	0.002940	42.14	14.11	0.6058	0.1419	0.8416	0.05617
8	EPA OWHH	Birch	High	Hot	0.01478	22.71	7.868	1.489	0.02244	1.522	0.1164
9	EPA OWHH	Birch	Low	Hot	0.009038	35.87	13.10	1.045	0.1052	1.222	0.06380
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.03415	12.71	8.891	1.438	0.1723	1.713	0.06350
12	Conventional Wood Stove	Spruce	High	Hot	0.002766	6.271	1.617	0.3130	0.05139	0.3995	0.01943
14	Conventional Wood Stove	Spruce	Low	Hot	0.007561	57.58	20.16	0.3634	0.1568	0.6226	0.1286
13	Conventional Wood Stove	Birch	High	Hot	0.02882	54.14	40.63	0.4056	0.4524	1.150	0.3733
15	Conventional Wood Stove	Birch	Low	Hot	0.01514	58.18	43.21	0.2933	0.2839	0.7647	0.2507
40	Oil Furnace	Oil #1	Single	Hot	1.249	ND	1.126	2.015	1.131E-04	1.943	0.01055
17	Oil Furnace	Oil #2	Single	Hot	2.104	0.05885	1.324	1.382	0.08905	1.468	0.003219
18	Waste Oil Burner	Waste Oil	Single	Hot	4.759	1.600	0.4495	6.745	0.001347	6.721	0.004684
35	Coal Stove	Wet Stoker Coal	High	Hot	1.562	42.96	7.089	1.974	0.3305	2.524	0.1359
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.2366	68.33	15.89	1.418	0.5762	2.333	0.7912
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.7496	56.57	14.74	1.555	0.3955	2.214	0.6960
20	Coal Stove	Dry Stoker Coal	High	Hot	1.153	32.26	8.778	1.541	0.3472	2.093	0.08622
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.9785	65.70	8.666	1.492	0.5623	2.351	0.6516
37	Coal Stove	Wet Lump Coal	Low	Hot	0.8780	77.69	8.459	1.881	0.3078	2.385	0.6934
36	Coal Stove	Wet Lump Coal	Low	Cold	0.2238	53.05	19.29	1.413	0.4087	2.094	0.9331
38	Coal Stove	Dry Lump Coal	Low	Hot	0.6077	49.43	18.72	1.829	0.3231	2.371	0.3957
25	Non-Qualified OWHH	Spruce	High	Hot	0.04020	N/A	11.94	0.2543	0.1613	0.5181	0.06957
30	Non-Qualified OWHH	Spruce	Low	Hot	0.04583	>25.54	>19.89	0.2098	0.1420	0.4424	0.07480
31	Non-Qualified OWHH	Birch	High	Hot	0.02518	>19.50	>13.96	0.4378	0.3767	1.053	0.2126
32	Non-Qualified OWHH	Birch	Low	Hot	0.06015	>27.29	>22.93	0.3019	0.4041	0.9676	0.1863
33	Non-Qualified OWHH	Birch	Low	Cold	0.02561	21.12	19.01	0.3095	0.3602	0.9019	0.2369
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.1834	N/A	11.60	0.5559	0.4132	1.229	0.5447
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.06218	24.54	21.92	1.034	0.5229	1.878	0.9411
28	Auger-Fed HH	Wet Stoker Coal	Single	Cold	3.248	9.311	0.1444	2.396	0.5334	3.271	0.01311
29	Auger-Fed HH	Wet Stoker Coal	Single	Hot	3.352	7.576	0.08052	2.353	0.5155	3.197	0.002622

Table 14. Emission Factor of Gas By-Products in g/MJ Input, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/MJ input)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.01473	0.2876	0.05150	0.1309	0.003037	0.1159	0.002082
3	EPA Wood Stove	Spruce	High	Hot	0.001590	1.006	0.1325	0.04128	0.01070	0.05298	0.001656
6	EPA Wood Stove	Spruce	Low	Hot	9.078E-04	4.237	0.4932	0.02379	0.004202	0.03130	0.004812
2	EPA Wood Stove	Birch	High	Hot	0.003416	1.762	0.1072	0.05016	0.01755	0.07385	0.002891
5	EPA Wood Stove	Birch	Low	Hot	0.002417	3.070	0.9615	0.05142	0.007441	0.06355	0.009916
41	EPA Wood Stove	Birch	Low	Cold	0.001398	1.984	0.5291	0.04512	0.01252	0.06611	0.004081
10	EPA OWHH	Spruce	High	Hot	1.324E-05	1.562	0.1530	0.05607	0.001540	0.05838	0.001805
11	EPA OWHH	Spruce	Low	Hot	1.826E-04	2.617	0.8760	0.03762	0.008814	0.05227	0.003488
8	EPA OWHH	Birch	High	Hot	9.097E-04	1.397	0.4842	0.09164	0.001381	0.09365	0.007162
9	EPA OWHH	Birch	Low	Hot	5.561E-04	2.207	0.8062	0.06429	0.006472	0.07522	0.003926
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.002102	0.7821	0.5471	0.08848	0.01060	0.1054	0.003907
12	Conventional Wood Stove	Spruce	High	Hot	1.718E-04	0.3895	0.1004	0.01944	0.003192	0.02481	0.001207
14	Conventional Wood Stove	Spruce	Low	Hot	4.696E-04	3.576	1.252	0.02257	0.009737	0.03867	0.007989
13	Conventional Wood Stove	Birch	High	Hot	0.001774	3.332	2.500	0.02496	0.02784	0.07074	0.02297
15	Conventional Wood Stove	Birch	Low	Hot	9.319E-04	3.580	2.659	0.01805	0.01747	0.04705	0.01543
40	Oil Furnace	Oil #1	Single	Hot	0.04707	ND	0.04244	0.07591	4.261E-06	0.07322	3.974E-04
17	Oil Furnace	Oil #2	Single	Hot	0.08009	0.002240	0.05038	0.05261	0.003389	0.05586	1.225E-04
18	Waste Oil Burner	Waste Oil	Single	Hot	0.1839	0.06181	0.01737	0.2606	5.206E-05	0.2597	1.810E-04
35	Coal Stove	Wet Stoker Coal	High	Hot	0.08134	2.238	0.3693	0.1028	0.01722	0.1314	0.007079
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.01232	3.559	0.8278	0.07384	0.03001	0.1215	0.04121
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.03905	2.946	0.7678	0.08098	0.02060	0.1153	0.03625
20	Coal Stove	Dry Stoker Coal	High	Hot	0.06008	1.680	0.4572	0.08029	0.01809	0.1090	0.004491
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.05097	3.422	0.4514	0.07771	0.02929	0.1225	0.03394
37	Coal Stove	Wet Lump Coal	Low	Hot	0.04735	4.190	0.4562	0.1015	0.01660	0.1286	0.03739
36	Coal Stove	Wet Lump Coal	Low	Cold	0.01207	2.861	1.040	0.07619	0.02204	0.1129	0.05032
38	Coal Stove	Dry Lump Coal	Low	Hot	0.03277	2.665	1.009	0.09863	0.01742	0.1278	0.02134
25	Non-Qualified OWHH	Spruce	High	Hot	0.002497	N/A	0.7413	0.01580	0.01002	0.03218	0.004321
30	Non-Qualified OWHH	Spruce	Low	Hot	0.002846	1.586	1.235	0.01303	0.008820	0.02748	0.004645
31	Non-Qualified OWHH	Birch	High	Hot	0.001550	1.200	0.8590	0.02694	0.02318	0.06480	0.01308
32	Non-Qualified OWHH	Birch	Low	Hot	0.003701	1.679	1.411	0.01858	0.02487	0.05954	0.01146
33	Non-Qualified OWHH	Birch	Low	Cold	0.001576	1.299	1.170	0.01905	0.02216	0.05550	0.01458
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.009555	N/A	0.6043	0.02896	0.02152	0.06404	0.02837
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.003239	1.278	1.142	0.05385	0.02724	0.09781	0.04902
28	Auger-Fed HH	Wet Stoker Coal	Single	Cold	0.1692	0.4850	0.007519	0.1248	0.02779	0.1704	6.828E-04
29	Auger-Fed HH	Wet Stoker Coal	Single	Hot	0.1746	0.3946	0.004194	0.1225	0.02685	0.1665	1.366E-04

Table 15. Emission Factor of Gas By-Products in g/MJ Output, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/MJ output)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.02043	0.3989	0.07143	0.1816	0.004212	0.1607	0.002888
3	EPA Wood Stove	Spruce	High	Hot	0.002057	1.301	0.1714	0.05340	0.01384	0.06854	0.002142
6	EPA Wood Stove	Spruce	Low	Hot	1.299E-03	6.062	0.7056	0.03403	0.006011	0.04478	0.006884
2	EPA Wood Stove	Birch	High	Hot	0.005053	2.607	0.1586	0.07420	0.02596	0.1092	0.004277
5	EPA Wood Stove	Birch	Low	Hot	0.003433	4.361	1.366	0.07304	0.01057	0.09027	0.01409
41	EPA Wood Stove	Birch	Low	Cold	0.002012	2.854	0.7613	0.06492	0.01801	0.09512	0.005872
10	EPA OWHH	Spruce	High	Hot	1.633E-05	1.926	0.1887	0.06914	0.001899	0.07199	0.002226
11	EPA OWHH	Spruce	Low	Hot	2.597E-04	3.723	1.246	0.05351	0.01254	0.07435	0.004962
8	EPA OWHH	Birch	High	Hot	1.122E-03	1.723	0.5970	0.1130	0.001703	0.1155	0.008831
9	EPA OWHH	Birch	Low	Hot	7.734E-04	3.070	1.121	0.08942	0.009001	0.1046	0.005460
34	EPA OWHH, Catalyst	Birch	Low	Hot	3.204E-03	1.192	0.8340	0.1349	0.01616	0.1607	0.005956
12	Conventional Wood Stove	Spruce	High	Hot	3.416E-04	0.7744	0.1996	0.03865	0.006346	0.04932	0.002400
14	Conventional Wood Stove	Spruce	Low	Hot	7.599E-04	5.786	2.026	0.03652	0.01576	0.06257	0.01293
13	Conventional Wood Stove	Birch	High	Hot	0.003548	6.664	5.000	0.04992	0.05568	0.1415	0.04594
15	Conventional Wood Stove	Birch	Low	Hot	1.561E-03	5.997	4.454	0.03023	0.02926	0.07881	0.02585
40	Oil Furnace	Oil #1	Single	Hot	0.05826	ND	0.05253	0.09395	5.273E-06	0.09062	4.919E-04
17	Oil Furnace	Oil #2	Single	Hot	0.09489	0.002654	0.05969	0.06233	0.004016	0.06619	1.452E-04
18	Waste Oil Burner	Waste Oil	Single	Hot	0.2620	0.08805	0.02474	0.3713	7.416E-05	0.3700	2.578E-04
35	Coal Stove	Wet Stoker Coal	High	Hot	0.1289	3.547	0.5853	0.1629	0.02729	0.2082	0.01122
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.02047	5.912	1.375	0.1227	0.04985	0.2018	0.06846
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.05298	3.998	1.042	0.1099	0.02795	0.1565	0.04919
20	Coal Stove	Dry Stoker Coal	High	Hot	0.08356	2.337	0.6359	0.1117	0.02516	0.1516	0.006246
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.07507	5.040	0.6648	0.1144	0.04314	0.1804	0.04999
37	Coal Stove	Wet Lump Coal	Low	Hot	0.06504	5.755	0.6266	0.1394	0.02280	0.1767	0.05137
36	Coal Stove	Wet Lump Coal	Low	Cold	0.01631	3.866	1.406	0.1030	0.02978	0.1526	0.06800
38	Coal Stove	Dry Lump Coal	Low	Hot	0.04514	3.671	1.390	0.1358	0.02400	0.1761	0.02939
25	Non-Qualified OWHH	Spruce	High	Hot	0.006258	N/A	1.858	0.03960	0.02511	0.08065	0.01083
30	Non-Qualified OWHH	Spruce	Low	Hot	0.008866	4.941	3.847	0.04059	0.02748	0.08561	0.01447
31	Non-Qualified OWHH	Birch	High	Hot	0.003460	2.679	1.917	0.06013	0.05174	0.1446	0.02920
32	Non-Qualified OWHH	Birch	Low	Hot	0.01111	5.042	4.237	0.05580	0.07468	0.1788	0.03441
33	Non-Qualified OWHH	Birch	Low	Cold	0.004439	3.659	3.296	0.05366	0.06242	0.1563	0.04107
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.03196	N/A	2.021	0.09686	0.07197	0.2142	0.09488
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.008948	3.530	3.155	0.1488	0.07525	0.2702	0.1354
28	Auger-Fed HH	Wet Stoker Coal	Single	Cold	0.2071	0.5936	0.009203	0.1528	0.03401	0.2086	8.357E-04
29	Auger-Fed HH	Wet Stoker Coal	Single	Hot	0.2219	0.5014	0.005329	0.1557	0.03412	0.2116	1.736E-04

Table 16. Emission Rate of Gas By-Products in g/hr, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Rate (g/hr)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.5681	11.09	1.986	5.050	0.1171	4.471	0.08029
40	Oil #1	Single	Hot	Oil Furnace	2.361	0	2.129	3.808	2.137E-04	3.673	0.01994
17	Oil #2	Single	Hot	Oil Furnace	4.502	0.1259	2.832	2.957	0.1905	3.140	0.006887
18	Waste Oil	Single	Hot	Waste Oil Burner	21.06	7.078	1.989	29.84	0.005961	29.74	0.02072
3	Spruce	High	Hot	EPA Wood Stove	0.1113	70.36	9.269	2.889	0.7484	3.707	0.1158
10	Spruce	High	Hot	EPA OWHH	0.002837	334.9	32.80	12.02	0.3301	12.51	0.3869
12	Spruce	High	Hot	Conventional Wood Stove	0.03949	89.52	23.08	4.468	0.7336	5.702	0.2774
25	Spruce	High	Hot	Non-Qualified OWHH	0.9604	N/A	285.2	6.076	3.854	12.38	1.662
6	Spruce	Low	Hot	EPA Wood Stove	0.02587	120.7	14.06	0.6780	0.1197	0.8919	0.1371
11	Spruce	Low	Hot	EPA OWHH	0.01611	230.9	77.30	3.320	0.7777	4.612	0.3078
14	Spruce	Low	Hot	Conventional Wood Stove	0.04720	359.3	125.8	2.267	0.9782	3.884	0.8025
30	Spruce	Low	Hot	Non-Qualified OWHH	0.6206	>345.8	>269.3	2.841	1.923	5.991	1.013
2	Birch	High	Hot	EPA Wood Stove	0.2107	108.7	6.613	3.095	1.082	4.556	0.1784
8	Birch	High	Hot	EPA OWHH	0.1965	301.9	104.6	19.80	0.2983	20.23	1.547
13	Birch	High	Hot	Conventional Wood Stove	0.2504	470.5	353.1	3.524	3.931	9.989	3.244
31	Birch	High	Hot	Non-Qualified OWHH	0.5069	>392.6	>281.0	8.812	7.582	21.20	4.279
5	Birch	Low	Hot	EPA Wood Stove	0.05873	74.59	23.36	1.249	0.1808	1.544	0.2409
41	Birch	Low	Cold	EPA Wood Stove	0.07125	101.1	26.96	2.299	0.6377	3.368	0.2079
9	Birch	Low	Hot	EPA OWHH	0.05227	207.5	75.77	6.042	0.6082	7.069	0.2916
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.1701	63.31	44.29	7.162	0.8584	8.534	0.3163
15	Birch	Low	Hot	Conventional Wood Stove	0.1100	422.5	313.8	2.130	2.062	5.554	1.821
32	Birch	Low	Hot	Non-Qualified OWHH	0.6068	>275.3	>231.3	3.046	4.077	9.761	1.880
33	Birch	Low	Cold	Non-Qualified OWHH	0.3818	314.8	283.4	4.615	5.370	13.45	3.531
35	Wet Stoker Coal	High	Hot	Coal Stove	3.835	105.5	17.41	4.847	0.8117	6.197	0.3149
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.3705	107.0	24.89	2.220	0.9022	3.653	1.239
39	Wet Stoker Coal	Low	Cold	Coal Stove	1.706	128.7	33.54	3.537	0.8999	5.038	1.583
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	1.998	N/A	126.4	6.055	4.501	13.39	5.933
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.3524	139.1	124.2	5.859	2.963	10.64	5.333
28	Wet Stoker Coal	Single	Cold	Auger-Fed HH	49.91	143.1	2.218	36.82	8.197	50.27	0.2014
29	Wet Stoker Coal	Single	Hot	Auger-Fed HH	50.74	114.7	1.219	35.61	7.804	48.39	0.03969
20	Dry Stoker Coal	High	Hot	Coal Stove	2.955	82.66	22.49	3.949	0.8896	5.362	0.2209
21	Dry Stoker Coal	Low	Hot	Coal Stove	1.466	98.44	12.99	2.236	0.8425	3.523	0.9764
37	Wet Lump Coal	Low	Hot	Coal Stove	1.212	107.3	11.68	2.597	0.4249	3.292	0.9573
36	Wet Lump Coal	Low	Cold	Coal Stove	0.4983	118.1	42.96	3.147	0.9102	4.663	2.078
38	Dry Lump Coal	Low	Hot	Coal Stove	0.9417	76.59	29.00	2.834	0.5006	3.673	0.6132

Table 17. Emission Factor of Gas By-Products in g/kg of Dry Fuel, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/kg dry fuel)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.2543	4.966	0.8891	2.260	0.05244	2.002	0.03594
40	Oil #1	Single	Hot	Oil Furnace	1.249	ND	1.126	2.015	1.131E-04	1.943	0.01055
17	Oil #2	Single	Hot	Oil Furnace	2.104	0.05885	1.324	1.382	0.08905	1.468	0.003219
18	Waste Oil	Single	Hot	Waste Oil Burner	4.759	1.600	0.4495	6.745	0.001347	6.721	0.004684
3	Spruce	High	Hot	EPA Wood Stove	0.02560	16.19	2.133	0.6647	0.1722	0.8531	0.02666
10	Spruce	High	Hot	EPA OWHH	2.132E-04	25.16	2.464	0.9028	0.02480	0.9400	0.02907
12	Spruce	High	Hot	Conventional Wood Stove	0.002766	6.271	1.617	0.3130	0.05139	0.3995	0.01943
25	Spruce	High	Hot	Non-Qualified OWHH	0.04020	N/A	11.94	0.2543	0.1613	0.5181	0.06957
6	Spruce	Low	Hot	EPA Wood Stove	0.01462	68.23	7.942	0.3831	0.06766	0.5040	0.07749
11	Spruce	Low	Hot	EPA OWHH	0.002940	42.14	14.11	0.6058	0.1419	0.8416	0.05617
14	Spruce	Low	Hot	Conventional Wood Stove	0.007561	57.58	20.16	0.3634	0.1568	0.6226	0.1286
30	Spruce	Low	Hot	Non-Qualified OWHH	0.04583	>25.54	>19.89	0.2098	0.1420	0.4424	0.07480
2	Birch	High	Hot	EPA Wood Stove	0.05551	28.64	1.742	0.8152	0.2851	1.200	0.04698
8	Birch	High	Hot	EPA OWHH	0.01478	22.71	7.868	1.489	0.02244	1.522	0.1164
13	Birch	High	Hot	Conventional Wood Stove	0.02882	54.14	40.63	0.4056	0.4524	1.150	0.3733
31	Birch	High	Hot	Non-Qualified OWHH	0.02518	>19.50	>13.96	0.4378	0.3767	1.053	0.2126
5	Birch	Low	Hot	EPA Wood Stove	0.03928	49.89	15.62	0.8356	0.1209	1.033	0.1611
41	Birch	Low	Cold	EPA Wood Stove	0.02272	32.24	8.598	0.7332	0.2034	1.074	0.06632
9	Birch	Low	Hot	EPA OWHH	0.009038	35.87	13.10	1.045	0.1052	1.222	0.06380
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.03415	12.71	8.891	1.438	0.1723	1.713	0.06350
15	Birch	Low	Hot	Conventional Wood Stove	0.01514	58.18	43.21	0.2933	0.2839	0.7647	0.2507
32	Birch	Low	Hot	Non-Qualified OWHH	0.06015	>27.29	>22.93	0.3019	0.4041	0.9676	0.1863
33	Birch	Low	Cold	Non-Qualified OWHH	0.02561	21.12	19.01	0.3095	0.3602	0.9019	0.2369
35	Wet Stoker Coal	High	Hot	Coal Stove	1.562	42.96	7.089	1.974	0.3305	2.524	0.1359
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.2366	68.33	15.89	1.418	0.5762	2.333	0.7912
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.7496	56.57	14.74	1.555	0.3955	2.214	0.6960
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.1830	N/A	11.60	0.5559	0.4132	1.229	0.5447
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.06218	24.54	21.92	1.034	0.5229	1.878	0.9411
28	Wet Stoker Coal	Single	Cold	Auger-Fed HH	3.248	9.311	0.1444	2.396	0.5334	3.271	0.01311
29	Wet Stoker Coal	Single	Hot	Auger-Fed HH	3.352	7.576	0.08052	2.353	0.5155	3.197	0.002622
20	Dry Stoker Coal	High	Hot	Coal Stove	1.153	32.26	8.778	1.541	0.3472	2.093	0.08622
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.9785	65.70	8.666	1.492	0.5623	2.351	0.6516
37	Wet Lump Coal	Low	Hot	Coal Stove	0.8780	77.69	8.459	1.881	0.3078	2.385	0.6934
36	Wet Lump Coal	Low	Cold	Coal Stove	0.2238	53.05	19.29	1.413	0.4087	2.094	0.9331
38	Dry Lump Coal	Low	Hot	Coal Stove	0.6077	49.43	18.72	1.829	0.3231	2.371	0.3957

Table 18. Emission Factor of Gas By-Products in MJ Input, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/MJ input)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.01473	0.2876	0.05150	0.1309	0.003037	0.1159	0.002082
40	Oil #1	Single	Hot	Oil Furnace	0.04707	ND	0.04244	0.07591	4.261E-06	0.07322	3.974E-04
17	Oil #2	Single	Hot	Oil Furnace	0.08009	0.002240	0.05038	0.05261	0.003389	0.05586	1.225E-04
18	Waste Oil	Single	Hot	Waste Oil Burner	0.1839	0.06181	0.01737	0.2606	5.206E-05	0.2597	1.810E-04
3	Spruce	High	Hot	EPA Wood Stove	0.001590	1.006	0.1325	0.04128	0.01070	0.05298	0.001656
10	Spruce	High	Hot	EPA OWHH	1.324E-05	1.562	0.1530	0.05607	0.001540	0.05838	0.001805
12	Spruce	High	Hot	Conventional Wood Stove	1.718E-04	0.3895	0.1004	0.01944	0.003192	0.02481	0.001207
25	Spruce	High	Hot	Non-Qualified OWHH	0.002497	N/A	0.7413	0.01580	0.01002	0.03218	0.004321
6	Spruce	Low	Hot	EPA Wood Stove	9.078E-04	4.237	0.4932	0.02379	0.004202	0.03130	0.004812
11	Spruce	Low	Hot	EPA OWHH	1.826E-04	2.617	0.8760	0.03762	0.008814	0.05227	0.003488
14	Spruce	Low	Hot	Conventional Wood Stove	4.696E-04	3.576	1.252	0.02257	0.009737	0.03867	0.007989
30	Spruce	Low	Hot	Non-Qualified OWHH	0.002846	1.586	1.235	0.01303	0.008820	0.02748	0.004645
2	Birch	High	Hot	EPA Wood Stove	0.003416	1.762	0.1072	0.05016	0.01755	0.07385	0.002891
8	Birch	High	Hot	EPA OWHH	9.097E-04	1.397	0.4842	0.09164	0.001381	0.09365	0.007162
13	Birch	High	Hot	Conventional Wood Stove	0.001774	3.332	2.500	0.02496	0.02784	0.07074	0.02297
31	Birch	High	Hot	Non-Qualified OWHH	0.001550	1.200	0.8590	0.02694	0.02318	0.06480	0.01308
5	Birch	Low	Hot	EPA Wood Stove	0.002417	3.070	0.9615	0.05142	0.007441	0.06355	0.009916
41	Birch	Low	Cold	EPA Wood Stove	0.001398	1.984	0.5291	0.04512	0.01252	0.06611	0.004081
9	Birch	Low	Hot	EPA OWHH	5.561E-04	2.207	0.8062	0.06429	0.006472	0.07522	0.003926
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.002102	0.7821	0.5471	0.08848	0.01060	0.1054	0.003907
15	Birch	Low	Hot	Conventional Wood Stove	9.319E-04	3.580	2.659	0.01805	0.01747	0.04705	0.01543
32	Birch	Low	Hot	Non-Qualified OWHH	0.003701	1.679	1.411	0.01858	0.02487	0.05954	0.01146
33	Birch	Low	Cold	Non-Qualified OWHH	0.001600	1.300	1.170	0.01900	0.0222	0.05550	0.01458
35	Wet Stoker Coal	High	Hot	Coal Stove	0.08134	2.238	0.3693	0.1028	0.01722	0.1314	0.007079
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.01232	3.559	0.8278	0.07384	0.03001	0.1215	0.04121
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.03905	2.946	0.7678	0.08098	0.02060	0.1153	0.03625
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.009555	N/A	0.6043	0.02896	0.02152	0.06404	0.02837
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.003239	1.278	1.142	0.05385	0.02724	0.09781	0.04902
28	Wet Stoker Coal	Single	Cold	Auger-Fed HH	0.1692	0.4850	0.007519	0.1248	0.02779	0.1704	6.828E-04
29	Wet Stoker Coal	Single	Hot	Auger-Fed HH	0.1746	0.3946	0.004194	0.1225	0.02685	0.1665	1.366E-04
20	Dry Stoker Coal	High	Hot	Coal Stove	0.06008	1.680	0.4572	0.08029	0.01809	0.1090	0.004491
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.05097	3.422	0.4514	0.07771	0.02929	0.1225	0.03394
37	Wet Lump Coal	Low	Hot	Coal Stove	0.04735	4.190	0.4562	0.1015	0.01660	0.1286	0.03739
36	Wet Lump Coal	Low	Cold	Coal Stove	0.01207	2.861	1.040	0.07619	0.02204	0.1129	0.05032
38	Dry Lump Coal	Low	Hot	Coal Stove	0.03277	2.665	1.009	0.09863	0.01742	0.1278	0.02134

Table 19. Emission Factor of Gas By-Products in MJ Output, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/MJ output)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.02043	0.3989	0.07143	0.1816	0.004212	0.1607	0.002888
40	Oil #1	Single	Hot	Oil Furnace	0.05826	ND	0.05253	0.09395	5.273E-06	0.09062	4.919E-04
17	Oil #2	Single	Hot	Oil Furnace	0.09489	0.002654	0.05969	0.06233	0.004016	0.06619	1.452E-04
18	Waste Oil	Single	Hot	Waste Oil Burner	0.2620	0.08805	0.02474	0.3713	7.416E-05	0.3700	2.578E-04
3	Spruce	High	Hot	EPA Wood Stove	0.002057	1.301	0.1714	0.05340	0.01384	0.06854	0.002142
10	Spruce	High	Hot	EPA OWHH	1.633E-05	1.926	0.1887	0.06914	0.001899	0.07199	0.002226
12	Spruce	High	Hot	Conventional Wood Stove	3.416E-04	0.7744	0.1996	0.03865	0.006346	0.04932	0.002400
25	Spruce	High	Hot	Non-Qualified OWHH	0.006258	N/A	1.858	0.03960	0.02511	0.08065	0.01083
6	Spruce	Low	Hot	EPA Wood Stove	0.001299	6.062	0.7056	0.03403	0.006011	0.04478	0.006884
11	Spruce	Low	Hot	EPA OWHH	2.597E-04	3.723	1.246	0.05351	0.01254	0.07435	0.004962
14	Spruce	Low	Hot	Conventional Wood Stove	7.599E-04	5.786	2.026	0.03652	0.01576	0.06257	0.01293
30	Spruce	Low	Hot	Non-Qualified OWHH	0.008866	4.941	3.847	0.04059	0.02748	0.0856	0.01447
2	Birch	High	Hot	EPA Wood Stove	0.005053	2.607	0.1586	0.07420	0.02596	0.1092	0.004277
8	Birch	High	Hot	EPA OWHH	0.001122	1.723	0.5970	0.1130	0.001703	0.1155	0.008831
13	Birch	High	Hot	Conventional Wood Stove	0.003548	6.664	5.000	0.04992	0.05568	0.1415	0.04594
31	Birch	High	Hot	Non-Qualified OWHH	0.003460	2.679	1.917	0.06013	0.05174	0.1446	0.02920
5	Birch	Low	Hot	EPA Wood Stove	0.003433	4.361	1.366	0.07304	0.01057	0.09027	0.01409
41	Birch	Low	Cold	EPA Wood Stove	0.002012	2.854	0.7613	0.06492	0.01801	0.09512	0.005872
9	Birch	Low	Hot	EPA OWHH	7.734E-04	3.070	1.121	0.08942	0.009001	0.1046	0.005460
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.003204	1.192	0.8340	0.1349	0.01616	0.1607	0.005956
15	Birch	Low	Hot	Conventional Wood Stove	0.001561	5.997	4.454	0.03023	0.02926	0.07881	0.02585
32	Birch	Low	Hot	Non-Qualified OWHH	0.01111	5.042	4.237	0.05580	0.07468	0.1788	0.03441
33	Birch	Low	Cold	Non-Qualified OWHH	0.004507	3.661	3.295	0.05352	0.06254	0.1563	0.04107
35	Wet Stoker Coal	High	Hot	Coal Stove	0.1289	3.547	0.5853	0.1629	0.02729	0.2082	0.01122
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.02047	5.912	1.375	0.1227	0.04985	0.2018	0.06846
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.05298	3.998	1.042	0.1099	0.02795	0.1565	0.04919
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.03196	N/A	2.021	0.09686	0.07197	0.2142	0.09488
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.008948	3.530	3.155	0.1488	0.07525	0.2702	0.1354
28	Wet Stoker Coal	Single	Cold	Auger-Fed HH	0.2071	0.5936	0.009203	0.1528	0.03401	0.2086	8.357E-04
29	Wet Stoker Coal	Single	Hot	Auger-Fed HH	0.2219	0.5014	0.005329	0.1557	0.03412	0.2116	1.736E-04
20	Dry Stoker Coal	High	Hot	Coal Stove	0.08356	2.337	0.6359	0.1117	0.02516	0.1516	0.006246
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.07507	5.040	0.6648	0.1144	0.04314	0.1804	0.04999
37	Wet Lump Coal	Low	Hot	Coal Stove	0.06504	5.755	0.6266	0.1394	0.02280	0.1767	0.05137
36	Wet Lump Coal	Low	Cold	Coal Stove	0.01631	3.866	1.406	0.1030	0.02978	0.1526	0.06800
38	Dry Lump Coal	Low	Hot	Coal Stove	0.04514	3.671	1.390	0.1358	0.02400	0.1761	0.02939

Table 20. Particulate Emissions and Efficiency, by Run

Run	Appliance	Fuel	Burn Rate	PM2.5 Emissions (g/hr)	PM2.5 Emissions Factor (g/kg)	Efficiency* (%)	Emissions (g/MJ input)	Emissions (g/MJ output)
1	Pellet Stove	Alaskan Pellets	Single	3.31	1.48	72.1	0.080	0.111
2	EPA Certified Woodstove	Birch	High	1.84	0.49	67.6	0.028	0.041
3	EPA Certified Woodstove	Spruce	High	1.17	0.27	77.3	0.016	0.021
5	EPA Certified Woodstove	Birch	Low	6.12	4.08	70.4	0.233	0.331
6	EPA Certified Woodstove	Spruce	Low	1.68	0.95	69.9	0.055	0.079
8	EPA Qualified OWHH	Birch	High	10.72	0.81	81.1**	0.046	0.057
9	EPA Qualified OWHH	Birch	Low	14.07	2.66	71.9**	0.152	0.212
10	EPA Qualified OWHH	Spruce	High	5.12	0.38	81.1**	0.022	0.027
11	EPA Qualified OWHH	Spruce	Low	4.32	0.79	70.3**	0.046	0.065
12	Conventional Woodstove	Spruce	High	2.89	0.45	50.3	0.026	0.051
13	Conventional Woodstove	Birch	High	94.56	10.89	50	0.623	1.246
14	Conventional Woodstove	Spruce	Low	13.16	2.11	61.8	0.122	0.197
15	Conventional Woodstove	Birch	Low	44.02	6.06	59.7	0.347	0.581
17	Central Heating Indoor Furnace	No. 2 Heating Oil	Single	0.13	0.06	78.5	0.001	0.002
18	Waste Oil Burner	Waste Motor Oil	Single	10.41	0.67	66.2	0.015	0.023
20	Coal Stove	Dry Stoker Coal	High	17.45	6.61	71.9	0.330	0.459
21	Coal Stove	Dry Stoker Coal	Low	1.74	1.16	67.9	0.058	0.085
23	Coal Stove	Stoker Coal	Low	11.13	7.09	60.2	0.354	0.589
25	Non Qualified OWHH	Spruce	High	130.10	5.45	39.9**	0.315	0.789
26	Non Qualified OWHH	Coal	Single	294.60	27.05	29.9**	1.352	4.522
27	Non Qualified OWHH, Catalyst	Coal	Single	135.60	23.92	36.2**	1.195	3.302
28	Auger-fed HH	Coal (cold start)	Single	7.17	0.45	81.7	0.022	0.027
29	Auger-fed HH	Coal (hot start)	Single	7.78	0.48	78.7	0.024	0.030
30	Non Qualified OWHH	Spruce	Low	174.00	12.85	32.1**	0.743	2.315
31	Non Qualified OWHH	Birch	High	119.30	5.93	44.8**	0.339	0.757
32	Non Qualified OWHH	Birch	Low	44.47	4.41	33.3**	0.252	0.757
33	Non Qualified OWHH	Birch (cold start)	Low	34.75	2.33	35.5**	0.133	0.376
34	EPA Qualified OWHH, Catalyst	Birch	Low	33.82	6.79	65.6**	0.389	0.592
35	Coal Stove	Stoker Coal	High	7.83	3.18	63.1	0.159	0.252
36	Coal Stove	Lump Coal (cold start)	Low	16.32	6.48	74	0.335	0.453
37	Coal Stove	Lump Coal	Low	2.75	1.99	72.8	0.103	0.142
38	Coal Stove	Dry Lump Coal	Low	8.19	5.28	72.6	0.274	0.377
39	Coal Stove	Stoker Coal (cold start)	Low	14.49	6.36	73.7	0.318	0.431
40	Central Heating Indoor Furnace	No. 1 Heating Oil	Single	0.31	0.16	80.2	0.004	0.004
41	EPA Certified Woodstove	Birch (cold start)	Low	6.86	2.18	69.5	0.125	0.180

*Efficiencies calculated using CSAB415.1-10 Stack Loss Method unless otherwise noted

**Efficiencies calculated per EPA Method 28 OWHH, based on delivered heat output to the load side of the heat exchanger

4. Summary

4.1 Scope and Methods

A wide variety of source testing measurements were taken on a selection of home heating appliances. Emissions from eight appliances, each representative of a popular category, were sampled while burning fuel local to the Fairbanks North Star Borough area. Wood-burning appliances included a conventional wood stove, an EPA certified wood stove, and one each of EPA Phase-II qualified and non-qualified outdoor wood-fired hydronic heaters. The wood used for these tests was birch and spruce cordwood of typical moisture. A coal stove utilized local coal, both typical moisture and air-dried. A pellet stove used local wood pellets. Heating oil (both #1 and #2) was burned in an oil heater. Finally, used motor oil from local sources was used to fuel a waste oil burner.

Sampling was conducted using four separate systems, three of which sampled out of a dilution tunnel. The first was a gas sampling system which measured volatile organic compounds, SO_2, CO, NO, and NO_x. Combustion gas (O_2, CO_2, and CO) gas measurements were taken directly from the stack. The third system sampled ammonia as nitrogen by pulling the sample though sulfuric acid which was then recovered and analyzed for nitrogen. Finally, particulate matter was sampled using a single cyclone head to deliver particulate matter under 2.5 microns in diameter to four sample filters. All of the sampling performed was governed by applicable EPA methods.

4.2 Summary of Results

4.2.1 Comparison of Emissions per Useful Heat Output

In an effort to compare the performance of a wide variety of appliances, the following figures were created to provide some illustrations of the particulate matter emissions based on the amount of useful heat created.

Figure 7 shows the various single room heating, wood-burning appliances tested. The data shows that EPA certified stoves burn cleaner than the older, conventional stoves. Additionally, it appears that for these appliances spruce generally burns cleaner than birch.

Figure 7. Particulate Emissions per Useful Heat Output, Wood Burning Space Heaters

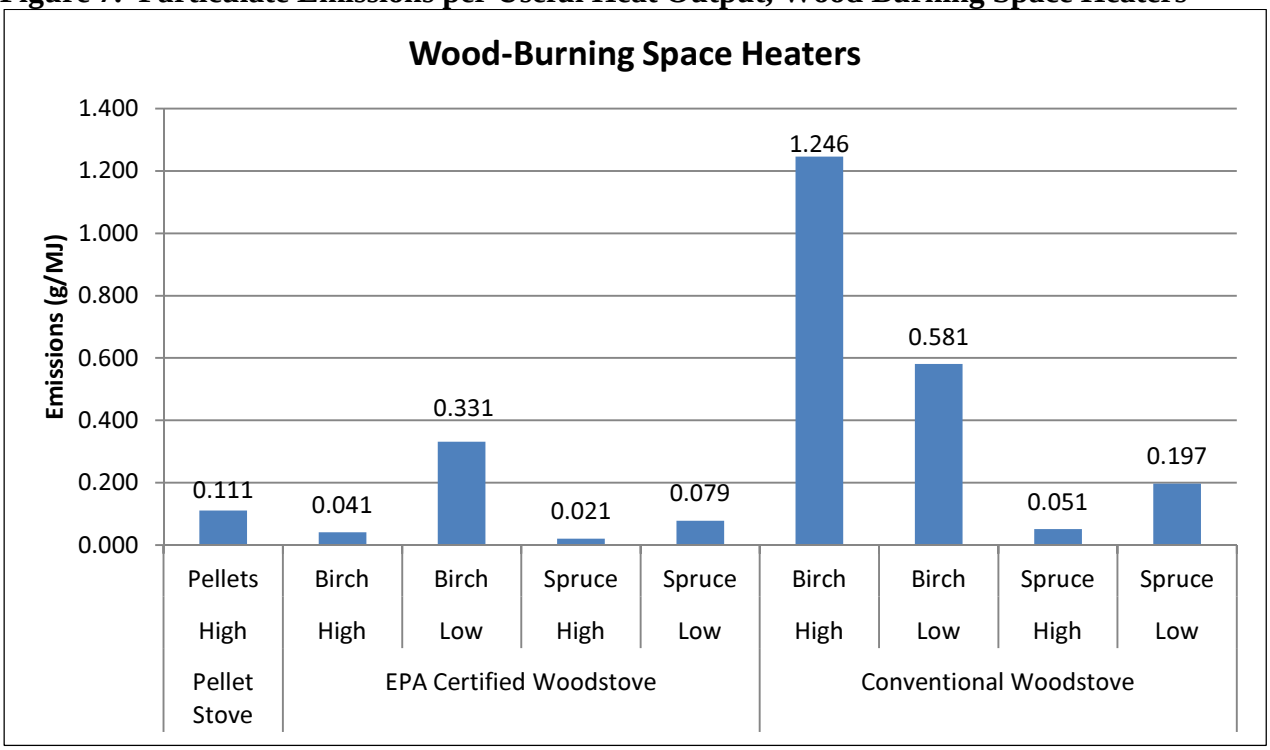


Figure 8 is a comparison of outdoor hydronic heaters, burning both wood and coal. Again, the EPA qualified model is significantly cleaner than the non-qualified unit, which produced extremely high emissions while burning coal. The auger-fed HH, on the other hand, shows that coal can be burned in a clean manner. With regards to the wood burning devices, there does not appear to be a significant difference between birch and spruce.

Figure 8. Particulate Emissions per Useful Heat Output, Outdoor Hydronic Heaters

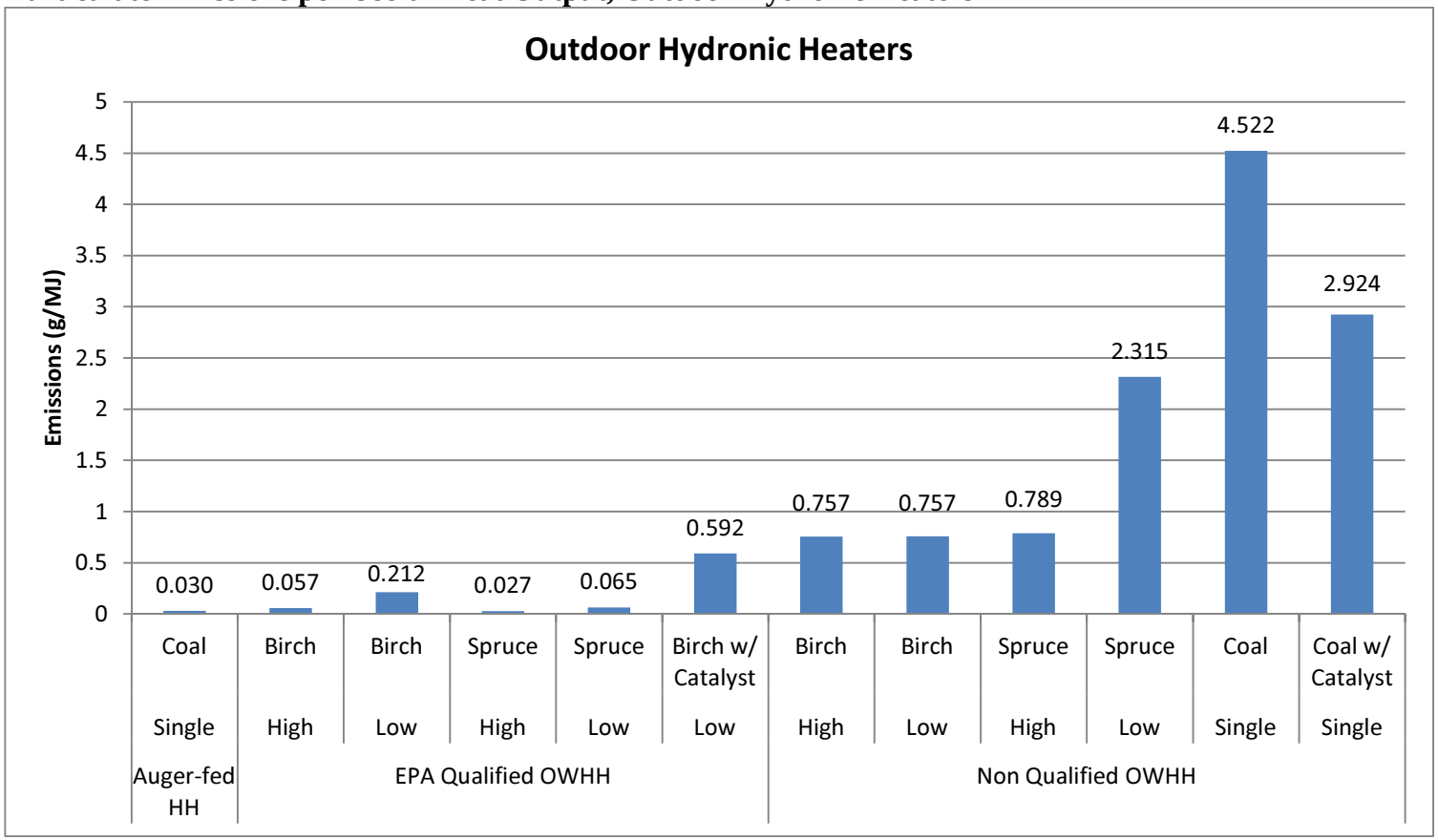


Figure 9 shows the results of the coal-fired room heater. There does not appear to be any particular pattern or favorable fuel based on the available data. Comparing it the wood-burning room heaters, the performance is similar to that of the conventional wood stove.

Figure 9. Particulate Emissions per Useful Heat Output, Coal Heater

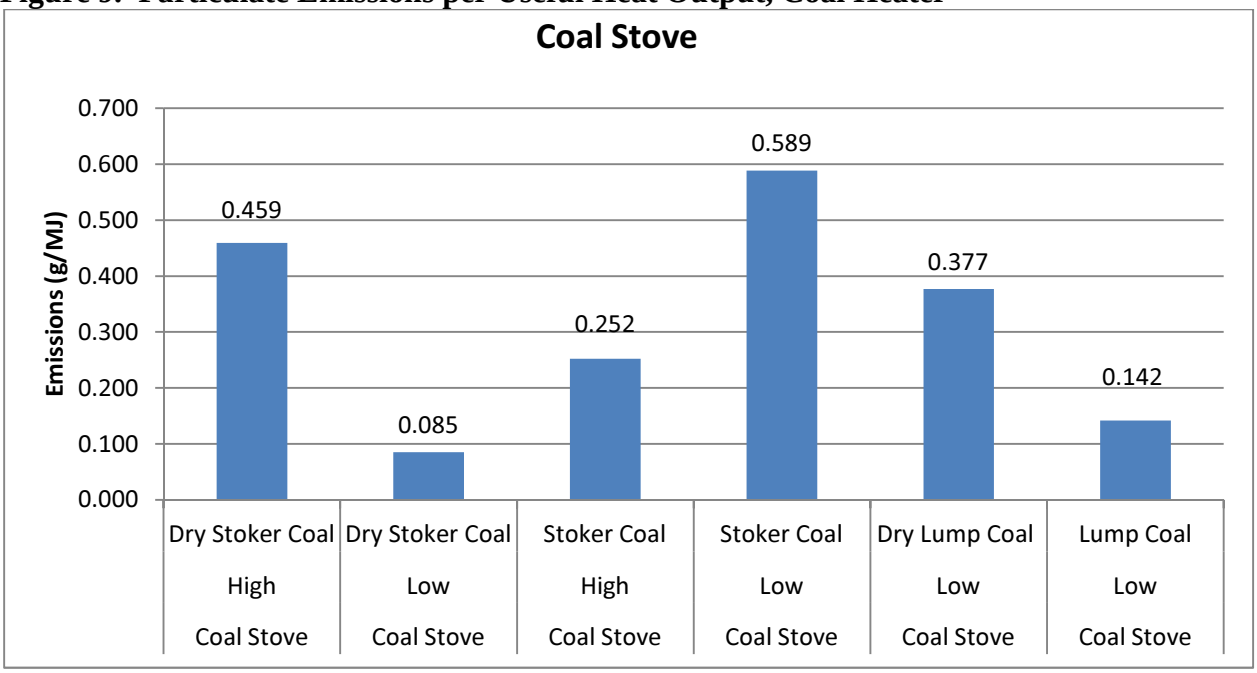
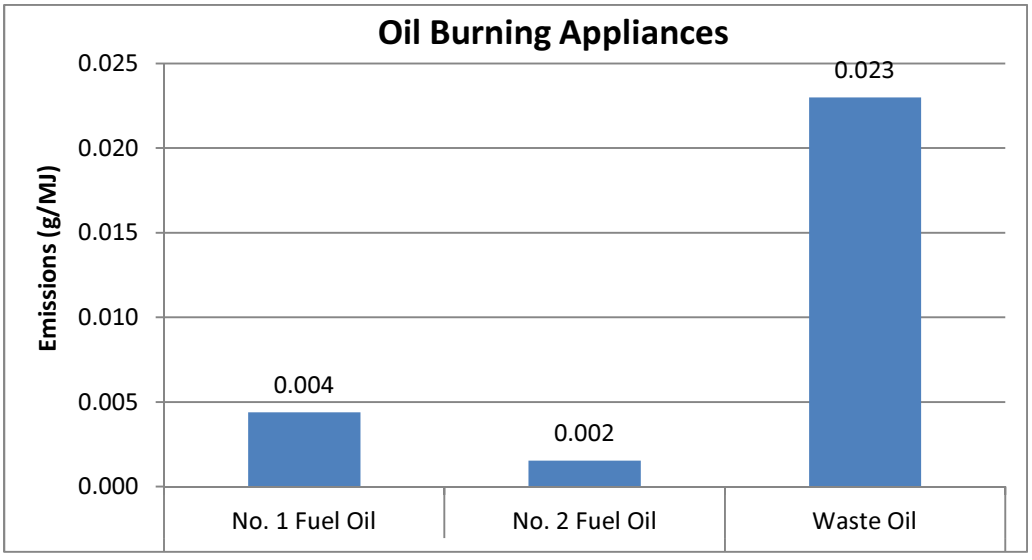


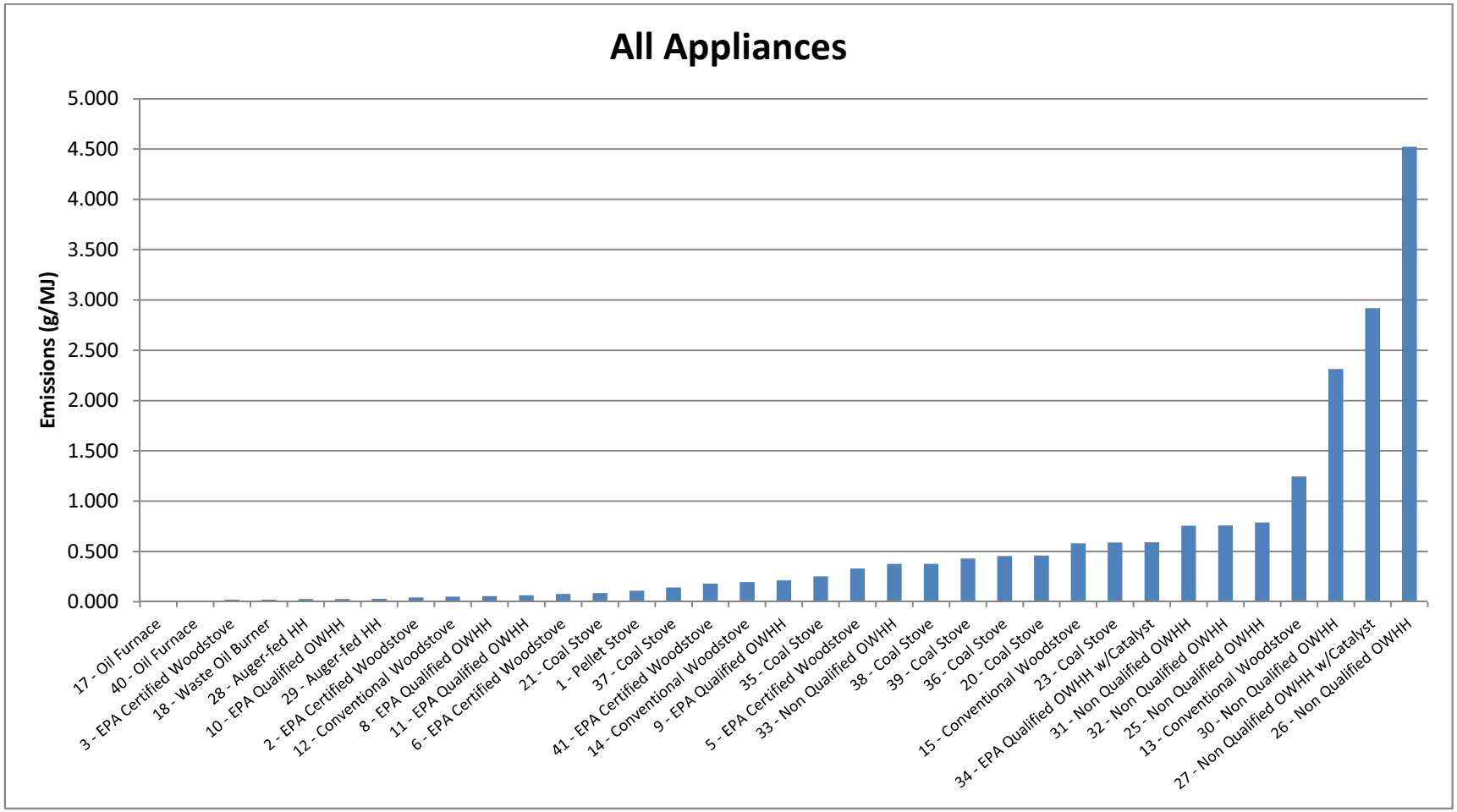
Figure 10 shows that all oil fuels produce low amounts of particulate matter.

Figure 10. Particulate Emissions per Useful Heat Output, Oil-Burning Furnaces



Finally, Figure 11 shows a comparison of all appliances tested. With the exception of some overlap, there is a clear delineation between cleaner burning appliances and high emissions appliances. The models that are EPA certified or qualified are, in general, more efficient and cleaner burning. Additionally, all of the continuously fed units - the auger-fed HH, and the oil units - are designed for optimal burning conditions and efficiency, which is reflected in the data.

Figure 11. Particulate Emissions per Useful Heat Output, All Appliances



4.2.2 Cold Start Comparison

The emissions of a cold start test can be modeled as emissions from each phase (fuel load) of the test, that is, the kindling phase, the preburn phase, and the test fuel phase. Emissions (in terms of total particulate) from each phase are added together to generate total emissions for the run:

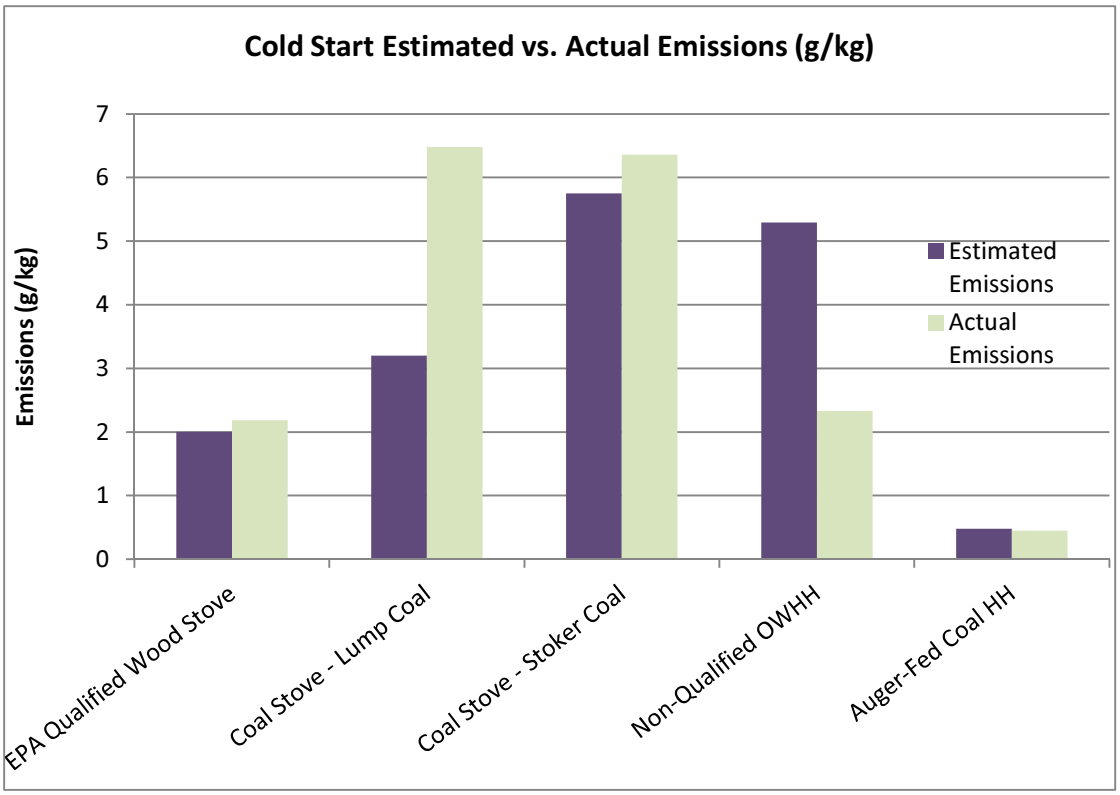
$$E_{Cold\ Start} = E_{Kindling} + E_{Preburn} + E_{Test\ Fuel}$$

Similarly, emissions factors (in grams per kilogram) can be added together to generate an estimated overall emissions factor for the run. These emissions factors come from tests performed earlier in the study. An example governing equation (for a birch low burn cold start) is shown below:

$$EF_{Cold\ Start} = \frac{EF_{Birch\ High}(m_{Kindling}) + EF_{Birch\ High}(m_{Preburn}) + EF_{Birch\ Low}(m_{Test\ Fuel})}{m_{Total}}$$

Using this method, expected emission rates were calculated for each cold start test. These data points were then compared to the actual emission rates for these runs, the difference between the estimated and actual values are presumably the effect of higher emissions from the cold start. Results are shown in Figure 12. The results for the Non-Qualified OWHH seem to be anomalous and are most likely the effect of high variability in a high emissions unit burning large quantities of fuel.

Figure 12. Comparison of Expected and Actual Cold Start Emissions



4.2.3 AP-42 Data Comparison

The issue has been raised that data generated by OMNI for this report are, in some cases, inconsistent with data from AP-42, *Compilation of Air Pollutant Emission Factors*. See Figure 13 for PM2.5 comparison data. This section of the report has been prepared to address the potential reasons for the discrepancy.

Figure 13. PM2.5 Comparison of OMNI and AP42 Data

	PM 2.5 (lb/ton)	
	OMNI	**AP42 [1]**
Conventional Wood Stove	0.9-21.8	30.6
EPA-certified Wood Stove	0.6-8.2	14.6-20.0
Non-qualified OWHH	4.7-25.7	27.0*
EPA-qualified OWHH	0.8-5.3	4.3-8.1*
Pellet Stove	3.0	4.2-8.8
Oil Furnace	0.1-0.3	0.1*
Waste Oil	1.3	7.4*
Coal Stove	2.3-14.2	6.2

*Alaska emission inventory estimates (based on AP-42 or other sources, with assumed fuel properties)

While the coal stove and oil furnace data is similar in both the OMNI and AP-42 studies, for all other appliances the OMNI emissions rates are noticeably lower. The causes of this can be found in differences between the data collection procedures.

A primary goal of OMNI's testing was a high degree of consistency between runs due to small sample size. This was achieved by the use of EPA Method 28, which governs testing procedures for wood-fired appliances. Method 28 was written to assure consistent, comparable results across different appliances, making it ideal for this testing.

AP-42 is intended as a compendium of emissions data. The data collection procedure for wood stove emissions is described as follows in this excerpt from the 5th edition of the report, "The emission factors for PM and CO in Tables 1.10-1 and 1.10-2 are averages, derived entirely from field test data obtained under actual operating conditions." [2] The realism of the reported averages was achieved by virtue of the wide array of differences between the studies, and variability within those studies, which together create a large amalgam of field-use situations.

The data show that Method 28 results are moderately lower than field results. This is strongly supported by data from a field use study very similar to those cited by AP-42, *Long-Term Performance of EPA-Certified Phase 2 Woodstoves, Klamath Falls and Portland, Oregon: 1998/1999*. This study generated field emissions rate values for several stoves already certified by the EPA. A comparison between the emissions rates generated from certification testing and those from field testing is shown in Figure 14.

Figure 14. Method 28 vs. Field Data

Appliance Name	Emissions Rate (Method 28 Certification) [g/hr] [3]	Emissions Rate (field) [g/hr][4]
Hearth and Home Quadrafire 2100	2.0	8.9
Pacific Energy Super 27	3.4	5.2
Waterford Stanley Limited 104 MK II	2.9	4.0
Country Stoves T-Top	5.7	9.9

This data shows that Method 28 results tend to have lower emissions rates than actual field testing. The differences in emission rates between OMNI and AP-42 data are primarily due to this discrepancy.

References

1. AP- 42 *Compilation of Air Pollutant Emission Factors*, United States Environmental Protection Agency, October 1996.

2. ibid.

3. *List of EPA Certified Wood Stoves*, United States Environmental Protection Agency, September 2011

4. L . H. Fisher, J. E. Houck, P. E. Tiegs, J. McGaughey, In *Long-Term Performance of EPA-Certified Phase 2 Woodstoves, Klamath Falls and Portland, Oregon: 1998/1999*, OMNI Environmental Services, Inc., Beaverton, OR, 1999.