Operation and Fueling (O/F) Workgroup Meeting Notes from December 15, 2016 Teleconference

(Note: Voting Members are in bold-face)

Meeting led by **John Crouch** (HPBA, Co-Chair of O/F Workgroup) and **Lisa Rector** (NESCAUM, Co-Chair of Steering Committee)

Meeting Invitees (not necessarily all present): Bob Lebens (WESTAR, Co-Chair of Steering Committee), **Rod Tinnemore** (Washington) **& Phil Swartzendruber** (Puget Sound Clean Air Agency), **Marc Cohen** (Massachusetts), **Cindy Heil** (Alaska), John Wakefield (Vermont), **Lisa Herschberger** (Minnesota), Anne Jackson (Minnesota), **Randy Orr** (New York) **& John Barnes** (New York), Adam Baumgart-Getz (EPA OAQPS, Wood Heater NSPS Group Leader), Amanda Aldridge (EPA OAQPS, Wood Heater NSPS Lead), Stef Johnson (EPA OAQPS, Measurement Group Leader), Mike Toney (EPA OAQPS, Measurement Group), Bob Ferguson (Consultant to HPBA, President of Ferguson, Andors & Company), **Tom Butcher** (Brookhaven National Lab, BNL), Rebecca Trojanowski (BNL), Adam Bennett (BNL), **Gregg Achman** (Hearth & Home Technologies), **Allen Carroll** (Applied Ceramics), Rick Curkeet (Intertek), **Ben Myren** (Myren Labs), **John Voorhees** (US Stove), **Tom Morrissey** (Woodstock Soapstone), Dan Henry (5G3 Consulting), Mark Champion (Hearth Lab Solutions), John Steinert (Dirigo lab), Doug Towne (Dirigo lab), Gaetan Piedalue (Polytests lab), Jared Sorenson (OMNI lab), Sebastian Button (OMNI lab), Alex Tiegs (OMNI lab), Kelli O'Brien (ClearStak), Jeff Hallowell (Biomass Controls), Lee Mitchell (Applied Catalysts), Martin Morrill (Applied Catalysts), Jill Mozier (EPA contractor, meeting note taker)

Primary Conclusions from Meeting:

- Lisa Rector gave an overview of the survey results which asked workgroup members to rank list operation and fueling topics for discussion by the group. It was noted that all respondents from labs, industry and consultants wanted to discuss fueling protocols first, while the majority of SLT and federal regulator/agency personnel wanted to discuss operational procedures first. Nonetheless, it was agreed that the topics are inter-related and circling back between operational and fueling issues will likely be necessary.

- Mark Champion gave an overview of his testing for EPA into the effect of wood species on primarily PM emissions and burn rate. Crib testing on 6 different species – Douglas Fir, Red Oak, White Pine, White Birch, Red Maple and Ash – has been performed in a pre-NSPS stove (with little to no control technology) at both low and high burn rates. PM factor (g/kg) is a function of burn rate (kg/hr) and a linear regression appears to correlate very well for PM factor versus burn rate for the species testing, while PM rate (g/hr) versus burn rate is likely to be fit best with a curve rather than linearly. Cordwood testing on several of the 6 species tested as crib wood will likely begin in January. Definitive conclusions have not yet been drawn from the data, although workgroup member expressed interest in understanding the big picture conclusions that may be drawn from this species testing.

- Regarding results from Mark's/EPA's testing, it was noted that it would be helpful for the data to show the length of the burn (due to the importance of the charcoal tail in determining the g/hr PM emission metric). It was also noted that it would be helpful for narrative portions of the results' write-up to discuss why Mark and EPA made the choices that they did for the experimental design.

- Bob Ferguson presented a condensed chronology regarding the wood stove testing Mark Champion performed for the ASTM Task Group (TG) in 2014 and 2015. This testing was meant to inform ASTM's cordwood method development and allow the TG to move past discussion to actual data and observations. Bob's summary memo follows these notes and is also posted to Basecamp.

To-Do List:

- Lisa Rector or Mark Champion will post Mark's data from EPA's crib species testing to Basecamp, once Mark has finished his QA review. George Allen will post his TEOM data to Basecamp taken during Mark's EPA species testing.
- Workgroup members should review George's TEOM data along with Mark's spreadsheet data and write down any questions. Workgroup members are also encouraged to slice and dice the data in different ways and suggest their own analysis to the group.
- Workgroup members should review the ASTM graphs posted to Basecamp along with Bob's memo and write down questions for the next January meeting.
- Lisa Rector will confirm with workgroup members via e-mail that January 12th and 26th work for January O/F workgroup meeting dates.

Highlights from Meeting:

- Lisa Rector opened the meeting noting that Adam Baumgart-Getz and Amanda Aldridge could not join today's call, and Stef Johnson and Mike Toney may not be able to join either. John Crouch noted that Gregg Achman could also not join.

- Lisa Rector noted that the following people were in attendance: Bob Lebens, Mark Champion, John Voorhees, Lisa Herschberger, Randy Orr, Rick Curkeet, Rod Tinnemore, George Allen, John Barnes, Bob Ferguson, John Wakefield, Dan Henry, Ben Myron, Cindy Heil, Rebecca Trojanowski and Tom Morrissey, as well as others who did not announce themselves.

- Regarding the agenda, Lisa noted that this is the only call for December and the next currently-scheduled call is during a NESCAUM Board of Directors meeting on Thursday January 5th. (Note that alternative meeting dates of January 12th and 26th were discussed later in the meeting, as summarized at the end of the notes.) Lisa noted that today's meeting will be a review of survey results and then Mark Champion will present data from his testing done as part of an EPA research effort into wood species.

- John Crouch announced that during today's meeting Bob Ferguson will also walk the group through Mark Champion's work for HPBA over the course of 10 months, as agreed upon in Albany. Bob prepared a summary that is posted to Basecamp (memorandum regarding "Testing conducted to support ASTM cordwood test method development") and Bob will present it today, after Mark's presentation. Bob Ferguson noted that he will post all 5 original ASTM cordwood reports to Basecamp. Lisa Hershberger mentioned that there are 5 summary reports posted to Basecamp. Lisa Rector will put them in the correct folder.

Lisa Rector's review of Survey Results from Rank Listing of Operation and Fueling Topics:

- Lisa thanked everyone for completing the Survey Monkey she sent around regarding listing and ranking the fueling and operational topics the O/F workgroup needs to discuss.

- Lisa noted that Question #1 (Q1) asked the group: should we discuss fuel or operational procedures first? Lisa explained that slightly more respondents wanted to discuss fueling issues/protocols before operational procedures. However, when Lisa looked behind the data to see what group answered how, she noted that all respondents from labs, industry and consultants wanted to discuss fueling protocols first, while the majority of SLT and federal regulator/agency personnel wanted to discuss operational procedures first. Lisa noted that it might be helpful to understand why the two groups had differing perspectives. Lisa offered that she voted for operational protocol first because she thought a lot of fuel questions would follow operational protocol. For example, if it's decided that the operational protocol involve high, low and steady state phased on an existing coal bed (like M28's protocol) then discussing fuel first makes sense. But if, on the other hand, the workgroup is thinking about an integrated run as in the ASTM or beReal protocols, then that would require a different thought process on fuel. Lisa continued that therefore, the operational protocol would guide the fuel discussion in some ways, in order to ensure the fuel could accomplish that operational protocol. But Lisa noted that this is a chicken or egg question in some ways.

- John Crouch asked labs to chime in. Bob Ferguson said the fueling and operational topics are intertwined and the workgroup will have to circle around more than once, no matter which topics the group starts with. Bob noted that he personally does not have an issue with starting the discussion with operational topics. However, Bob further noted that dealing with and managing fuel is such a big part of what testers have to deal with on a daily basis, that it makes sense [to labs and industry] to deal with fueling first.

- Cindy Heil explained that she voted for operational issues to be discussed first because we haven't gotten EPA results from species testing yet. Therefore, it seemed most efficient timing-wise, in Cindy's opinion, to move forward on operational issues while and until the species results come in. Rod Tinnemore agreed with Cindy, noting that he'd like to see the EPA/Champion species results. However, Rod noted that he too is fine with starting on either topic first.

- Lisa Rector suggested that she go through the survey results with the workgroup and then come back to these questions after Mark and Bob give their presentations, noting that people may feel differently after seeing some results of EPA's work.

- Regarding Q2 on the survey "Please order the fueling elements to determine which items we should develop recommendations", the following order of importance was given by respondents: fuel species, fuel characteristics, fuel load weight and fuel loading protocol. Lisa noted that Q2 responses did not have an obvious split between lab/industry and regulatory/agency respondents, as Q1 had had.

- Regarding other fueling issues, respondents commented that:

- The test should not prescribe a generally clean/low emission species. It should be either a higher emissions species, or both a high and low, with shorter tests and more repetitions.
- Fuel load volume is related to fuel load weight. Some folks have reported issues getting the load to fit in the stove using the draft ASTM cordwood method.
- Compare with the ASTM cordwood fueling protocol to see if we are missing something important.
- You will have to discuss fueling first because what you decide to do in terms of fueling will then determine how the stove will be operated.
- Three additional issues: species versus specific gravity, practicality, lab costs

- Lisa noted that the research items in the list are useful. Bob Ferguson had given Lisa a long list to incorporate and Lisa thanked Bob for that list. Bob noted he would like to speak with Lisa about the list before it's shared more widely [as it's in draft form].

- Regarding Q4 "Please order the operational elements to determine which items we should develop recommendations", survey results revealed the order to be as follows:
  - What is the test run cycle;
  - Appliance adjustments;
  - Appliance requirements.

  Lisa noted that Q4 responses did not have an obvious split between lab/industry and regulatory/agency respondents.

- Other operational issues noted include:
  - I think the group/process should make every effort to significantly shorten the testing time for individual tests so that more repetitions can be performed.
  - Explore the application of the procedure to the many emerging designs, e.g., automated stoves, twin-chamber stoves, new designs.
  - End of test marker.
  - Efficiency testing.

- Lisa noted that she wanted the workgroup to think about the fueling and operational issues not as an either or, but rather discuss [for example] what the test run would look like and then go to fuel and volume and then flip back into operational questions. Lisa further noted that she agrees with Bob Ferguson that the two items are linked and so separating them may not make sense. Rather, Lisa suggests that trying to understand what issues flow into each other may be a better approach.

Mark Champion's Presentation regarding EPA species testing:

- Mark Champion began giving his presentation regarding his testing for EPA's initial species characterization in a pre-NSPS stove. Regarding discussion of data, Mark clarified for John Crouch that the QA/QC plan is in place and Jill Mozier confirmed that the QAPP is signed.

- Mark noted he's finishing up the first phase of burning 6 species of crib wood in a 1979 pre-NSPS Vermont Castings stove. Mark explained that the stove is 3 cubic feet and is very old technology which is geared towards efficiency not emissions; so there is very little emissions control in this

stove. John Crouch pointed out that this stove (the Vigilant) was used nationwide all the way to Alaska and all over north America.

- Lisa Rector ensured that everyone understood the rationale of using a pre-NSPS stove [to avoid control technology introducing another variable and potentially complicating the effect of species]. Lisa noted that in terms of trying to characterize the impact of moving from one species to another, the research didn't want to introduce the variable of how well the stove controlled emissions. It was deemed important that the stove not interfere [or interfere as little as possible with the results]. Lisa also pointed out that the results are not looking at the g/hr values for PM, but rather the results are looking for percentage differences [in PM emissions] from species to species. Mark noted that this research is not intended to evaluate the stove, but rather to compare the species. The stove is just a vessel to burn wood. To clarify, Lisa noted that they could have used a campfire for this species research, were that deemed safe enough by EPA.

- Mark presented a table showing the specific gravity results. For each species, samples were cut from dimensional 4x4 crib stock and all block samples were from the same tree for each species. Mark calculated the average specific gravity for each species based on 4 measurements. The average measured specific gravity for the species were as follows:
    - Douglas fir: 0.47
    - Red Oak: 0.69
    - White Pine: 0.33
    - Red Maple: 0.50
    - White Birch: 0.52
    - Ash: 0.58

  Mark noted that the specific gravity for Maple, Birch and Douglas fir were all around 0.5. Mark showed a photo of the 4x4s blocks used for taking specific gravity measurements (4 blocks for each species), noting that he first ensured they were all down to the proper moisture content.

- Mark showed a photo of the cordwood and dimensional lumber, noting that the moisture content goal was 20% and that was achieved for all samples. Mark also noted that for Maple, Birch and Ash the cordwood came from the same tree as the dimensional lumber.

- Mark showed a photo of a typical crib load, noting that it was Method 28-inspired but not M28-compliant, due to stove dimension limitations. Mark noted that this crib was placed on a coal bed formed per M28 using 2x4s of the same species. Some modifications to M28 were used because the Vigilant stove was not designed to burn per M28 and therefore run-away fires could have resulted, and on the other hand some fires went out.

- Lisa Herschberger asked if testing was done on cordwood in addition to crib. Mark explained that only crib testing had been done to-date, that he may do a few repeat tests or gap fillers on crib, and then cordwood burning/testing is next. Mark noted that Adam invites comments and suggestions from the O/F workgroup. All data will be available in a spreadsheet. Lisa Rector further clarified that there will be cordwood testing, but testing had to start with crib since the current test method is based on crib. Therefore, the idea was to first see species changes in crib and then

move onto cordwood. Lisa noted that Stef Johnson had recommended moving in this way with the testing. Mark agreed that cordwood testing would proceed soon.

- Mark showed the following spreadsheet which includes the 5 tests on crib from each of the 6 species (although there were 7 tests on Douglas fir to tune the method and to vary and examine the crib piece length of the wood load). Mark noted that for all other species there were 2 low and 3 high fire/burn tests and that real-time data was collected for numerous parameters including PM, CO, burn rate, stack gas, draft, temperature and load weight.

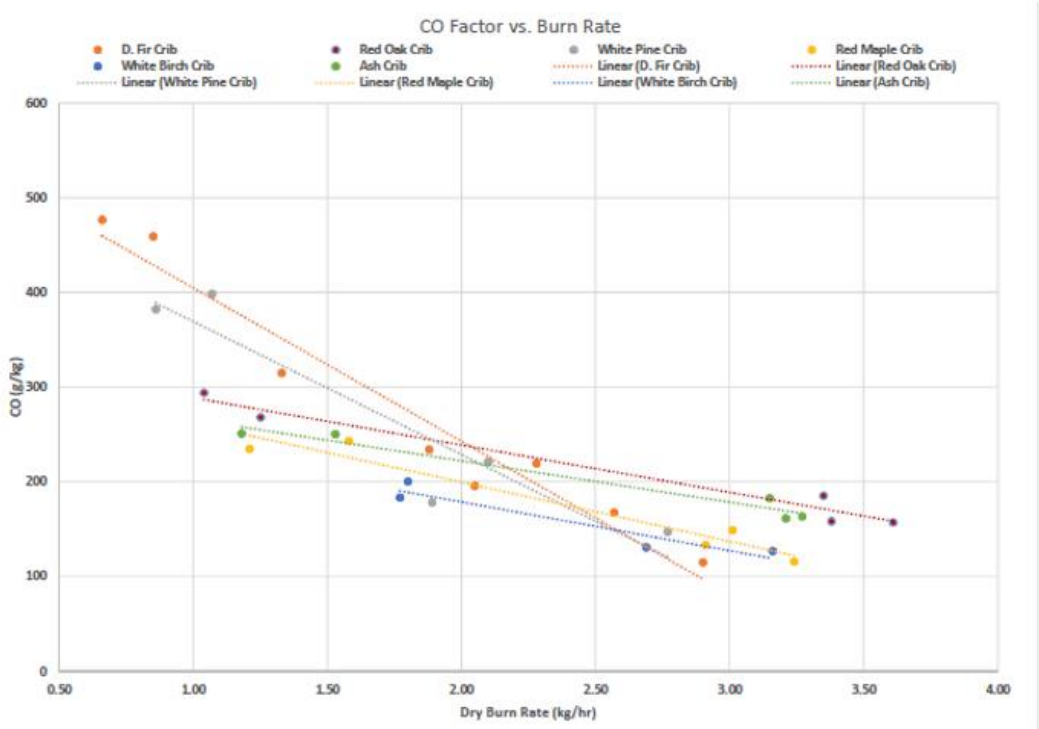
File	Fuel	Test Setting	PM, g/hr	PM, g/kg	CO, g/kg	Burn Rate, dry kg/hr	Train 1 time 0 front catch, mg	Train 2 time 0 front catch, mg	Final PM Precision, %
Vig1608161	D. fir crib	high	27.7	13.5	196	2.05			
Vig1608211	D. fir crib	high	33.4	17.8	234	1.88	54.1	53.9	1.4
Vig1608231	D. fir crib	high	29.5	11.5	168	2.57	34.1	34.2	0.3
Vig1608251	D. fir crib	high	35.1	15.4	220	2.28	33.8	34.8	1.9
Vig1608271	D. fir crib	Low	24.4	28.6	459	0.85	54.4	56.6	0.0
VigOak1608311	Red oak crib	high	37.4	11.2	186	3.35	29.0	28.2	2.6
VigOak1609011	Red oak crib	high	30.1	8.4	158	3.61	21.1	21.0	0.1
Vig1609031	D. fir crib	low	38.1	28.6	315	1.33	66.8	63.4	3.8
Vig1609101	D. fir crib	high	21.0	7.3	115	2.90	17.2	17.5	0.4
Vig1609201	D. fir crib	low	20.6	31.3	477	0.66	44.3	44.2	3.4
VigOak1609211	Red oak crib	high	28.3	8.4	159	3.38	21.3	21.6	1.9
VigOak1609221	Red oak crib	low	36.0	34.5	294	1.04	68.6	67.9	3.7
VigOak1609271	Red oak crib	low	46.5	37.2	268	1.25	106.5	104.4	0.7
VigWPine1610151	White Pine crib	high	32.2	11.6	148	2.77	17.1	17.1	3.0
VigWPine1610152	White Pine crib	high	43.8	20.9	222	2.10	34.3	32.9	0.9
VigWPine1610161	White Pine crib	low	47.1	54.6	382	0.86	92.2	90.4	0.8
VigWPine1610181	White Pine crib	low	58.7	54.8	399	1.07	88.5	86.8	0.8
VigWPine1610211	White Pine crib	high	29.8	15.8	179	1.89	25.0	23.9	2.8
VigMaple1610301	Red Maple Crib	high	34.7	11.6	149	3.01	26.4	25.9	0.1
VigMaple1610302	Red Maple Crib	high	24.2	7.5	116	3.24	16.6	16.2	1.2
VigMaple1610311	Red Maple Crib	low	52.1	43.1	235	1.21	99.6	98.1	0.3
VigWBirch1611031	White Birch Crib	high	36.5	13.6	131	2.69	32.9	31.7	0.4
VigWBirch1611051	White Birch Crib	low	55.1	30.7	201	1.80	78.3	73.3	3.7
VigMaple1611061	Red Maple Crib	low	61.9	39.3	243	1.58	91.8	91.8	0.4
VigWBirch1611071	White Birch Crib	high	23.0	7.3	127	3.16	15.5	15.6	1.4
VigMaple1611151	Red Maple Crib	high	18.8	6.4	134	2.91	13.6	13.6	2.5
VigAsh1611161	Ash Crib	high	27.7	8.6	162	3.21	21.7	21.5	2.8
VigAsh1611171	Ash Crib	high	26.0	8.3	183	3.15	19.8	20.1	0.5
VigAsh1611191	Ash Crib	low	59.5	38.9	251	1.53	106.1	108.6	1.4
VigWBirch1611201	White Birch Crib	low	42.4	23.9	184	1.77	56.2	56.8	0.7
VigWBirch1611221	White Birch Crib	high	19.6	6.3	113	3.08	14.5	14.3	0.4
VigAsh1611261	Ash Crib	low	49.5	41.8	252	1.18	106.2	106.7	0.4
VigAsh1611301	Ash Crib	high	19.8	6.1	164	3.27	14.6	14.8	0.4

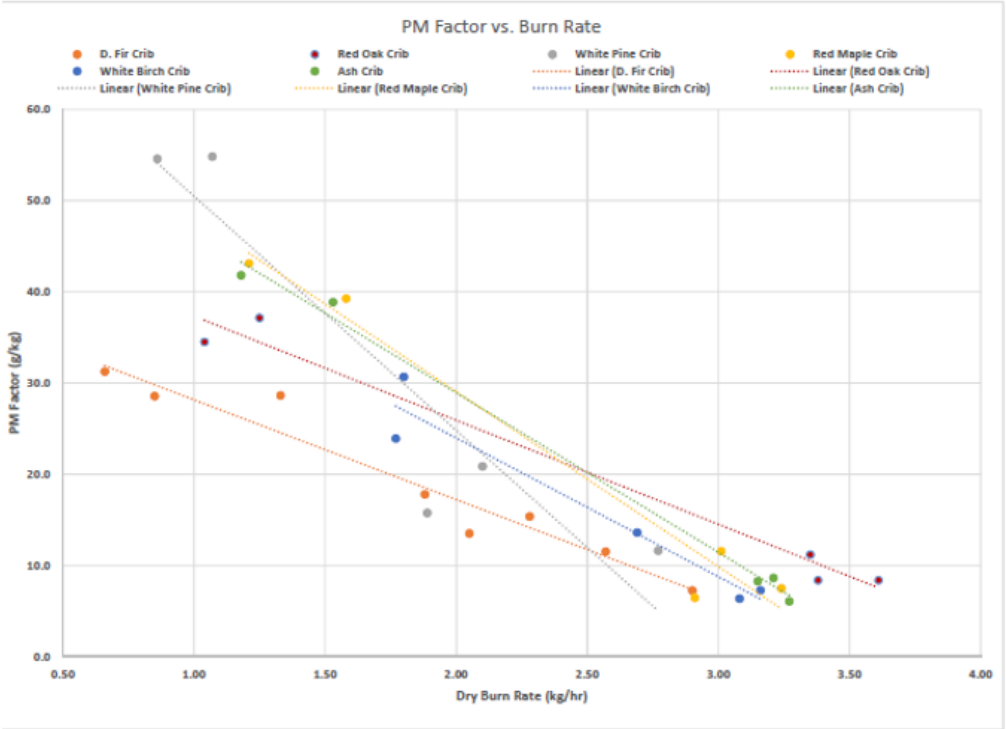
- Mark then displayed several graphs/plots of the data (shown below) for: CO Factor (g/kg) versus Dry Burn Rate (kg/hr); PM Factor (g/kg) versus Dry Burn Rate; PM Factor versus Normalized Load Mass or Normalized Dry Burn Rate (kg/hr); and PM Rate (g/hr) versus Dry Burn Rate.

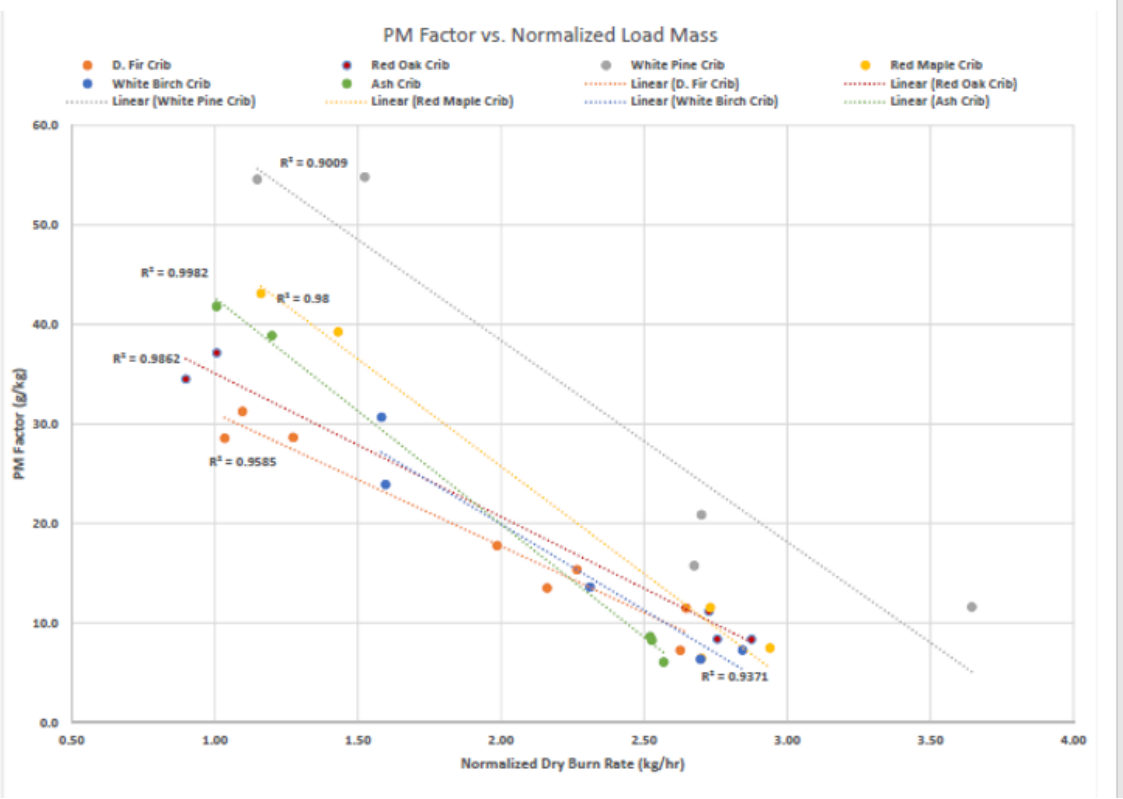
- Mark explained that to the left of the 2 kg/hr dry burn rate was essentially the fixed low burn setting and to the right of 2 kg/hr was the fixed high burn setting. Mark pointed out that the graphs underscore there was a range of burn rates even at the same setting of the stove. Reproducibility appeared to vary as well – for example, Mark noted that the graph suggests that Ash has reproducible burn rates but the burn rates on Douglas fir were not so reproducible.

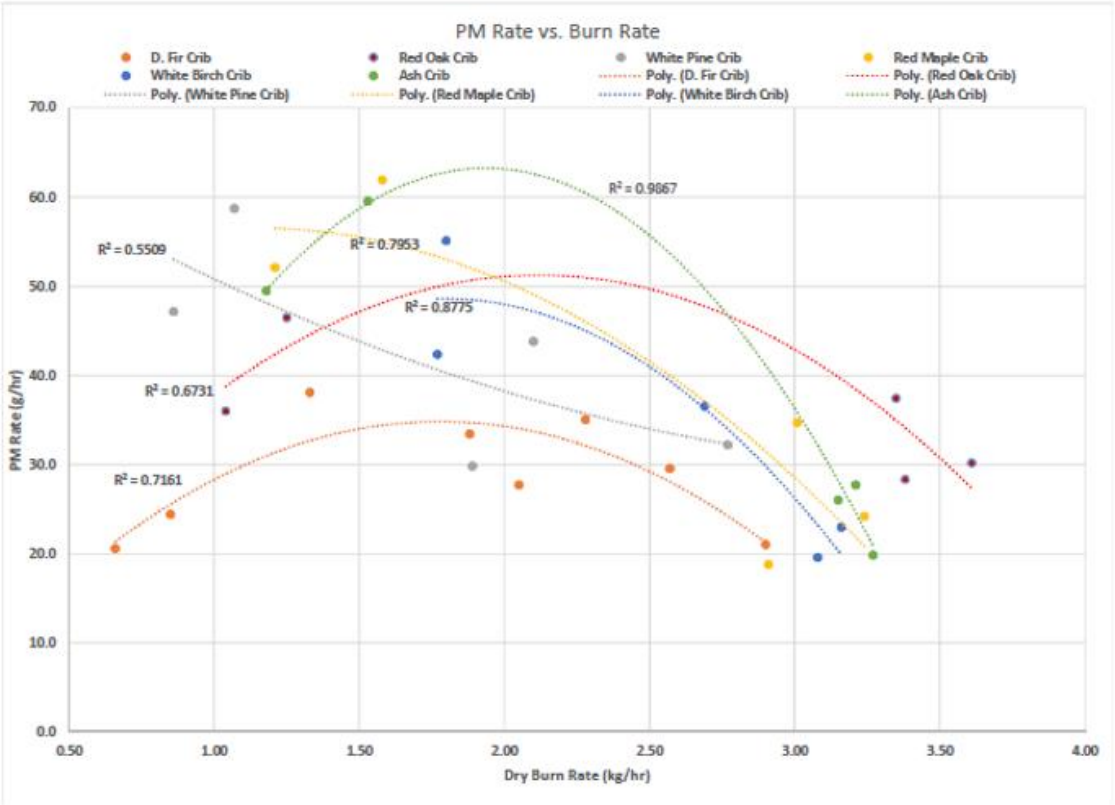
- Regarding PM factor versus burn rate (with regression lines drawn), Mark noted there was pretty good correlation. However, there was variation of burn rates even at the same high setting. Mark therefore attempted to normalize each load to the weight of a Douglas fir load. Mark explained that, due to the higher density of Red Oak for example, there is 60% more wood in the same volume load [when comparing Red Oak to less dense species like Douglas fir]. Therefore, with this extra wood, a higher burn rate is expected. Normalizing to the weight of a Douglas fir load was

meant to account somewhat for the variation in load weight/density, although Mark noted that he's not certain the normalization is entirely appropriate or helpful.






PM Factor vs. Normalized Load Mass
D. Fir Crib
Red Oak Crib
White Pine Crib
Red Maple Crib
White Birch Crib
Ash Crib
Linear (D. Fir Crib)
Linear (Red Oak Crib)
Linear (White Pine Crib)
Linear (Red Maple Crib)
Linear (White Birch Crib)
Linear (Ash Crib)
R² = 0.9009
R² = 0.9982
R² = 0.98
R² = 0.9862
R² = 0.9585
R² = 0.9371
PM Factor (g/kg)
Normalized Dry Burn Rate (kg/hr)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00


PM Rate vs. Burn Rate
D. Fir Crib
Red Oak Crib
White Pine Crib
Red Maple Crib
White Birch Crib
Ash Crib
Poly. (D. Fir Crib)
Poly. (Red Oak Crib)
Poly. (White Pine Crib)
Poly. (Red Maple Crib)
Poly. (White Birch Crib)
Poly. (Ash Crib)
R² = 0.9867
R² = 0.5509
R² = 0.7953
R² = 0.8775
R² = 0.6731
R² = 0.7161
PM Rate (g/hr)
Dry Burn Rate (kg/hr)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

- Lisa Herschberger asked Mark to explain more how the data was normalized. Mark explained that he took the 4.5 kg load of a Douglas fir load and divided that by the actual load [for each and every test run] and then multiplied by burn rate. This effectively adjusted the burn rate for graphical reasons. Mark noted that, in effect, the higher density fuels get burn rates adjusted down and the lower density fuels get burn rates adjusted upwards.

- John Crouch noted that [this normalization] allows comparison of the crib woods by accounting for the fact that more energy is going into the stove with Red Oak with the same volume compared to Douglas fir. John further noted that he likes the effort to normalize to account for different amounts of energy. Mark clarified that one rationale is to give credit to those higher density fuels for giving more heat with time. On other hand, Mark noted that some homeowners may turn the stove down to lower the heat output [from higher density wood fuels]. Mark concluded that the normalization is primarily another angle to view the species question from.

- Regarding the PM rate versus Burn rate graph, Mark noted that he added the curves and that [the data regression] gets messy here. Mark explained that the PM rate graphs look very different than the PM factor graph since PM factor is a function of burn rate, while PM rate is related to the stove/appliance. Mark noted that these curves are not proven and further noted that the experimental design group is discussing possibly filling in middle data points, which may help prove or disprove the characterization [curves] as shown here.

- Mark concluded his presentation, noting that he needs to do a final run-through of the data. For example, Mark had instituted a self-imposed QA trigger for precision and for 3 test runs Mark needs to further QA the results to ensure the results are good.

- John Barnes asked why the curve for White Pine is concave [on the PM rate vs Burn rate graph, while all the other species appear to have convex curves]? Mark replied that the White Pine burned erratically with a poor coal bed, noting that it can't be explained beyond noting that White Pine was not a nice fuel to burn on high or low. Mark concluded that this could be caused by the variation in the coal bed, but the reason(s) can't be known with certainty.

- Lisa Rector asked why [the PM rate vs burn rate] graph uses curves rather than straight line regressions. Mark replied that there's better correlation with the curve than with a linear fit. Mark also noted that he sees it [the curve] in the data and further noted that one can argue that g/hr should go to 0 as burn rate goes to 0. Bob Ferguson remarked that part of the problem is that time [hours] is in both variables [both burn rate and PM rate]. Bob noted that this is reminiscent of Oregon presenting data 30 years ago using curves; there is no reason to expect any straight lines. The g/kg had good R^2 but one stove had a good emission profile at low burns but not at high burns. There are a variety of factors that can explain what was going on in any given stove. The g/hr [PM rate] versus kg/hr [burn rate] have often been represented by curves.

- Mark noted that he could come up with physics that drive the curve(s) in this old [Vigilant] stove. In new stoves, the technology would drive those curves. Mark further noted that while this stove is not a campfire, there is very little technology.

- George Allen noted that it was striking on the lower left portion [of the PM rate graph] that the two Douglas fir low burn rates are some of the cleanest overall, even regardless of burn rates. George noted that he hasn't burned wood before, but he was surprised to see that Douglas fir in g/hr burns as clean at the low burn rate as on the high burn rate. George asked if this was surprising to anyone else. Mark noted that the result is not a surprise but it is a hard to explain mechanism. Mark further noted that those two data points actually line up on the g/kg chart. Bob Ferguson explained that the rate is affected by the device itself and how wood is burning. If the wood is burning slow and the draft goes away, this results in a low g/hr even though the g/kg [may not be as low]. Mark confirmed that the low burn rate data points occurred with very long tails. Bob Ferguson explained that therefore the emissions get cut in half, since time [hour] is a variable in both [the PM rate and burn rate]. John Crouch suggested that in those cases the fire just didn't go out and was burning for a long time [long tail]. John noted that this means the denominator in hours goes up, which drives down the g/hr [PM rate] metric. Mark agreed.

- Lisa Rector noted that it would be helpful to see total burn time in the table. Mark said he could show that. Lisa pointed out for the workgroup that the definition of the end of the test for Mark's EPA testing was burning 95% of the wood load (not 100%) or no scale change for 15 minutes. Mark confirmed this was the definition of the end of the test used and noted that only 2 or 3 test runs stopped because the fire went out or the weight loss criteria was met.

- Bob Ferguson noted that these results emphasize the need to look at data in a g/kg basis. Bob noted that one needs to understand what's happening on g/kg basis before adding in the additional variable of test length. Very different conclusions might be drawn by looking at g/hr versus g/kg. Lisa Rector replied to Bob that she agrees that looking at g/kg is important, but the current metric is g/hr – therefore, both g/kg and g/hr information are needed. Lisa noted that each crib had a different weight and this needs to be look at/considered as well as burn time, since the g/hr is directly affected by the charcoal tail. Mark cautioned care, as some of these results are specific to this stove. Mark noted that he agreed with Bob and that one needs to look at the nature of the wood burning [in g/kg] as that reveals more in this stove.

- Rod Tinnemore asked what was the big picture that this data reveals and asked Mark for his conclusions. Mark replied that he hadn't come to any conclusions, that this data is being generated for EPA, but no conclusions have been drawn yet. Rod noted that the data seems to be confirming some of the variability inherent to solid fuel, but it's hard to see definitive conclusions.

- Rick Curkeet remarked that, if he understands this correctly, it's an experiment on the effect of species on emission rate, with the null hypothesis being that species doesn't matter. Rick noted therefore that the question is, does this prove the null hypothesis incorrect? Rick said the good thing is that the g/kg looks linear for all species – that is, that the emission factors are directly related to burn rate for all species. Furthermore, the slopes are similar – there is not a big difference and the White Pine outlier may be a true outlier, depending on statistical testing.

- Lisa Rector noted that she wanted to remind the workgroup that this data is only based on crib wood testing. Testing hasn't proceeded yet to cordwood.

- Rod Tinnemore noted that he wanted to get to the big picture/conclusions, since not everyone has the capacity to look at big tables of data and interpret them [correctly].

- John Crouch remarked that Rod is segueing the discussion to older data that is cordwood. John further noted that this is good to normalize crib and get this in record for all time.

- Bob Lebens remarked that this information is useful, noting to Mark that it would be helpful to understand why Mark [and EPA] made the choices that they did [for the experimental design] in the narrative portions of the result's write-up. Mark noted that could be done and again noted to the workgroup that Adam is welcoming discussion and comments and these suggestions should be made to Adam.

- Lisa Rector asked if a report will be written up. Mark noted that there would be a report about the results, although he is not sure if it will include analysis. Mark noted that he is not in a position to do analysis, that it is up to larger groups to analyze and conclude. Mark noted that he is shying away from analysis. Lisa noted that she primarily wanted to temper expectations – that is, that a report is not being prepared which will provide analysis. Lisa concluded that this might be a question to ask Adam when he's on the line.

- Mark explained that the reason for linear regression is that PM factor (g/kg) is a function of burn rate and the linear regression correlates very well for PM factor. The data demonstrates the clear linear relationship, although it needs to be statistically validated still.

- Lisa Rector noted that she looks forward to seeing Mark's data posted to Basecamp. Lisa noted that another question for Adam is what's the time frame for asking questions and finding out what other information/data people would like to see. Lisa suggested that people perhaps comment on Mark's data by the next meeting in January. Mark noted he needed to do a final quality review, which would just take a few days, and then he thought the data could be posted to Basecamp. Lisa noted that the workgroup should review the data before January 5th [which may be changed to January 12th, as noted below] or before the second January call.

- Mark noted that he will do more burning/testing, but the moisture content must be within range before proceeding with the cordwood burning. Mark noted that he is currently discussing with EPA doing a few more crib tests to fill-in middle burn rates and do some repeat burns – nothing has yet been decided, but it's being discussed. After any additional crib tests, corwood testing would happen next. Mark noted that how the cordwood testing should be done is being discussed – that is, should the same nominal mass be used, or the same volume, how should the coalbed be prepared, does the cordwood bed need to be the same as crib coalbed, etc. Mark noted that his guess is that cordwood burning will happen in January.

- Lisa Herschberger asked if the moisture content was recorded in the data. Mark replied that yes, the moisture content is recorded for all tests in the data, just not in the summary page.

- John Crouch noted that it was time to transition to Bob Ferguson's presentation. John noted that after workgroup members have looked at Mark's spreadsheet of data, it may be useful for Mark to walk people through the data again with Stef and Adam on the call.

Bob Ferguson's Presentation regarding Chronology of ASTM testing by Mark Champion:

- Bob Ferguson noted that workgroup members asked for a short version [of the chronology of ASTM testing]. Because no additional ground was being gained by discussion, it was decided to start testing a draft of the ASTM method; the ASTM Task Group (TG) members realized that we needed to burn fuel to proceed. So, Mark Champion was contracted to provide supportive testing for the TG. The main reports [produced from the testing] are informal as the process was done dynamically – that is the TG looked at the data, discussed how to modify the approach and then try again before moving onto the next issue. This kind of testing was done on 5 certified stoves that differed in volume, material of construction, whether catalytic or non-catalytic. Therefore, although the sample was small, it was a somewhat representative sample of stove differences.

- Bob noted that the memo he posted to Basecamp [entitled "**Memo regarding ASTM Cordwood Method Development Testing 13.Dec.16**"] is extracted from larger reports to make them read in chronological order. John Crouch noted that Bob's memo was posted to Basecamp yesterday. Bob reviewed his memo for the workgroup, which is attached following these meeting notes. Bob explained that the memo is the summary of the summaries and tracks directly to reports as they are numbered [in the attached memo]. In most cases conclusions and observations were brought back to TG regarding whatever topic was being discussed/examined.

- Bob noted, for example, that the TG tried tying back to M28 where we could, but the loading density from low to high changed with charcoal amount. There was too much leftover start-up fuel. The 10 cubic ft loading density worked for some stoves, but not for smaller firebox sizes. The TG was also interested in the end of the test – that is, when does the test run end. Long charcoal tails were possible on especially big stoves, and on high fire tests, artificially low heat output would result. Therefore, in his testing, Mark looked at visual cues like flaming and what the fuel looked like and Mark brought his observations back to the TG.

- Cold start testing continued with the recognition that the higher loading density resulted in too much charcoal. The recommendation therefore was to lower that high load density. Bob noted that the idea was to get something that would work and then worry about stoves that might be adversely impacted. There's a report that focusses on the end of test. Regarding the "dreaded charcoal tail", Bob noted that the rate of heat output is affected by the long tail, and the g/hr results are also affected by the long tail (making the emission results lower). Therefore, the TG based some decisions on observations, since [for example] homeowners don't have a scale. [Rather than basing things on weight or other parameters the homeowner would not be privy to] the TG just based such decisions as when to re-load on how it [the fuel and fire] looks to the homeowner.

- Bob noted that he was now on page 3 of his memo now. Regarding #4 on page 3 that a different determinant of max heating capability involving the peak burn rate over a prescribed time interval (one or two hours) could be extracted from the high fire test data, Bob noted that this didn't get traction from anyone.

- Bob continued, that how much kindling and start-up fuel to place in the stove also had to be decided. For the high fire, a load density of 10 lb/cubic ft worked okay for most stoves (except the smallest). Maple was used in the testing, which is in the middle of the allowable range [for ASTM's specific gravity range]. For the coalbed, Mark burned down to 10 or 15% of the test load fuel weight and then put the test fuel on. The TG came up with alternative end of 90% of fuel being burned. This 90% point appeared to coincide with place where visually the stove was ready for reloading and the flames were down as well, with the burn rate beginning a rapid decline.

- Regarding the low fire after high fire, Mark and the TG noted that the residual coal bed after the cold-start/high fire burn cycle provided an excellent coalbed for the low fire/burn load and the prescribed loading density of 12 lb/cubic ft worked for all stoves (although it was a tight fit in smallest stoves). Bob noted that EPA M28 has a Delta T (temperature) requirement. ASTM originally had a Delta Q (energy) requirement rather than Delta T requirement, reflecting the fact that small stoves have much different Delta T than large stoves. However, Bob explained that neither the Delta T nor the Delta Q limits appeared to be a problem (related to the stove being hot when it was loaded for the low burn cycle). The TG determined that the end of the test and when to refuel were more important issues.

- Bob noted that he was now on page of his memo. Bob pointed out that it was difficult to define a medium burn rate, but Mark noticed an interesting phenomenon – that is, the stove could achieve a medium burn rate without Mark/the operator having to do anything (see bottom of page 5 onto page 6 of Bob's memo). Mark provided graphical representation of what that looked like, which was helpful to the TG.
- Bob noted that other interesting observations (page 6 item 5 of memo) included that the burn rate at the medium setting was actually above the burn rate at the high fire setting. The reason for this goes back to what Mark said about the mass of wood in the firebox – that is, the fact that the load was 10 lb/cubic ft for the high fire burns but 12 lb/cubic ft for the low and medium fire burns.

- Bob noted that when the TG finally settled on the definition of test runs, then additional work was needed to look at [define] the end of test and how tests can meet medium burn rate requirements. Bob further noted that what would happen if a stove couldn't meet the medium burn rate also needed to be considered, but it was very unlikely that this [failure to achieve a medium burn] would happen with a pre-conceived medium burn rate setting.

- Bob noted that from the fall through the end of 2014 and then in the spring and summer of 2015, little ASTM work/testing was done because that's when everyone was focused on the new NSPS.

- Bob offered that anyone could contact him regarding the graphs and that he's happy to be the ASTM historian and recreate the timeline and discussions. John Crouch suggested that an excellent piece of homework would be for the workgroup members to look at the graphs along with Bob's memo and write down questions.

- Bob concluded that the big takeaway from this [the ASTM experience] is that these questions are brought up hypothetically or based on test data. Therefore, the group must be prepared to come up with their best shot at what will work and ultimately "the proof is in the pudding". Bob explained that the initial values were in some cases not too bad, but were not so great in other cases. The only way to refine test methods was to have data that would address answering a specific question. For processes where the TG wasn't sure, testing was used to try to generate data for how to move forward.

- Ben Myron commented that all of this data has/had great impact on what ASTM did, but it assumes that stoves are not going to change much to burn cordwood cleanly. Ben asserted that's an assumption that needs to be questioned, because Ben's experience says otherwise. Bob replied that ASTM was not trying to stifle innovation in any way. Not stifling innovation was one of ASTM's goals. Bob noted that the other goal was to get something out there. That something [method] was not perfect, it still had lumps, but the method needed to get out there and get people to burn [with it]. Ben agreed but noted that some of this is based on Phase 2 stoves. Ben asserted that, as stoves are designed to burn cordwood cleanly, some of those things will disappear. Bob agreed and again noted that ASTM didn't want to box anyone in. Ben again agreed and concluded that his point is that stoves designed to burn cordwood cleanly will change dramatically.

- John Crouch noted that most people in the industry agree with Ben – that is, once a cordwood test is settled on, the stoves produced will act differently and be more in-line with how stoves burn in the real world [in homes]. John noted the he would like to call attention to the fact that the ASTM group spent a lot of time on the end of test criteria. John further noted that currently [the industry] is stuck with a metric that includes time and it is frustrating for the labs and industry to watch [a long] charcoal tail with no PM emissions. The PM emission part is over [during this tail]. John explained that this is why, as we [the ASTM group] looked at a cordwood method, it wrestled a lot with a reasonable way to define the end of test. In [the current] artificial end of test criteria, we [industry] recognizes that [the method] does something different than what consumers would do. John concluded that consumers would operate their stoves differently.

- Lisa Rector noted that NESCAUM has a TEOM running with Mark Champion's filter data [during his EPA-funded testing]. Lisa explained that the TEOM provides real-time PM measurement and is doing a good job tracking with the filter data. The goal is to gather data to track when the test can be stopped and how much fuel is left at that point. Lisa noted that this will need to be converted back to long tail tests. Lisa offered that George Allen could present some of that TEOM data [during a future meeting].

- Lisa Rector and John Crouch discussed when NESCAUM was available in January for O/F teleconferences and Lisa concluded that January 12th and 26th would work for NESCAUM. Lisa will

e-mail workgroup members including EPA to determine if those January dates will work for everyone.

- John Crouch noted that these January dates give workgroup members more time to create questions for Bob, which is homework for everyone. John suggested that just before George presents his TEOM data, perhaps Mark can go through his data and the O/F workgroup members can ask Mark any questions.

- Lisa Rector noted that workgroup members may wish to look at the data and slice and dice it in different ways. Lisa invited people to give their take on data. George Allen agreed, noting that they were looking for people to analyze the data. George noted that he could probably post the TEOM data to Basecamp next week.

- John Crouch asked the workgroup to look at the TEOM data while looking at Mark Champion's spreadsheet.

- John noted that the group would tentatively meet on January 12th unless that date doesn't work for many people, in which case the workgroup would meet on January 5th without NESCAUM.

- Happy Holidays and Happy New Year to everyone. **Meeting adjourned.**

ATTACHMENT – MEMORANDUM

To: Cordwood Operation and Fueling Group
From: Bob Ferguson
Date: December 13, 2016
Re: Testing conducted to support ASTM cordwood test method development

The purpose of this memorandum is to provide a chronological accounting of the testing, test results, conclusion and recommendations as they emerged from the testing conducted by Mark Champion of Hearthlab Solutions during 2014 and 2015. More complete reports were provide to the ASTM Task Group prior to meetings and those reports have also been made available to all interested parties and have been posted on the OFG Base Camp site. It is important to remember that the testing specifics evolved over time based on on-going test results and after discussion during ASTM Task Group calls and meetings. This testing was conducted using five individual stove models that bracketed size, materials and technology. All models were EPA certified.

There was considerable discussion about the various fuel and operational parameters for many months prior to the recognition that actual testing was needed to fairly evaluate the proposed test conditions within the draft method. The evolution of the test method to the point when the initial test runs began was memorialized in numerous call reports and will not be included here.

Most of what is included here is extracted from the larger reports. Those reports included graphs, charts and photos in various combinations so you will see references to those even though the graphics are missing. As previously mentioned, the full reports were posted to Base Camp for those that want more detail.

The main takeaway from this is that testing was conducted to help inform the ASTM Task Group as they worked through testing details that were proposed for the draft cordwood method. Issues that were uncovered during the testing we given consideration and procedural modifications proposed. Additional testing confirmed whether the issues had been satisfactorily addressed in the method. The latest draft reflects the information learned during this testing program.

It was also fully recognized by the ASTM Task Group that other substantive procedural issues could be anticipated once the method was more widely in use. It was simply not possible to predict if some parts of the procedure would prove problematic for stove models that are less typical in their individual designs. This is just a fact in test method development and the ASTM process allows the consideration of method improvements or corrections at any time. It was the intent to get the best possible initial method completed and out in use so that data could be generated and the method refined as justified by supporting evidence.

Report 1: Nov. 17, 2014

Observations, Conclusions, Recommendations

1. The currently proposed residual start-up fuel weight range at the conclusion of the cold start portion of the high fire test run is 15 to 25% of the test fuel load weight. It appears that range could be lowered to 10 – 20% or even 10 – 15% and provide a realistic fuel loading condition with more available headroom in the firebox for the fitting in the test fuel load.
2. The proposed nominal 10 lb/ft^3 loading density is workable across the range of stoves tested but may result in a very tight load for smaller firebox volume stoves with the wood load very close proximity to the firebox ceiling.
3. The test ending criterion may need more attention. At least with the wood used for this study, long charcoal tails are possible (particularly on the larger stoves). This will reduce output ratings. We are collecting data and looking at alternatives to the current scale driven test end definition. These include visual cues, stove temperature, presence of flaming, etc.

Report 2: Dec. 9, 2014

Additional cold start testing has been conducted since the last conference call. Based on previous test runs, it was decided that adding the high fire test fuel load after the kindling and start-up fuel burned down to 10% of the test fuel load weight represented a realistic loading point based on the visual appearance of the fire. The range in the current draft is 15 - 25% of the test load weight. This range was carried over from previous drafts where the high fire test nominal loading density was 7 lb/ft^3 so the resultant range of residual fuel is would be ~40% greater (10/7's) based on the current 10 lb/ft^3 loading density.

Conclusions Regarding the Residual Start-up Fuel Weight Range

1. Lowering the residual start-up fuel weight range appears to make sense based on the limited testing that has been conducted so far. The currently proposed 25% upper limit (and probably even a 20% upper limit) could result in start-up conditions at the point the test fuel load is added that are not very representative of conditions when a homeowner might actually add the first fuel load after a cold start. There is also some thought that loading at the high end of the currently proposed range could contribute to increased variability of results.

2. Lowering the range to 10 – 15% may be warranted however it should be cautioned that we have a very limited experience base and some stove models may be adversely impacted once this protocol has been more extensively used.

Defining the End of Test for the High Fire Test Run

1. The current draft defines the end of the high fire test run as the point where the full weight of the high fire test fuel load has been consumed. In other words, the point where the scale weight returns to the weight at the time the test fuel load was added to the stove (residual start-up fuel weight).

2. During the recent test runs, it has been observed that the cordwood fuel test runs tend to have long tails, even on the maximum air settings for the high fire tests. These tails have two impacts on the test results that should be fully considered before the test method development can proceed toward completion.

3. The first is that the high fire test burn rate can be significantly reduced if the test run includes a long tail. Test length is the denominator in the calculation. Secondly, the g/h emission rates are also dependent on the test length. Artificially long tails affect the emission rate.

4. It has been observed during the test runs that waiting for the consumption of the charcoal at the end of the high fire test run can add dramatically to the length of the test run, in some cases doubling the test length. This charcoal tail occurs after all volatiles in the test fuel have been consumed (all yellow flaming has ceased) and when PM emissions are almost always negligible. The charcoal is generally in a somewhat compact configuration with the bottom of the pile not engaged to any great degree in the combustion process. This significantly slows the rate of combustion and extends the test time.

5. Several observers of the test runs have opined that a typical homeowner will rake the coal bed and add more fuel well before the weight-based end of test as currently proposed.

<u>Possible Options for Defining the End of the High Fire Test Run</u>

1. Keep the current definition of the end of test where 100% of the test fuel load weight must be consumed. Determine whether the 15% residual start-up fuel weight will adequately reduce the tailing without other adverse impacts to the test procedure or without increasing variability or decreasing comparability of test results.

2. End the high fire test run before the full test fuel load weight is consumed. This may better simulate homeowner operation where fresh fuel is likely to be added once yellow flaming has ceased and there is substantial charcoal bed remaining. There would be deminimus impact on the PM emission capture and the test run would be substantially shorter. A range of 90 to 95% of the test fuel load weight might be reasonable to consider. This might also result in a better estimation of the high fire burn rate and heat output capability of the model. It has been determined that the impact on the CSA B415.1-10 efficiency calculation will be extremely small.

3. Use a visual cue, average surface temperature cue or flue gas cue (or some combination) to determine the end point for the high fire test. It would have to be determined whether this concept will be biased for different stove models and whether it will introduce additional variability to the test results.

4. A different determinant of maximum heating capability might also be considered where the peak burn rate over a prescribed time interval (one or two hours, for example) could be extracted from the high fire test data. This would at least insure consistency in the way rated heat output is determined and would provide comparative information for consumers. At the moment, manufacturers often employ differing procedures for determining their advertised heating capability.

Report 3: Jan. 7, 2015

Thus far, five stove models covering a range of firebox size, construction and technology have been tested using the draft ASTM cordwood test method. Cold-Start/High Burn testing was the main focus however a preliminary examination of Low Burn cycles was accomplished by loading the low burn fuel loads onto the residual coals of the High Burn cycle. Of particular interest during all the testing were issues of load density, reloading points, resulting burn rate measurements (and consequent heat output determination) and test end criteria, all with the intent of mimicking realistic practices likely to occur in field use. While PM measurements were made for all test cycles, these were of less importance for the current work since the results are dependent on the fueling method and that method was changing throughout the course of this testing. A wide range of emissions results was encountered and these are not reported here.

<u>Significant Findings and Adaptions</u>
Cold Start/High Burn:
1. A kindling and start-up fuel mass consisting of 50% of the High Burn mass appears to provide an adequate residual coalbed for the high burn cycle.

2. Load density of 10 lb/ ft^3. physically worked in all stoves but was a tight fit in the smallest stove of the study. (fire wood s.g. average of 0.60, middle of the allowable range).

3. The range of start-up residual fuel (15 to 25% of HB) seemed unrealistically high with both too much unburned fuel and active flaming. Work included examining a lower
bottom boundary of 10% which worked well in four stoves but was not tested in the 2.5 ft^3. Non-cat.

4. Residual fuel conditions (mass, flaming, breakup of coals) can significantly affect the burn rate and emissions results of the High Burn test cycle.

5. Very long coalbed tails can result using the cordwood procedures which impact both heat output and emissions determinations significantly.

6. An alternate High Burn test end criterion of "90%" consumption appears to consistently be a place where visually the stove is ready for reloading, flames are nearly out and the burn rate begins a rapid decline.

Low Burn Cycle:
1. The residual coal bed of a Cold-Start/High Burn cycle provides an excellent starting coalbed for a Low Burn load.

2. Generally, a coalbed range of 10-20% appears realistic and works well.

3. If the High Burn test ends at the 90% consumption point, there can be 40 to 180 minutes of continued burning before reaching the low end of a Low Burn charcoal bed range.

4. The loading density of 12 lb/ft^3 (s.g. =~ 0.60) worked in all stoves but was a tight fit in the smallest of the stoves.

5. Long charcoal tails can result with cordwood fueling. Laboratory instrumentation was automated and unmanned during these tests so opportunities for stirring were not taken. Resulting burn rates, emissions, Delta T and Delta Q measurements must consider this.

6. Given the unmanned, long tails encountered and the fact that Low Burn cycles were started on the residual coals of a stove on its highest setting (i.e., Loaded on a hot stove), Delta T and Delta Q values do not appear to be a significant problem.

7. More attention to the tail end of the Low Burn cycle is needed to determine the need and effect of stirring, possible alternate end points, etc.

Report 4: June 30, 2015

This report provides the preliminary and unaudited results of the continued cordwood testing in Vermont that resumed after the suspension of regular ASTM Task Group meetings (due to resource and time constraints) during the final months of the NSPS process that resulted in the current rules.

There were two primary goals of this testing. The first was to provide data showing the relative emissions of one-hour, start-up only and main load periods during the cold-start/High Fire phase of the ASTM draft method. The second was to explore the starting and ending points of the proposed Medium Fire test cycle and provide burn rate and emissions results for two test- end scenarios (ie. 90% consumption and 100% consumption). Results are reported graphically and can't be easily summarized without looking at the charts.

Report 5: Aug. 5, 2015

A continued analysis of burn rate data generated during the cordwood testing in Vermont was presented. The effort was to look for further Medium Fire definition possibilities in relation to the burn rates achieved on High and Low fire tests. One concern that was voiced during discussions was that it was felt to be important that a physical air control adjustment must be made to a medium air setting achieve the medium burn rate category requirement. Otherwise, some stoves could achieve a medium burn rate by simply setting the air control at maximum and burning 100% of the test fuel load due to a long charcoal tail. It was felt that this was not consistent with user practices. If they want a medium heat output, they will move the control to a medium air setting and that setting must result in less air going to the stove.

Graphs depicting fuel consumption in real time compare the High, Medium and Low fire cycles for each of the four stoves were provided. Two graphs were given for each stove model. The first (% Load Remaining vs. Elapsed Time) can be thought of as the net load weight with the Y-axis normalized to the fuel mass for each firing cycle. The second graph (Calculated Dry Burn Rate vs. % Consumed) shows the burn rate that would be calculated at any given load consumption over the course of each burn cycle. Of particular interest were the relative calculated burn rates at the 90% consumption point for the three firing cycles. These graphs do not include the cold start portion of the High Fire test but only the main fuel load.

Some interesting effects from the graphs were highlighted:
1. Only one of the four stoves (Large Steel Non-cat) exhibited a medium burn cycle which we might expect (until now) with a medium air setting. The medium burn rate, and presumably the heat output, falls right between the High and Low Fire test results for the entirety of the test cycle.

2. The Iron Non-cat stove had a Medium Fire burn rate profile which closely matched the High Fire burn rate until over 80% of the load had been consumed. At that point, the charcoal phase extended the burn time thus reduced the calculated burn rate.

3. The last two stoves (Stone NC and Iron Cat) had Medium Fire burn rates which exceeded that of the High Fire test until 80 or 90% of the medium load had been consumed. In other words, the heat output is presumed higher than the High Fire output until reaching the charcoal phase.

4. Despite the above anomalies, all of the Medium Fire cycles met the current draft definition of "The primary air control(s) for the medium fire test run shall be set so that a dry basis
burn rate that is equal to or less than the mid-point between the dry burn rates for the low fire and high fire test runs is achieved."

5. When looking at these graphs and considering the anomalies above, a few factors may be important. The nominal loading density of the High Fire test was 10 lb/ft^3 while the Medium

and Low Fire loading density was 12 lb/ft^3. This partially explains how the Medium Fire burn rate can exceed the High Fire burn rate for much of a firing cycle. Results are given for a single Medium Fire cycle run at a "best guess" medium setting and may differ considerably with slight setting changes. The data was presented in order of stove firebox volume (largest to smallest) and coincidentally, more "erratic" or "unexpected" behavior occurred as the firebox size decreased. This is clearly unproven but possibly is a factor in a stoves response to reduced air settings.

Additional Data

1. Four additional test runs were performed to provide more insight into the current draft medium burn rate category definition. Past tests have shown the possibility for very long charcoal "tails" when burning the cordwood used in this study (mostly maple, s.g. about 0.6). Of interest was the resulting burn rate when a 12 lb/ft^3 wood load was placed on the required coalbed for Medium and Low fire tests (i.e., the resulting coalbed of a cold-start, High Fire test) and the stove run at its maximum air setting until 100% of the fuel load was consumed. Would the resulting burn rate meet the current Medium Fire definition because of the long charcoal tail? How likely would it be that the Medium Fire definition is missed (i.e., a burn rate above the midpoint of the High and Low measured burn rates) resulting in a test that does not fit any defined category?

Some observations of the data were given:

1. In all but one stove, the iron catalytic, the resulting burn rate of the 12 lb/ft3 high air setting test fell within the current Medium Fire definition (i.e., below the mid-point).

2. In all but one stove, the iron non-catalytic, burn times were appreciably shorter and burn rates were appreciably higher than those measured during the previous Medium Fire tests using throttled air settings.

3. In the case of the iron non-catalytic stove, the high air setting hot-to-hot test had a lower burn rate than the previous Medium Fire test.

One concern expressed regarding the medium burn rate category definition was that a test run might miss the category by having too high of a burn rate despite having a significantly lower air setting. What happened to that run? These test results show that it is unlikely a Medium Fire test would be missed because the burn rate was too high. The definition of the Medium Fire category also includes factors of being a hot-to-hot test cycle, having a higher loading density and running until 100% fuel consumption. These further differentiate the Medium Fire test from the High Fire test and make it highly likely that the required burn rate cap will not be exceeded once manufacturers define an appropriate medium air setting.