January 24, 2012

sierra
research

1801 J Street
Sacramento, CA 95811
Tel: (916) 444-6666
Fax: (916) 444-8373

Ann Arbor, MI
Tel: (734) 761-6666
Fax: (734) 761-6755

Memo to: Dr. James Conner, FNSB

From: Sierra Research

Subject: Critical Review of Draft Report "Measurement of Space-Heating Emissions," dated December 23, 2011, by OMNI-Test Laboratories, Inc.

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The main purposes of this study were to measure emissions and to provide detailed source profiles for chemical mass balance modeling. This memorandum summarizes the results of a review by Sierra Research of OMNI's draft report and data. Consistent with Borough priorities and SIP planning needs, our review has focused on $PM_{2.5}$ emission factors and the data collected by OMNI to develop those emission factors and corresponding source profiles.

Summary of Sierra's Findings and Recommendations

Testing, Analysis and Reporting Shortcomings

In several areas, OMNI's testing, analysis and/or reporting were, in our opinion, inadequate to meet Borough needs. These areas are outlined below and discussed in detail in the later sections entitled "Issues with OMNI Testing/Analysis/Reporting" and "Other Issues/Errata."

1. OMNI tested one emission control device installed on two different heating appliances. However, because of a failure to test the retrofit control device with the feedback air control attached, this supplemental control device testing did not meet the Borough's need for testing that is representative of Alaskan (or other "real world") conditions. Those test results, from run nos. 27 and 34, are of no use to the Borough.

2. OMNI's approach to measuring cold start effects using one integrated filter sample to capture ignition+kindling+coldstart preburn+hotstart testburn was flawed, in our opinion, because it did not provide the measurement of cold start emissions (only) required by the Borough. OMNI's initial analysis of its "cold start" test data was also flawed, in our opinion, for the same reason. Because of these problems, the results from OMNI's (5) cold start tests are of limited use.

3. OMNI found in its testing that the non-qualified (i.e., non-phase 2 certified) OWHH produced “an extreme amount of PM and heat in the flue…far beyond the capabilities of the sampling equipment.” OMNI’s steps to address the resulting problems were extensive. But OMNI did not, in our opinion, demonstrate that those measures were fully successful. Furthermore, in certain cases the test results were counterintuitive, raising further questions about their validity. For these reasons, Sierra does not believe that the results from nonqualified OWHH testing (run nos. 25-27 and 30-33) should be relied upon for regulatory purposes without further validation.

4. OMNI’s analysis and review of its data and its reporting were insufficient to meet the Borough’s needs. OMNI was selected by the Borough to perform this contract in part due to its anticipated understanding, experience, and qualifications in testing and interpreting test results for wood-burning and other space heating appliances. However, OMNI’s analysis, interpretation, and reporting of test results, did not, in several areas, produce and properly identify much of what was critically needed by the Borough from the testing results. In particular, although OMNI’s testing involved a specified matrix of fuels, appliance types, and other factors, and OMNI collected potentially valuable data, OMNI did little more than report the data—missing were the analysis and the insights.

Sierra has attempted to develop this information from an analysis of data in the report along with additional information provided by OMNI. Our summary of these insights is presented in the subsection below. Details are presented in the “Key Findings” section later in this memo, and reflected in the figures and tables appended to this memo.

Insights Gained from OMNI’s Test Results

Notwithstanding the shortcomings described earlier, OMNI’s testing of space heating appliances produced a dataset from which we were able to make several findings that should be useful to the Borough for its SIP planning and emission reduction strategy development. These include those outlined below.

1. EPA-certified wood stoves have a significantly lower PM emission factor (lbs of PM per ton of wood burned, dry basis) than non-certified stoves (see Figure 1, attached). This is important for two reasons. First, it confirms that the Borough’s current strategy of providing incentives to remove non-certified wood stoves is an effective approach, even if such stoves are replaced by EPA-certified woodstoves (which were found to emit 70% less PM). Second, the developed emission factors allowed the quantification of the emission benefits per unit of fuel burned as well as per unit of useful heat output; this quantification provides support for the Borough’s PM emissions inventory and for the evaluation of potential future emission reduction strategies that involve space heating.

2. EPA qualified (phase 2) OWHHs have a significantly lower emission factor than nonqualified OWHHs (see Figure 2). Although OMNI’s testing of the

nonqualified OWHHs requires further validation in our opinion, a qualitative finding of much lower emissions is, we believe, supportable.

3. Emission factors for cordwood burned at” low” firing rate (about 35% of full load) are higher or much higher than at “high” (appliance maximum) firing rate, a result that has been reported by OMNI and others from previous measurement studies with other fuels. Emission factors were also found to be higher for birch than for spruce, which is contrary to the expectation of lower emissions for hardwoods compared to softwoods. These findings, which are detailed later and reflected in the 16 test runs shown in Figures 1 and 2, inform decisions about how and what to burn to minimize PM emissions and will assist both in the refinement of the Borough’s emissions inventory and in providing guidance and technical support for the SIP.

4. Emission factors for coal in various forms (wet/dry, lump/stoker, low/high firing rate) resulted in a range of emission factors with no obvious systematic variation (results for six test runs, shown in Figure 3). While less satisfying than the simple, more systematic patterns observed for cordwood, these findings help to quantify the magnitude and variability of PM emissions from residential coal combustion. This is valuable because residential coal combustion is not explicitly represented in EPA’s AP-42 emission factor compilation. The measurements shown also help to illustrate the substantial emission reduction possible when using augerfed coal compared to a conventional coal stove or coal-fired hydronic heater. (This and other comparisons of emission factors across fuel and appliance types are shown in Figures 4 and 5.)

5. The current OMNI study is the first systematic attempt to identify emission factors from Alaska-specific fuels and popular Alaska heating appliances, and results showed that emission factors with Alaska-specific fuels and appliances tend to be lower than EPA’s AP-42 emission factors (see Attachment A). Better understanding and documenting the differences between the two will help guide the development of an effective and technically defensible SIP.

6. Firing with more homogeneously burned fuels—like oil, augerfed coal, and wood chips—tends to produce lower or dramatically lower PM emissions than cordwood. This observation, which was made by OMNI, lends credibility to the measurements because it is very reasonable to expect that more uniform fuel air mixtures will result in reduced emissions of unburned or partially burned fuel, which contribute to PM; more importantly, however, it is indicative of the large potential benefit of fuel switching. For example, on the basis of grams of PM emitter per megajoule of useful heat provided, OMNI’s emission factors indicate that one conventional wood stove emits about 175 times as much PM as an oil burning appliance that produces the same amount of useful heat.

7. OMNI’s speciated PM source profiles represent the first systematic sampling of the elemental composition of Alaska-specific fuels and space heating devices and, pending further review and comparisons with existing EPA profiles, they are expected to be used for CMB analysis as part of the SIP. However, at least one

profile (Run No. 1, the pellet stove test, which is discussed later) showed problems and should not, in our opinion, be relied upon without further analysis.

8. Waste lubricating oil, burned in a special purpose burner, was tested and found to have relatively low PM emissions compared to the non-homogenous fuels. However, the emissions profile for waste oil shows high concentrations of chlorine, phosphorous, potassium, and zinc, as well as a higher sulfur level than the conventional fuel oils, as shown later.

9. All of the mass profiles provided by OMNI have been compiled by Sierra into percentage mass profiles, and a subset of nine of those has been provided to the University of Montana for review. The subset was selected by Sierra to represent each major appliance type and fuels, as described in Table 1, below. In lieu of replicate tests (which are not available), the last two profiles were selected to provide backup for wood and coal burning in case problems were identified with the corresponding primary profiles above. All of these profiles are currently undergoing review.

Table 1
OMNI Profiles Selected to Represent Specified Source Categories

Run No.	Representation (and rationale)
5	EPA-certified Woodstove (low firing rate is most common, birch is highest emitting)
9	EPA-qualified OWHH (low firing rate, birch)
15	Conventional woodstove (low firing rate, birch)
17	Oil burner (no.2 fuel oil is most common)
18	Waste oil burner (only test of this source)
23	Coal stove (wet stoker coal and low firing rate are believed most common)
29	Coal OHH (wet stoker coal most common, augerfed showed low PM EF)
6	Backup profile for wood burning (EPA woodstove, spruce, low firing rate)
38	Backup profile for coal burning (coal stove, dry lump coal, low firing rate)

10. Emissions measurements for NH_3 collected by OMNI have no direct counterpart in EPA's AP-42 compilation of emission factors. However, Sierra has extracted the emission factor measurements from the OMNI testing and compared them (Table 2, below) with the most closely corresponding estimates contained in the preliminary emissions inventory for the SIP, which are based on estimates by Pechan[1] using molar ratios to CO. As the table shows, OMNI's emission factors, expressed as lbs of NH_3 per ton of fuel burned, tend to be less than the values estimated by Pechan but are generally within a factor of 4-5.

[1] Roe, Stephen, *et al*, "Estimating Ammonia Emissions from Anthropogenic Nonagricultural Sources - Draft Final Report)", prepared for Emission Inventory Improvement Program, by E.H. Pechan and Associates, Inc., April 2004.

Table 2
NH_3 Emission Factors by OMNI (draft report) Compared to Estimates by Pechan based on molar ratio to CO
(All emissions in lb/ton)

Pechan category and EF		OMNI description and EFs*	
Residential Wood, non-catalytic woodstoves, conventional	1.70	1 conventional, noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.386 (0.039 – 0.747)
Residential Wood, non-catalytic woodstoves, low-emitting	0.90	1 advanced (EPA-certified) noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.156 (0.053 – 0.322)
Residential wood, non-catalytic woodstoves, pellet fired	0.30	1 pellet stove, Alaskan wood pellets, low firing rate (~35%)	0.072
Residential wood, boilers and furnaces	1.8	1 non-qualified and 1 qualified OWHH, avg (and range) of 8 tests: 2 units, high and low firing rate, spruce and birch cordwood	0.202 (0.058 – 0.425)

* OMNI's measurements are based on M28 (hot start) tests and are expressed on the basis of dry tons burned; Pechan does not specify whether their measurements are on a dry basis.

The remainder of this memorandum provides additional background on the OMNI testing program and Sierra's review, including the limitations of our review; more detail about testing and reporting issues and about insights from the testing; and other issues/errata.

Background

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The testing matrix was specified by the Borough to meet its highest priority needs for preparation of the State Implementation Plan for $PM_{2.5}$. (A brief description and listing of results from each test is included in Attachment B.)

As specified by the Borough, filters were analyzed by RTI and liquid fuels were analyzed by SWRI. Solid fuels were analyzed by Twin Ports Testing. As of this writing, all of the planned testing has been completed, and essentially all test results have been received by Sierra[2] for review.

Previously, at the Borough's request, OMNI provided (partially complete) draft reports to the Borough dated September 1, 2011, and October 14, 2011, which described those

[2] As of this writing, we are still awaiting final minor formatting changes to the profiles for test runs that were reanalyzed by RTI and clarification of several items by OMNI and RTI.

portions of the test results from RTI and others that were available at the time. In November and December, OMNI provided the remainder of the test results and other requested information to Sierra, including a draft report dated December 23, 2011.

Limitations of This Review

Although Sierra received excellent cooperation from OMNI staff, our review has been limited by several factors, including the following: Sierra did not witness any of the testing; replicate testing was not conducted (or practical) for this limited test program; and, while OMNI performed many procedures and checks that are commonly a part of quality assurance, there was no quality assurance plan per se for the test program.

Issues with OMNI Testing/Analysis/Reporting

1. OMNI's supplemental testing of the retrofit control device did not meet the Borough's need for testing that is representative of Alaskan (or any other "real world") conditions.

A major focus of the Borough's contract with OMNI was to produce emissions measurements that represent typical Alaskan fuels, space heating appliances, and normal operations (consistent with standard measurement techniques, as specified). As part of this effort, OMNI received supplemental funding from the Borough in an amount of more than $25,000 to conduct two tests using a specified retrofit control device. Two supplemental tests were reported as reflected by the data and our conversations with OMNI, but there is essentially no description in the narrative portion of the report of either how tests were set up and conducted or what the results mean. Notably, the report does not state whether the feedback air control system for the retrofit control device was installed and operating during the tests.

It is Sierra's understanding, based on telephone conversations with both OMNI and the control device manufacturer,[3] that the control device manufacturer and/or its representative performed the control device installations and was present during both tests of the device, but that the feedback control system for the subject retrofit device was not connected or operating during the tests. If our understanding is correct that the air control system is, in fact, an integral part of the retrofit control device,[4] the associated test results would not be expected to represent any normal operating condition, nor would they be consistent with the pertinent objective of the project and OMNI's stated intent of measuring "real world" emissions. For these reasons, the results should not be used for emission inventory development, control technology assessment, or other regulatory purposes.

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[3] Personal communications with OMNI and the control manufacturer, November and December 2011.

[4] The control device manufacturer has told Sierra that the furnace air control system is a part of the retrofit control system, and that they were instructed, either by the Borough directly or through OMNI, not to connect it. In contradiction, OMNI has told Sierra that the control device manufacturer was afforded all the time they required to install the control device completely and was present to witness the emissions testing that involved the control device.

2. OMNI's approach for measuring the effect of cold start on emissions represented a compromise between adherence to standard test methods, including Method 28 (which has no provision for cold-start testing) as specified by the Borough, and using a multi-test approach that, unavoidably, is subject to greater uncertainty. However, we believe the measurement as used and analyzed by OMNI to determine cold-start effect was flawed.

Briefly, OMNI used one integrated filter to capture emissions from four test phases: the cold start ignition, a kindling phase (which used a small charge of birch kindling), a high firing rate preburn charge (to prepare the hot coal bed for a Method 28 test), and a low firing rate test fuel charge. OMNI then used a modeling approach (initially suggested by Sierra after the testing was completed) of subtracting the emitted PM mass from the individual phases of the test to estimate the cold start effect. We view this approach as less than ideal because it requires taking differences from several tests, each of which unavoidably introduces additional (g/hr) uncertainties.

Subsequent to our most recent discussions with OMNI on this, we have a slightly revised, and we believe superior, approach to offer, whereby emissions for the ignition+kindling phase (together) are estimated by difference of the composite and two controlled (preburn and test) phases. However, neither this approach nor the one used by OMNI is able to fully compensate for the problematic integrated sampling approach used, which confounds the cold-start, high firing rate phase with the low firing rate main test phase.

Figure 6 provides an illustration of how we interpret the "cold start" tests. The two bars shown in the figure represent grams of PM emissions for the actual composite test (on the right), which had emissions of 38.73 grams, and an attempted reconstruction of that mass on the left, using emission factors from other low and high firing rate tests of the same unit and same fuel type, but using the fuel masses from the composite test. The difference of the reconstructed mass and the measured mass, which is shown lightly colored in the figure, is the mass attributed to the cold start—in this case, 4.67 grams out of the total of 38.73 grams, or 12.1% of the mass.

One may then ask, how do the mass emissions compare for a birch cordwood, low firing rate stove that is cold-started vs. one that is hot-started? The answer, from the figure, is that the hot start stove emits just 30.40 grams (time after time), whereas the cold started stove (after subtracting the preburn high firing rate charge, from the left hand bar), emits 35.07 (4.47+30.40) grams from start/kindling plus low firing rate test charge.

Similarly computed percentages are shown in Figure 7 for three other cold start tests, all of those 3 representing coal firing. The first two of those show relatively larger start effects, which may be real and caused by the relatively higher emission factor of the birch kindling compared to the coal pre-charge and test charge. In the case of augerfed coal (far right bar), the starting emissions are shown as negative, which is not true, but is a reflection of the uncertainty of the estimate showing them to be indistinguishable from zero. However, while not apparent from the figure, that also appears to be the case with the EPA certified wood stove (first bar), where the magnitude of the start effect is such that it likely is within the uncertainty of the measurement, and therefore indistinguishable from zero. This measurement is also far less than the several-fold difference suggested in

OMNI's 2009 report for Environment Canada.[5] OMNI's explanation of this to Sierra is that the Ontario report actually combines low firing rate and cold start and contrasts that result with high firing rate and hot start; thus, it too confounds the cold start effect. Sierra recommends that OMNI make a slight revision to its approach (as outlined above), include a more complete and detailed explanation in its report of how it analyzed the results, and provide a comparison of the current results with the results of Ontario (which appear to be the closest available comparison), explaining why the results are different.

One last interesting observation from Figure 6 is that it also permits an estimate of the effect of cold start upon mass emissions for a unit that burns birch cordwood at high (rather than low) firing rate. Here, we simply ignore (i.e., subtract out) the large contribution from the low firing rate main test charge and treat the preburn high firing rate phase as the main test charge. For this case, the mass emissions for a hot start are 3.66 grams and those for a cold start are 8.33 (4.67+3.66)—this represents a 128% increase, but results in relatively low emissions in either case because the relatively high emission factor associated with the low firing rate is eliminated.

3. Flow rates and filter loadings for the non-qualified OWHH testing (Run nos. 25-27 and 30-33, as listed in Attachment B) exceeded OMNI's testing system capabilities, requiring adaptations and non-standard test methods.

According to OMNI's assessment (p. 13):

> *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.*

OMNI was required to take extraordinary steps (some, but not all of which are detailed in the report[6]) to address condensation problems, filter plugging, and filter overloading, yet, in the end, concluded that all of the provided test results, including those for the non-qualified OWHH, are valid.[7] We are less confident in this conclusion for the non-qualified OWHH results, in part because RTI found that filter overloading clearly did invalidate at least some of the XRF analyses (which had to be redone, as discussed in footnote 6), and also because of the somewhat surprising results for firing at low vs. high firing rate (discussed under the Cold Start issue, below), which tend to contradict the general pattern observed by OMNI and others in wood appliance testing.[8,9,10]

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[5] Pitzman, Lyrik, et al, "Verification of Emission Factors USEPA Certified Wood Heaters (Volume 1)", prepared for Environment Canada, by OMNI, September 8, 2009.

[6] OMNI should identify in the report which runs had filters that were overloaded to the point that RTI concluded that XRF analysis required calibration for individual elements. OMNI should also document in the report that spare duplicate filters were used for the reanalysis and which elements were reanalyzed. If not already done, the emission profile results for any elements that were not reanalyzed in this way for overloaded filters should be removed from the report.

[7] Personal communication with OMNI, December 2011.

[8] For example, in a 2005 study prepared for the Hearth and Patio Association ("PM2.5 Emission Reduction Benefits of Replacing Conventional Uncertified Cordwood Stoves with Certified Cordwood Stoves or

Accordingly, we recommend that test results for the non-qualified OWHH not be relied upon for regulatory purposes.

4. The amount of potassium in the PM emissions from the pellet burner was extraordinary—about 1/3 of the PM mass—and investigation into this by RTI revealed other significant problems with the pellet stove profile, namely "clearly low" mass reconstruction and "very poor" ion balance, according to RTI.[11]

These and other aspects of the Run 1 (pellet burner) test profile should be documented in a stand-alone section of the appendix that includes RTI's assessment. For the main report volume, it should suffice to say that quality control checks on the results for the pellet burner indicate that the profile cannot be relied upon for regulatory analysis, although the relatively high potassium measurement may be sound and is not without precedent, according to RTI.

Additional Detail on Insights Gained from OMNI's Test Results

1. Four tests were conducted with a conventional wood stove and four with an EPA-certified wood stove. Both were reported by OMNI to be popular and representative models in interior Alaska. Each model was tested with two permutations of firing rate (high and low) and with two fuels (birch and spruce), allowing for evaluation not only of the conventional vs. certified factor, but also the birch vs. spruce factor and low vs. high firing rate. A brief description of each test, and the corresponding emissions data are shown in Table 3.

Table 3
Summary of OMNI Test Results for Woodstoves

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lb/ton)
2	EPA Certified Woodstove	Birch	High	0.041	0.977
3	EPA Certified Woodstove	Spruce	High	0.021	0.549
5	EPA Certified Woodstove	Birch	Low	0.331	8.16
6	EPA Certified Woodstove	Spruce	Low	0.079	1.90
12	Conventional Woodstove	Spruce	High	0.051	0.89
13	Conventional Woodstove	Birch	High	1.246	21.79
14	Conventional Woodstove	Spruce	Low	0.197	4.22
15	Conventional Woodstove	Birch	Low	0.581	12.13

Modern Pellet Stoves"), Houck et al of OMNI, appeared to suggest an average increase in PM emission factors (g/kg) of 344% when comparing a high and low burn rate for ten studies.

[9] Differences of <5 g/hr in emission rates might be interpreted as test to test variation, but the high to low firing rate PM emission difference observed for the nonqualified OWHH with birch was 75 g/hr.

[10] Sierra believes that variation in emission factors with load may be one of the key factors contributing to the uncertainty in the emission inventory for woodburning in Fairbanks.

[11] Personal communication with Dr. James Flanagan, RTI, December 2011.

For the woodstoves, Figure 1 shows an average emission factor from the four conventional stoves of 9.76 lbs/ton (dry basis) and an average of 2.90 lbs/ton for EPA-certified stoves, which is a 70% reduction. From the eight tests, all four of the pairwise comparisons (e.g. birch low-firing rate conventional vs. birch low-firing rate EPA certified) show a significant reduction. Similarly, with regard to birch vs. spruce, all four of the pairwise comparisons (e.g. birch low conventional vs. spruce low conventional) show a significant reduction. And finally, for low vs. high firing rate, three of the four pairwise comparisons (e.g. spruce low conventional vs. spruce high conventional) show a significant reduction. The exception is birch low conventional vs. birch high conventional, which shows an inversion of the usual pattern of higher emissions at low firing rate. We see no definitive explanation for this difference, although OMNI noted that the conventional stove had significant air leakage (which OMNI considered typical for an older, conventional stove) and, as a result, it was difficult to maintain tight air control for the "low" firing rate. Thus, if air could be more effectively controlled, the "true" emission factor for birch low conventional (and spruce low conventional) may be higher than was measured.

2. Similar to the woodstoves, four tests were run for each of two popular and believed representative outdoor wood hydronic heaters, a non-EPA-qualified unit and a qualified (Phase 2) unit, with the resulting lb/ton emission factors shown in Table 4 and Figure 2. Although we note a caution about the four nonqualified OWHH tests shown, we see an overall reduction of 84% from the 14.3 lb/ton 4-test average of the nonqualified unit to the 2.32 lb/ton average of the EPA qualified OWHH. Also, the patterns of wood type and firing rate are essentially identical to those observed for the woodstoves, including the inversion of the emission factors for high and low firing rates with birch of the nonqualified OWHH. The reasons in this case are also unknown.

Table 4
Summary of OMNI Test Results for OWHHs

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
8	EPA Qualified OWHH	Birch	High	0.057	1.61
9	EPA Qualified OWHH	Birch	Low	0.212	5.32
10	EPA Qualified OWHH	Spruce	High	0.027	0.769
11	EPA Qualified OWHH	Spruce	Low	0.065	1.576
25	Non Qualified OWHH	Spruce	High	0.789	10.89
30	Non Qualified OWHH	Spruce	Low	2.315	25.70
31	Non Qualified OWHH	Birch	High	0.757	11.85
32	Non Qualified OWHH	Birch	Low	0.757	8.82

3. There was no replicate testing performed that would permit rigorous statistical comparisons of the emission factors reported by OMNI. However, we view the

relative consistency of the results outlined above as a positive measure of their reliability. In addition, Sierra performed a simple multiple regression analysis of the above 16 emission factor test results using a log-linear model. The results, on average, showed the following:

- The lb/ton emission factor (EF) for conventional models was 390% compared to that for advanced (either qualified or certified), i.e., higher by nearly a factor of four;
- The EF for birch was 148% that of spruce;
- The EF for low firing rate vs. high was 134% (and only marginally significant statistically); and
- The EF for woodstove vs. OWHH was not statistically significant.

4. The emission factors for coal burning in a coal stove averaged 8.65 lbs/ton for the six tests shown in Table 5 and Figure 3. They ranged from a low of 2.3 lb/ton for dry stoker coal at low firing rate to 15.1 for wet stoker coal at a low firing rate. However, neither the effects of firing rate, nor pulverized vs. lump coal, nor even wet vs. dry coal were consistent. This may be due to high test variability, a more complex pattern of interactions than can be discerned by six tests, or other factors.

Table 5
Summary of OMNI Test Results for Coal Stoves and Augerfed HH

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
20	Coal Stove	Dry Stoker Coal	High	0.459	13.22
21	Coal Stove	Dry Stoker Coal	Low	0.085	2.32
23	Coal Stove	Stoker Coal	Low	0.589	15.07
29	Augerfed HH	Coal (hot start)	Single	0.030	0.96
35	Coal Stove	Stoker Coal	High	0.252	6.75
37	Coal Stove	Lump Coal	Low	0.142	3.98
38	Coal Stove	Dry Lump Coal	Low	0.377	10.57

This uncertainty in the emission factor for coal stoves is not, however, of much significance for the Borough's emission inventory, as the number of coal stoves is much smaller than the numbers of oil or wood-burning heating appliances. What the uncertainty does show, both for coal stoves and wood stoves, is that there is broad overlap of the two categories, i.e., despite the minor differences in average lb/ton values between woodstoves and coal stoves, there is no real difference between the two with regard to the amount of primary (i.e., direct) PM emissions per mass of fuel burned, and that both coal- and wood-burning produce far more PM than oil-burning.

The one exception to this pattern was the relatively low 0.96 lb/ton PM emission factor for the augerfed coal OHH (also shown in Table 5), which is nearly an order of magnitude below the average for the six coal stove test runs and only a factor of four greater than oil burning. Figure 4 illustrates these and other comparisons between emission factor test means, expressed as lbs/ton for the various fuel/appliance combinations. Figure 5, taken directly from OMNI's draft report, extends the comparison by showing, for each test, the g/MJ of heat output.

5. It would be difficult to overstate the significance of the OMNI study as the first systematic attempt to identify Alaska-specific emission factors representing both Alaska-specific fuel samples and heating appliances that were specifically selected to be popular and representative for interior Alaska. These two simple facts greatly increase the confidence associated with using the OMNI test results for Alaska's PM SIP.

It is also interesting to compare the OMNI test results, where possible, with EPA's compilation of emission factors as represented in EPA publication AP-42.
This comparison is attempted in Attachment A, where it may be seen that for six out of eight comparisons shown, the current OMNI lb/ton test results shown in column 1 are less than the AP-42 results shown in column 3. Exceptions are the coal stove (for which the AP-42 emission factor is really for a boiler, which is not directly comparable), and for the waste oil burner, where results depend (according to AP-42) on the specific ash content of the fuel.

6. There is, as demonstrated in Figure 5, a wide range of PM emissions from the various fuels and space heating appliances that represent Fairbanks. Furthermore, it's clear from the listing of these same emission factors in Attachment B that for the same useful heat output, the most extreme PM emitters can produce as much as 1,000 times higher PM emissions than at the cleaner end, and that even the next cleanest technology produces 3-4 times as much PM as fuel oil. The simple conclusion from this comparison is that a shift from burning wood to burning fuel oil would achieve PM emission reductions as soon as possible.

Other Issues/Errata

p. 3, Table 1. EPA Methods 28 and 28 OWHH are mentioned on subsequent pages but are not shown in Table 1. They should be.

p. 8, Section 2.4. It should be noted somewhere in the report, and this may be a logical place, that all tests with wood burning used cordwood of the specified types, which are popular in interior Alaska, rather than the crib wood of other types (which are specified in the respective test methods). Furthermore, birch kindling was used for the cold starts. Lastly, for reasons of practicality, the testing of each stove/fuel/condition used only one or two firing rates (low and high), as specified by the Borough, rather than four as specified in Method 28.

p. 9, Table 2. Run 27 is identified as a cold start, which is incorrect. It was a hot start (as implied in Table 10, pg 14).

p. 10, Section 2.4.2. The reference to Table 3 should be to Table 4, and in the same sentence, the word “load” should be inserted after “fuel.” A sentence should also be added to describe briefly the cold start of Run 41, which is a deviation from Method 28 and is listed in the table.

p. 15, Sections 2.5 and 2.6. Two sections should be added to describe the retrofit control device testing and the cold start testing, respectively. For the retrofit control device, the report should document the conditions of the device setup and testing as described above.

p. 16, Section 3.3. Regarding the number 1 fuel oil and CO concentration below detection limit, it is suggested that the corresponding entries in Tables 12 and 16 be changed from “0” to “ND” (not detected), which matches the other tables and better describes the results, and that a footnote be added at the bottom of each table to describe “ND”, “N/A” (not applicable), and “>” (exceeded instrument limit).

pp. 17-20, Tables 12-20. We understand that the data contained in the tables (and shown elsewhere in the report) used the initial (erroneous) lab analysis results for liquid fuels, and that these would be updated with the results from SWRI when available. Please confirm that the updated values have been incorporated throughout the report, including in the revised calculations of emission factors, etc. (and not just in Appendix B).

p. 25, Table 20. There is no reference or mention in the narrative of this important summary table. It should be referred to and briefly described in Section 3.1 (pg 16) in place of the reference to Appendix A. Similarly, the reference to Appendix B in Section 3.2 would be more useful if it referred instead to Tables 12 through 19.

p. 26, Section 4.1. It is stated here that “Emissions from eight appliances…were sampled…,” whereas it was stated earlier (p. 1, Section 1), “…nine heating appliances were selected and operated…” There were nine, and p. 26 should be corrected.

p. 27. At Sierra’s suggestion, OMNI provided graphs showing PM emissions per unit of useful heat output. Subsequently, EPA identified a problem with the measurements used to compute the efficiency of qualified OWHHs, and the agency removed the corresponding reported values from its website. OMNI should note this fact in its report, and state that it used the measurement and analysis procedures that were specified in Method 28 as of the time of its report.

On the same page, OMNI correctly notes that spruce generally burned cleaner (g/MJ) than birch, which Sierra also observed to be true on a lb/ton basis. This result is contrary to the general observation from prior testing that combustion of softwoods tend to have higher PM emissions than from hardwoods. OMNI should address this apparent contradiction between its test results and those in the literature.

p. 29. The reference to low amounts of particulate matter from waste oil needs to be qualified. In particular, the large fractions of chlorine, phosphorous, potassium and zinc on this filter, which are probably attributable to fuel oil additives, are noteworthy. The resulting profile from this test (Run 18) appears to be limited to certain elements. (Is this a rerun of a previously overloaded filter? Are there no other filter results which are a rerun of a previous filter and therefore limited in the elements listed?)

p. 31. The emissions bars in Figure 12 should be labeled and, in Sierra's opinion, the results for the non-qualified OWHH should be identified as a subject to confirmatory testing.

pp. 32 and 33. Figures 13 and 14 should instead be labeled as Tables 21 and 22, respectively.

Appendix A. Several tests show blank fields for elemental and organic carbon for the quartz fiber filter sample. It is understood that these are due to filter overloadings that prevented the analyses. That explanation should be included in the report, and indicator, e.g. "NA" (not available) should be used in place of the blank on the pertinent test summary sheets. The same indicator should be used for those elements on the Teflon filter samples that were not reanalyzed by XRF when backup filters were reanalyzed by RTI due to filter overloading.

Appendix C. The real time graphs for several tests show results for several tests that are strongly modulated periodically. This is understood to be due to the automatic OWHH control of combustion air. For several other appliances, it is understood that combustion air was manually adjusted in an attempt to achieve the targeted burn rates. Both explanations should be included in the report.

Appendix E. There is conflicting information about how ignition was performed for the five cold start tests, with one source indicating that a propane torch was used for all, while another statement indicated that a lighter (butane) was used in at least one case. This should be clarified.

Figure 1

(Preliminary) $PM_{2.5}$ Emission Factors from OMNI Testing for Conventional and EPA-Certified Wood Stoves, Using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

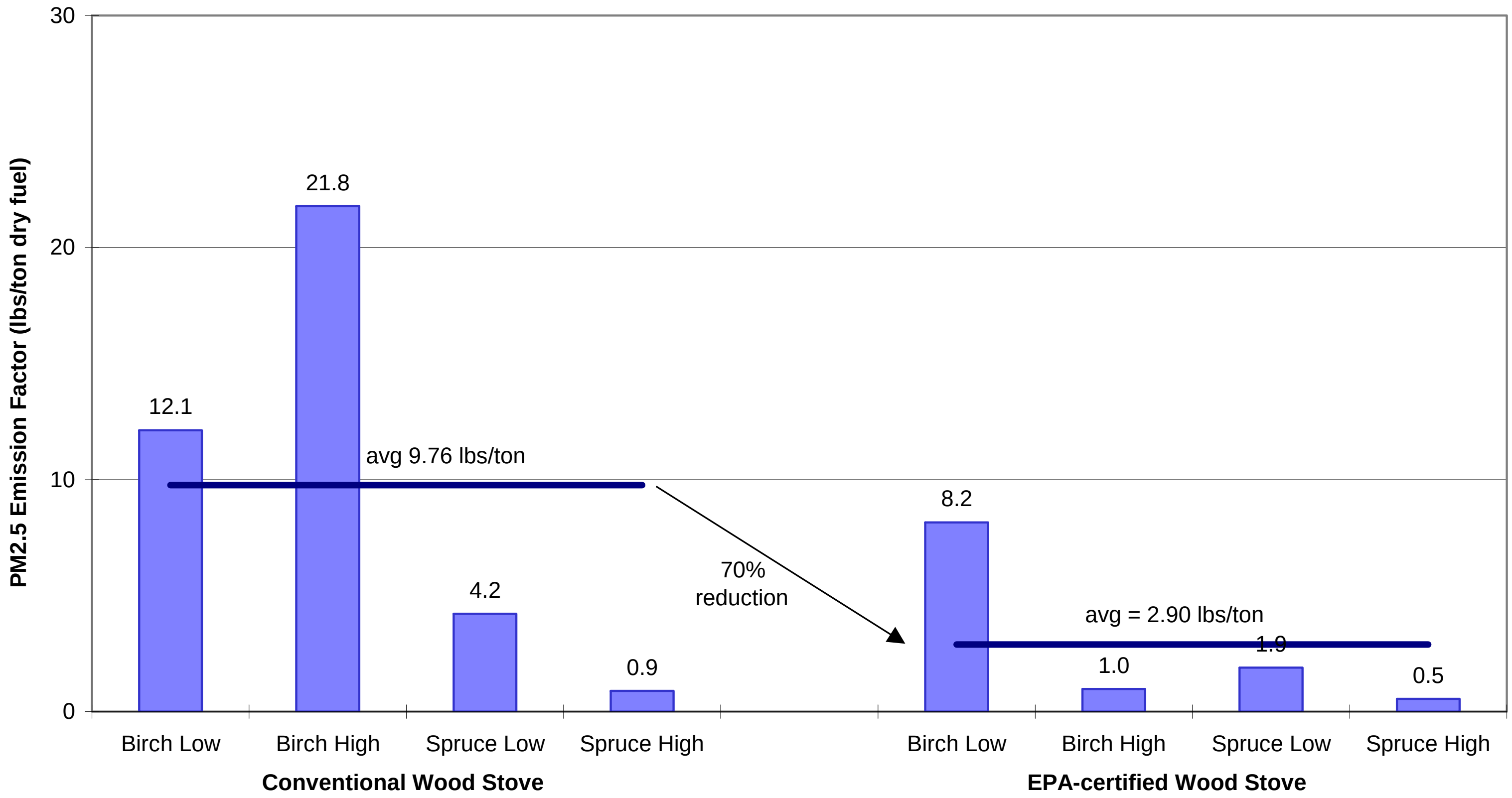


Figure 2

(Preliminary) Outdoor Wood Hydronic Heaters $PM_{2.5}$ Emission Factors from OMNI Testing for "Non-Qualified" and EPA-Qualified OWHHs using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

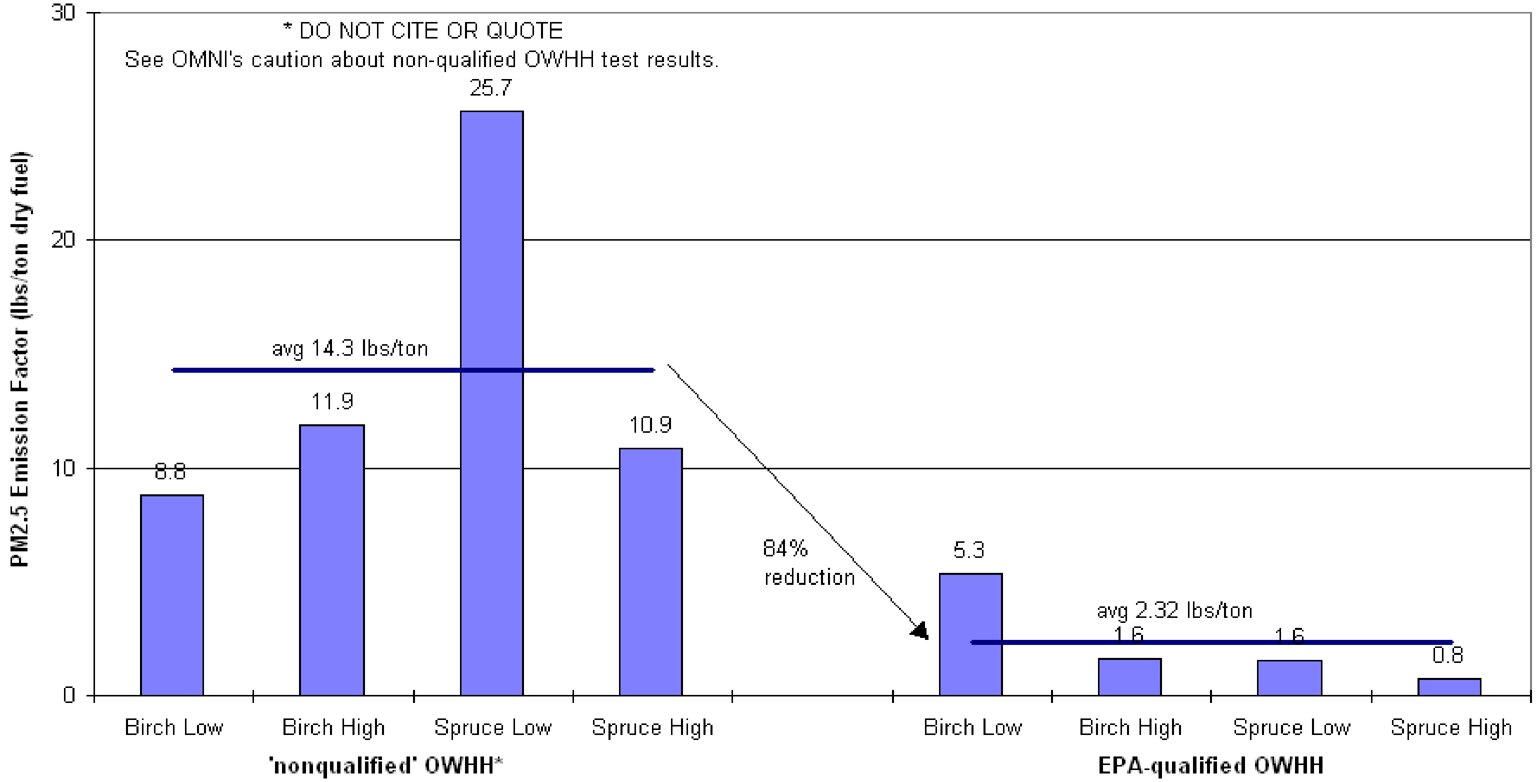


Figure 3

(Preliminary) Coal $PM_{2.5}$ Emission Factors from OMNI Coal Stove Testing for Wet or Dry Stoker and Lump Coal; Low and High Firing Rates; (lbs/ton of dry fuel)

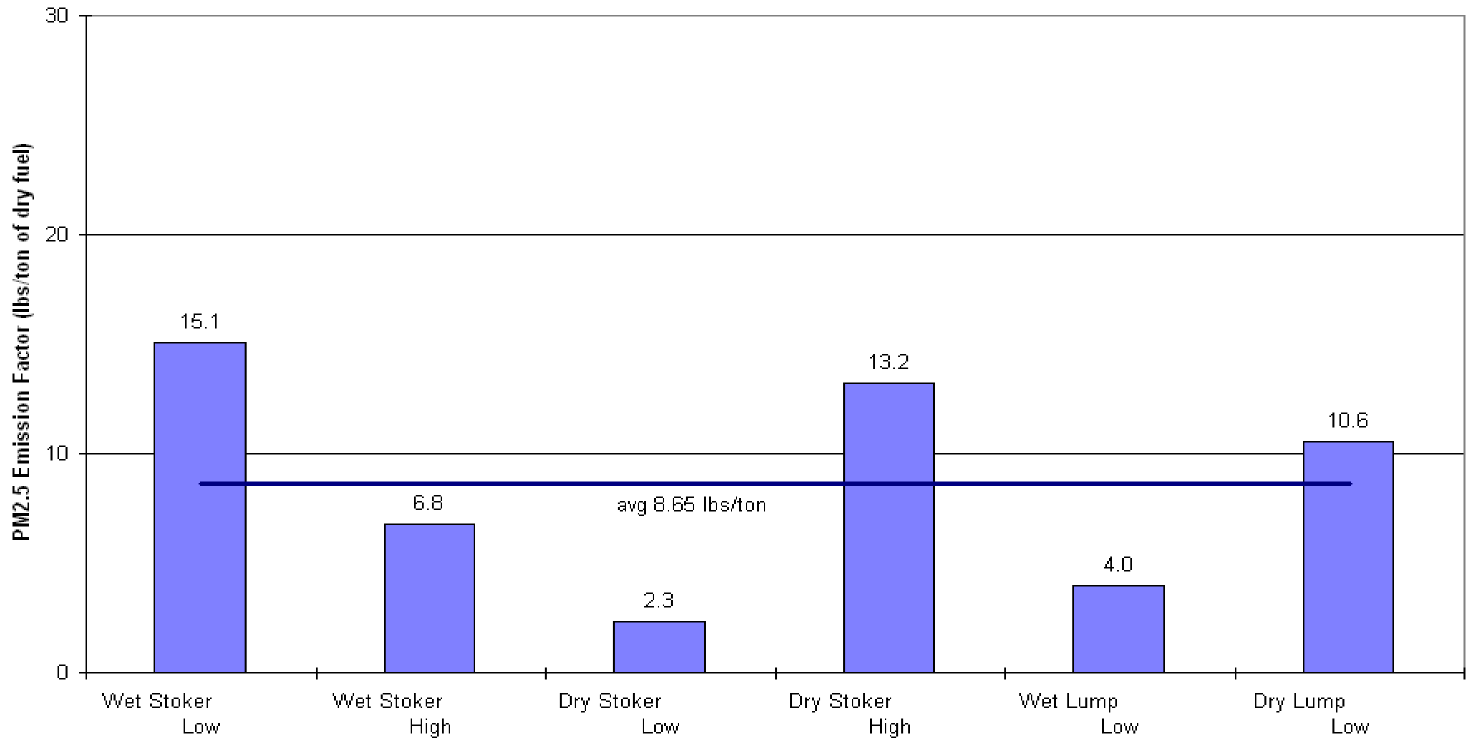


Figure 4

Preliminary Min, Max, and Average $PM_{2.5}$ Emission Factor by Appliance Type from OMNI Testing (lbs $PM_{2.5}$ emitted per ton of fuel burned)

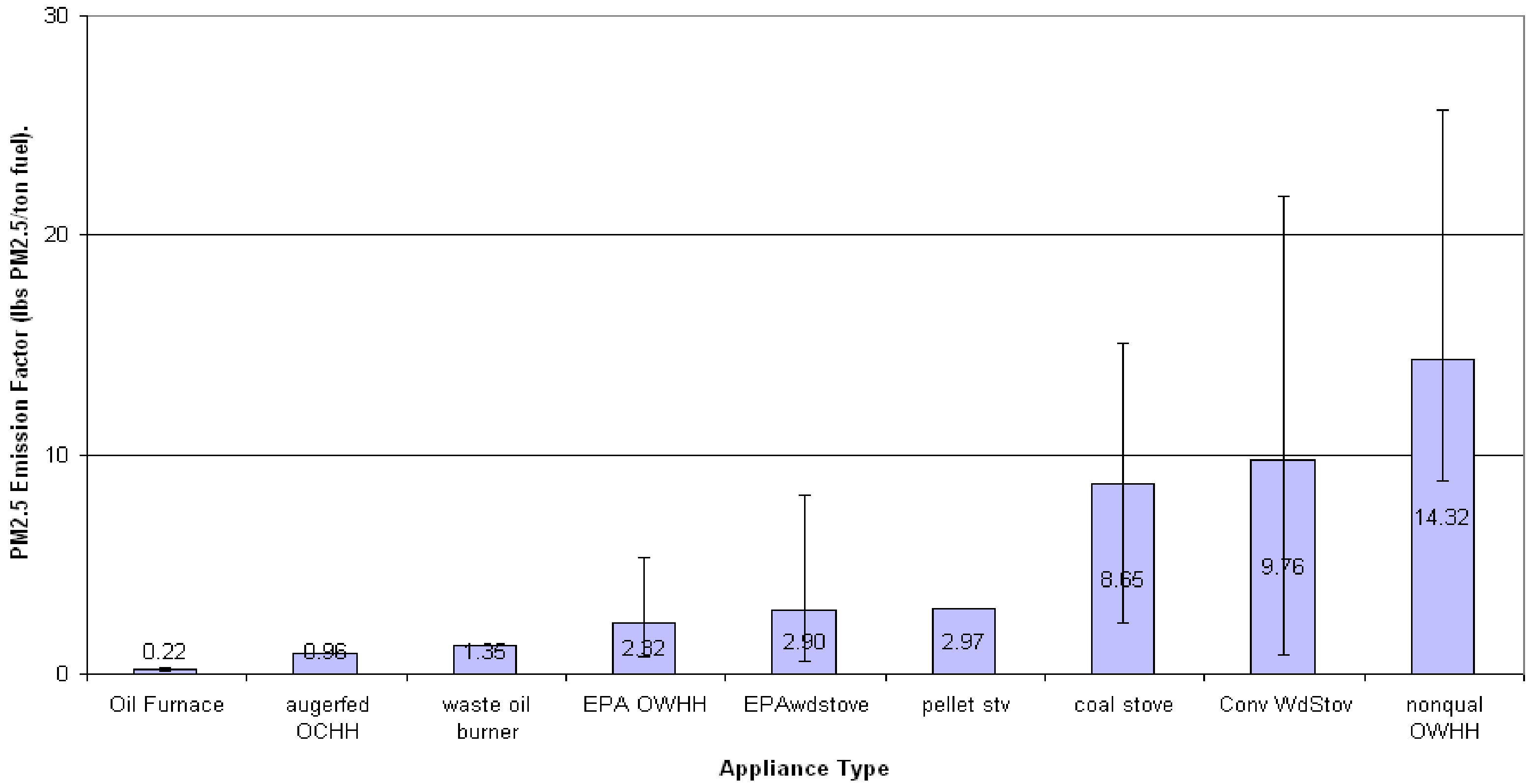


Figure 5

OMNI Preliminary Testing Results as $PM_{2.5}$ Emissions per Unit of Useful Heat Output (grams per megajoule)
(IMPORTANT – raw measurement results, see narrative for caveats)

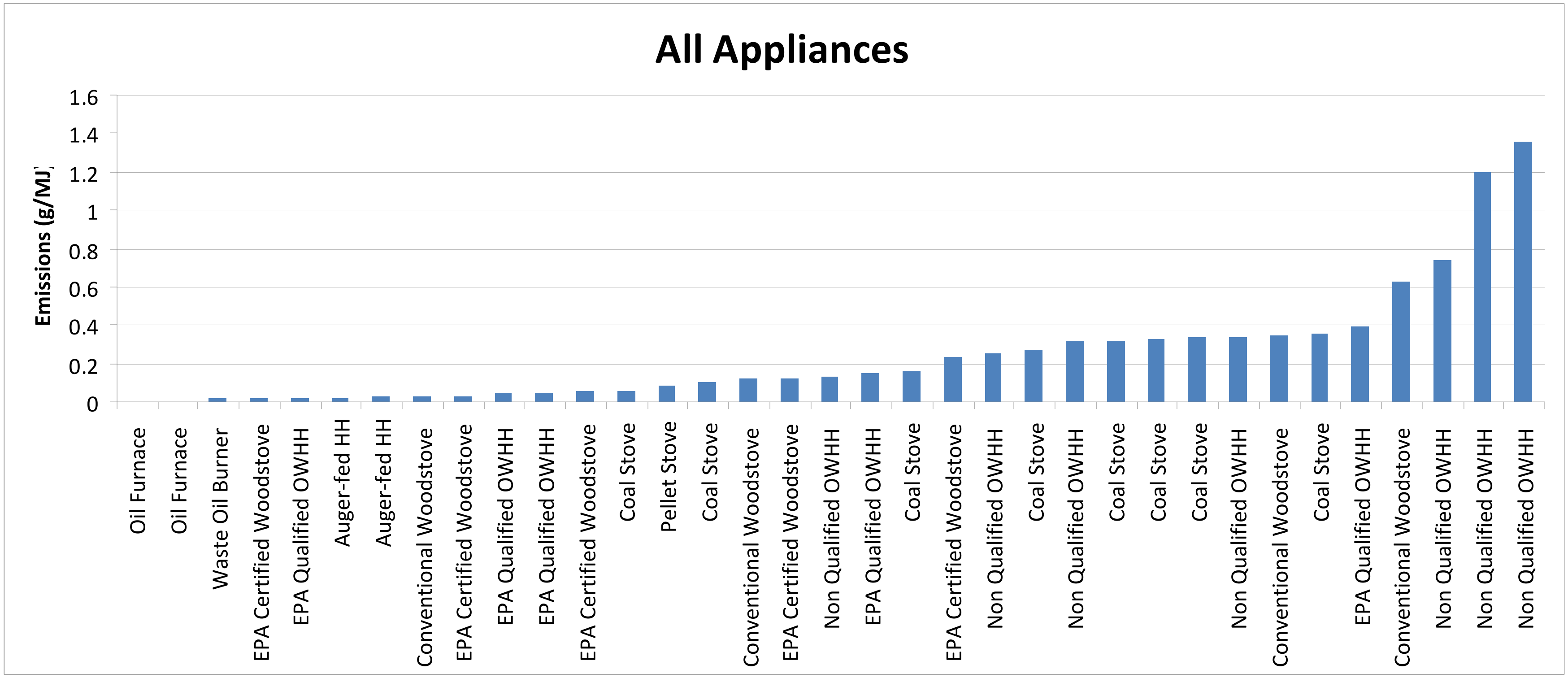


Figure 6

Cold Start Emissions for EPA Certified Wood Stove Burning Birch with Estimated Contribution from Each Test Phase

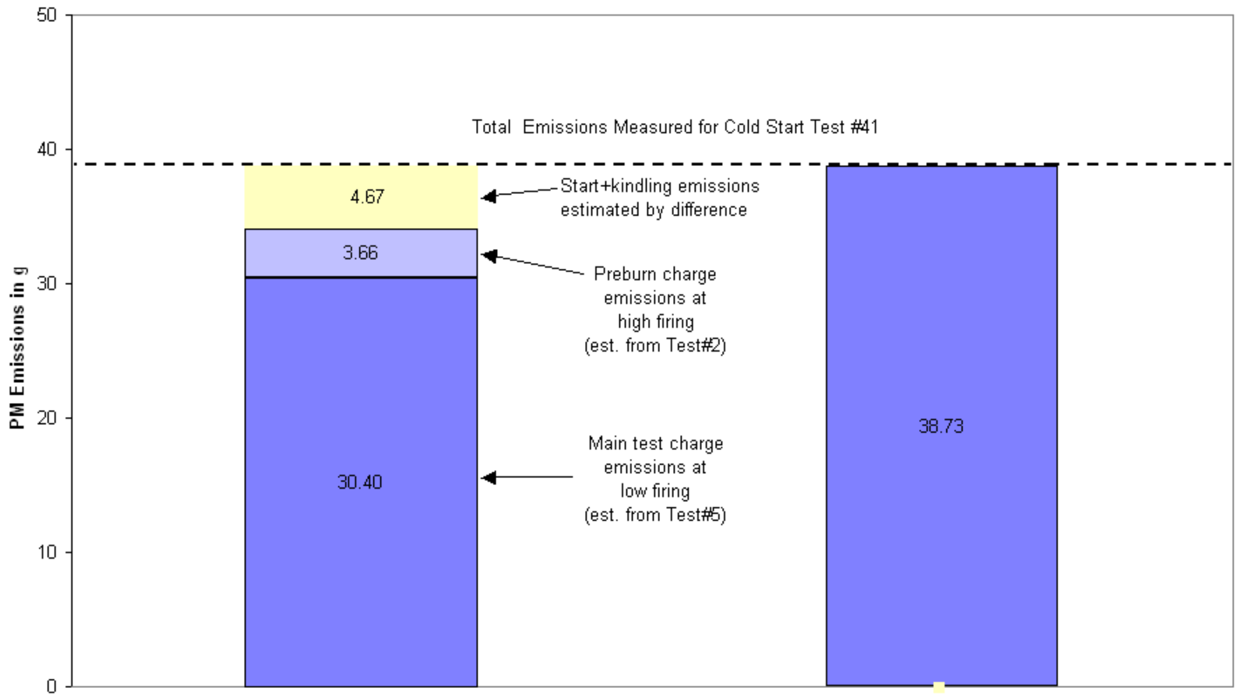
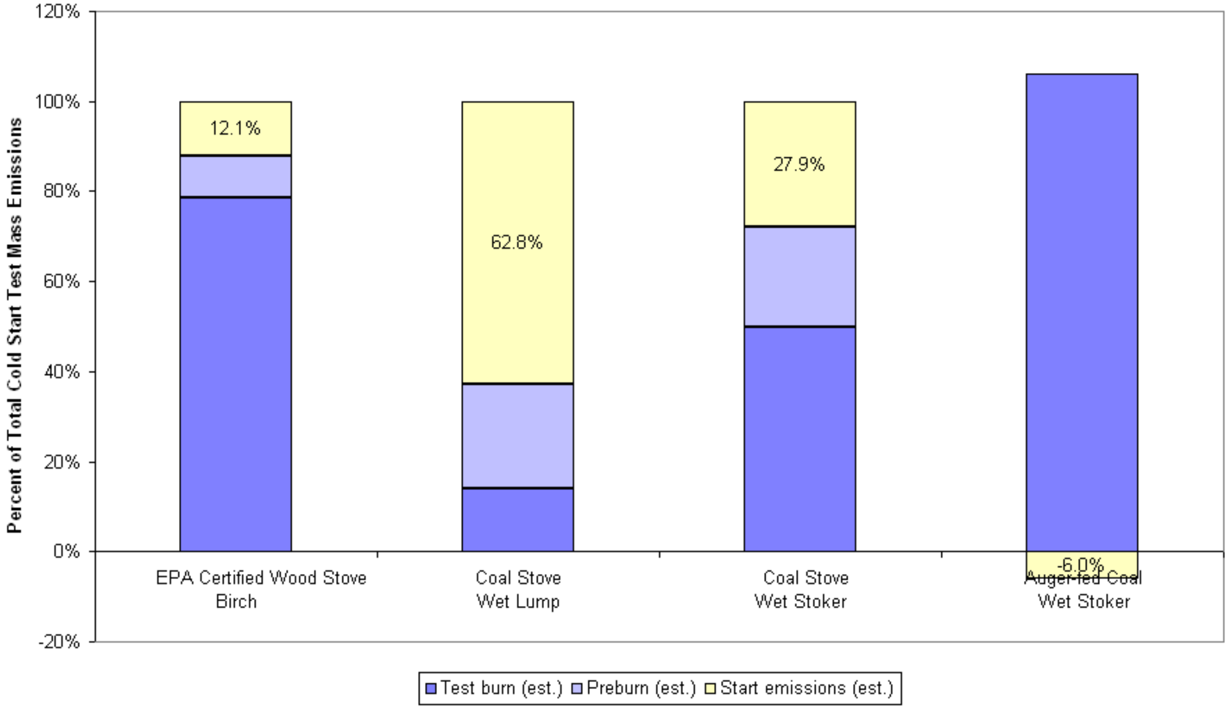


Figure 7

Estimated Contribution of Start+Kindling Emissions to Total Cold Start Test Emissions



Attachment A
Comparison of Selected OMNI PM Emission Factors Measurements (lbs/ton) with Prior Study Results & AP-42

Appliance Type	Current OMNI Testing Avg (range of conditions)	Earlier OMNI Testing of Same Model (fuel & method may vary)	AP-42 EFs (w. assumed or measured fuel properties)
Stove			
• Conventional, wood	9.8 (8.9 - 12.0)	7.1	30.6
• EPA-certified, wood	2.9 (2.4 - 5.3)	-	14.6 – 16.2
• Coal	8.7 (2.3 - 15.1)	-	-
OHH			
• Nonqualified, wood	14.3 (8.8 - 25.7)	-	-
• EPA Ph2 Qualified, wood	2.3 (0.77 – 5.3)	2.4	-
• Augerfed coal	0.96	-	3.8 (boiler)
Pellet Stove	3.0	-	4.2 - 8.8
Coal Stove	8.7 (2.3 – 15.1)	-	3.8 (boiler)
Oil burner			
• No. 1	0.33	-	0.55
• No.2	0.12	-	0.58
• Waste oil	2.97	-	0.17

Attachment B
List of Tests Performed by OMNI and Summary of Test Results

Run	Appliance	Fuel	Burn Rate	PM2.5 Emissions (g/hr)	Emissions (g/MJ output)	PM2.5 Emissions Factor (g/kg)
1	Pellet Stove	Alaskan Pellets	Single	3.31	0.111	1.48
2	EPA Certified Woodstove	Birch	High	1.84	0.041	0.49
3	EPA Certified Woodstove	Spruce	High	1.17	0.021	0.27
5	EPA Certified Woodstove	Birch	Low	6.12	0.331	4.08
6	EPA Certified Woodstove	Spruce	Low	1.68	0.079	0.95
8	EPA Qualified OWHH	Birch	High	10.72	0.057	0.81
9	EPA Qualified OWHH	Birch	Low	14.07	0.212	2.66
10	EPA Qualified OWHH	Spruce	High	5.12	0.027	0.38
11	EPA Qualified OWHH	Spruce	Low	4.32	0.065	0.79
12	Conventional Woodstove	Spruce	High	2.89	0.051	0.45
13	Conventional Woodstove	Birch	High	94.56	1.246	10.89
14	Conventional Woodstove	Spruce	Low	13.16	0.197	2.11
15	Conventional Woodstove	Birch	Low	44.02	0.581	6.06
17	Central Heating Indoor Furnace	No. 2 Heating Oil	Single	0.13	0.002	0.06
18	Waste Oil Burner	Waste Motor Oil	Single	10.41	0.021	0.67
20	Coal Stove	Dry Stoker Coal	High	17.45	0.459	6.61
21	Coal Stove	Dry Stoker Coal	Low	1.74	0.085	1.16
23	Coal Stove	Stoker Coal	Low	11.13	0.589	7.09
25	Non Qualified OWHH	Spruce	High	130.10	0.789	5.45
26	Non Qualified OWHH	Coal	Single	294.60	4.522	27.05
27	Non Qualified OWHH	Coal w/ retrofit control	Single	120.10	2.924	21.18
28	Augerfed HH	Coal (cold start)	Single	7.17	0.027	0.45
29	Augerfed HH	Coal (hot start)	Single	7.78	0.030	0.48
30	Non Qualified OWHH	Spruce	Low	174.00	2.315	12.85
31	Non Qualified OWHH	Birch	High	119.30	0.757	5.93
32	Non Qualified OWHH	Birch	Low	44.47	0.757	4.41
33	Non Qualified OWHH	Birch (cold start)	Low	34.75	0.376	2.33
34	EPA Qualified OWHH	Birch w/ retrofit control	Low	33.82	0.592	6.79
35	Coal Stove	Stoker Coal	High	7.83	0.252	3.18
36	Coal Stove	Lump Coal (cold start)	Low	16.32	0.453	6.48
37	Coal Stove	Lump Coal	Low	2.75	0.142	1.99
38	Coal Stove	Dry Lump Coal	Low	8.19	0.377	5.28
39	Coal Stove	Stoker Coal (cold start)	Low	14.49	0.431	6.36
40	Central Heating Indoor Furnace	No. 1 Heating Oil	Single	0.31	0.004	0.16
41	EPA Certified Woodstove	Birch (cold start)	Low	6.86	0.180	2.18