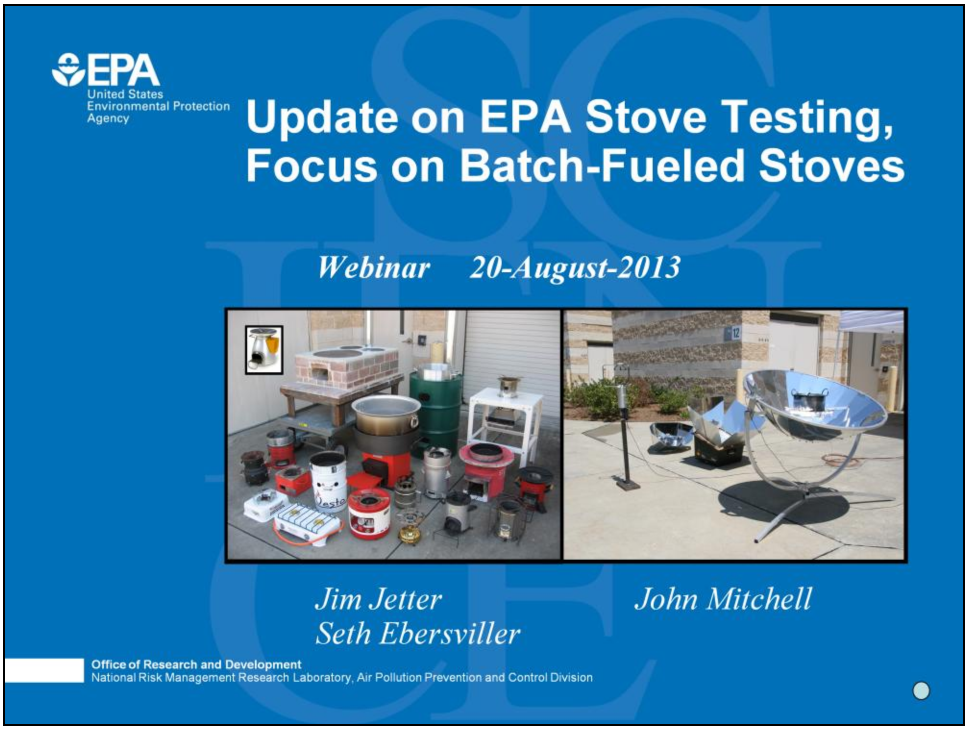

Thanks to Ranyee and the Global Alliance for Clean Cookstoves for hosting this webinar. Thank you all for joining us, and thank you for sending in your questions and comments. We will respond to as many questions as we can today, and if we can't get to them all, we will follow-up and respond to all comments received before, during, and after the webinar. Your input is valuable to us, and we appreciate the continued discussion.

Disclaimers:

1. This presentation has been reviewed and approved by the U.S. Environmental Protection Agency, but the views expressed are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

2. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Purpose of this Webinar

- Provide an update on EPA cookstove testing project
- Present a format (spreadsheet) for sharing data
- Discuss test methods
- Focus on example test results for a batch-fueled* pyrolytic TLUD (top-lit up-draft) cookstove
- Solicit your further comments on methods, spreadsheet, and data sharing

** A batch-fueled stove is loaded with fuel one time per burn-cycle, whereas a continuous-fed stove requires constant fuel metering during the burn-cycle*

2

The purpose of this webinar is to give you an update on our cookstove testing project. Some of you have expressed your interest in our test data (including raw data), as well as test results, so we are presenting a spreadsheet format for sharing data for your review and comments. We want to discuss test methods, especially for batch-fueled stoves, because we have found these stoves are challenging to test. After the webinar today, we will post the recorded session, the presentation slides with notes, and the spreadsheet for your further comments. The first part of this webinar will be on stove testing issues that may be of more broad interest to many of you, and the second part will focus on the spreadsheet that may be of more narrow interest to some of you.

Background – EPA Stove Testing

- Results from 1st round of stove testing published in *Biomass & Bioenergy*: http://www.pciaonline.org/files/Stoves_Paper_Final_Color_2.26.09.pdf
- Results from 2nd round published in *Environmental Science & Technology*: http://ehs.sph.berkeley.edu/krsmith/?p=1387
- Update on other EPA cookstove research activities – details presented at Clean Cooking Forum 2013: https://unfoundation.box.com/cleancookingforum2013/1/827053666/7662532730/1
- 3rd round of lab testing in progress – coordinated with field testing sponsored by EPA Office of Air and Radiation (John Mitchell, EPA)
- Stoves, fuels, and solar cookers were selected for testing through an application process with selection criteria
- EPA is a Partner of the Alliance, but EPA cookstove testing and research is funded independently (by EPA)
- EPA will participate in ISO Technical Committee 285, Clean Cookstoves and Clean Cooking Solutions http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=4857971

3

Here is some very brief background information. We conducted two previous rounds of testing, and results were published in scientific journal articles in 2009 and 2012 – links are provided for your information. If you are interested in more details on other EPA stove research activities, please see the link to the presentation from the recent Clean Cooking Forum. We are currently in the middle of a third round of laboratory testing that is coordinated with field testing sponsored by EPA's Office of Air and Radiation and led by John Mitchell. Update from John ….

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Purpose of EPA cookstove testing

- Provide an independent source of data to Partners in the Global Alliance for Clean Cookstoves
- Produce results and data that may be used for developing testing protocols and standards
- Support the development of Regional Testing and Knowledge Centers

4

The purpose of our cookstove testing is to provide an independent source of data to Partners of the Alliance. We hope our test results, data, and experience will be useful for developing testing protocols and standards. We support the development of the Regional Testing and Knowledge Centers – some of the Centers are sponsored by the Alliance.

In support of the Regional Testing and Knowledge Centers, we conducted a week-long Intensive Training Workshop at our laboratory in North Carolina this year. The Workshop was sponsored and co-hosted by the Alliance. We had 42 great participants from 16 different countries – they were scientists, engineers, and stove testers from many of the Regional Centers. Faculty included folks from EPA, Berkeley Air Monitoring Group, Colorado State University, Aprovecho Research Center, University of Illinois, Food and Fuel Consultants, and the SeTAR Centre. There were classroom sessions and laboratory activities in the EPA Cookstove Testing Facility. The Alliance will sponsor a series of cookstove testing workshops at rotating locations. EPA was honored to host the first workshop to support the development of the network of Centers. For more information, please see the links for training materials and for a communiqué that was issued by the participants.

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Testing Protocols

- Work with Regional Testing and Knowledge Centers focuses on sharing knowledge and good laboratory practices – ***Regardless of testing protocol!***
- EPA will participate in ISO Technical Committee 285, Clean Cookstoves and Clean Cooking Solutions
  http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=4857971
  - Working Groups will include experts from many countries
  - Standards and protocols will be based on consensus and best practices
  - Process will likely be three years
- In the interim, we are using:
  - ISO International Workshop Agreement (IWA) 11: 2012
    http://www.pciaonline.org/proceedings/iso-international-workshop-clean-and-efficient-cookstoves
  - Water Boiling Test (WBT) Version 4.2.2
    http://community.cleancookstoves.org/communities/home/22
- Other testing protocols are used by some labs

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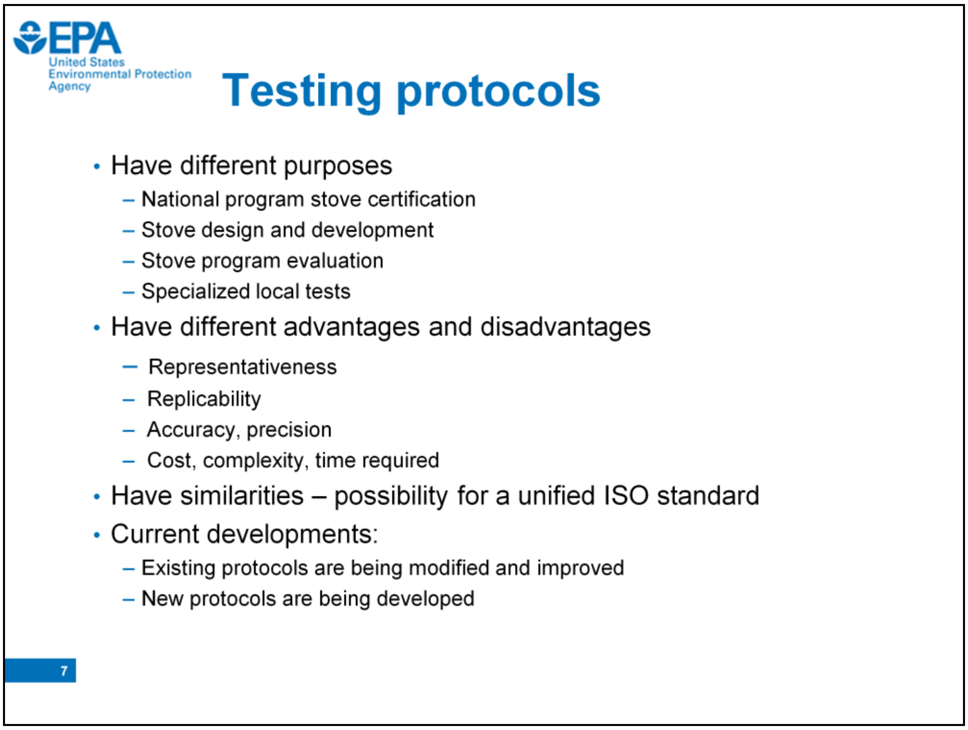
Our work with the Regional Testing Centers focuses on sharing knowledge and good practices – Regardless of the testing protocol that is used! As John discussed, we will participate in the ISO process to develop standards and test protocols for stoves. At first, the ISO process seemed a bit complicated to me, but now I understand that the real technical work of developing and drafting standards and protocols will be done by Working Groups that will be inclusive of experts from many countries. Standards and protocols will be based on consensus and best practices. The timeline is likely to be three years, beginning sometime after the first ISO meeting in November. We are testing stoves now, and we can't wait for three years for a final standard. So in the interim, we are using the guidelines from the ISO IWA and the Water Boiling Test protocol – links are provided. There are different water boiling test protocols, but when we refer to the Water Boiling Test (or the WBT) in this webinar, we are referring to the version specified here. Other testing protocols are used by some labs. Many of us stove testers share a burning desire to do good work, but we don't always agree with each other on the best approaches. Sometimes we disagree, but when we take time to carefully consider each others' viewpoints and data, we learn from each other, and we advance the science and art of stove testing. I've heard from some people who feel that stove testing is changing too quickly and it's difficult to keep up with all the changes, but then I've heard from others who feel frustrated that things are not changing fast enough. The ISO process will take time, but I think it gives us the best opportunity we've ever had to advance stove testing!



Various existing test protocols have different purposes or combinations of purposes. Protocols have different advantages and disadvantages, such as those listed here, and these are some of the factors that may be considered in the ISO process. Despite the differences between protocols, there are many similarities, and I believe there is a good opportunity for developing a unified ISO standard based on consensus protocols. There are ongoing developments – existing protocols are being modified and improved, and new protocols are being developed.

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Protocols – Developments

- WBT (Water Boiling Test) Version 4.2.2 posted
  http://community.cleancookstoves.org/communities/home/22
- Charcoal stove testing guidelines posted
  http://community.cleancookstoves.org/communities/forums/viewtopic/22/33/93?post_id=322#p322
- Plancha (griddle) stove testing protocol under development
  http://community.cleancookstoves.org/discussions/viewtopic/22/129
- Solar cooker testing standard under revision
  http://webstore.ansi.org/RecordDetail.aspx?sku=ASAE+S580+JAN2003+(R2008)
- Durability protocol being developed
  http://community.cleancookstoves.org/discussions/viewtopic/22/186
- Field testing protocol discussion groups established
  http://community.cleancookstoves.org/discussions/viewtopic/22/188
- ***Batch-fueled stove testing protocol development is needed*** – as expressed in ISO IWA Resolution 1.a.:
  http://www.pciaonline.org/files/ISO-IWA-Cookstoves.pdf

8

On protocol developments – the most recent Water Boiling Test version is posted, and the spreadsheet continues to be developed with input from users. Experimental guidelines for testing charcoal stoves were recently developed by an ad hoc working group formed at this year's Clean Cooking Forum. A plancha stove testing protocol is under development by a group of stakeholders. A solar cooker testing standard is under revision. A stove durability protocol is being developed. Field testing protocol discussion groups have been established. More information is available from the links. All of these efforts and many more developments may feed into the ISO process. Lastly, there is a need for a testing protocol for batch-fueled stoves. This need was expressed in a Resolution in the IWA, and this need is one of the reasons we are holding this webinar.

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Stoves/Fuels Currently Being Tested

A. BioLite HomeStove, wood
B. Patsari, wood
C. InStove 60L, wood
D. Turbococina, wood
E. Ecozoom Jet, charcoal
F. Prakti – institutional, wood
G. Envirofit CH-4400, charcoal
H. Prakti Leo, charcoal
I. Vesto, wood
J. Peko Pe (TLUD), wood
K. Mwoto (TLUD), wood
L. Ecocina, wood
M. JikoPoa, wood
N. CleanCook, alcohol
O. Solgas/Repsol, LPG
P. Butterfly Model 2668 wick stove, kerosene
Q. Butterfly Model 2412 pressure stove, kerosene
R. Greenway, wood
S. Eco-Chula XXL, wood

9

This photo shows stoves we are currently testing. Stoves listed in bold text are batch-fueled with wood. The stove shown inside the red circle is the one we will focus on in this webinar. It is a batch-fueled pyrolytic TLUD (top-lit up-draft) type cookstove. Thanks to Karsten Bechtel and CREEC in Uganda for permission to use preliminary results for the Mwoto stove for discussion purposes today and for review of the spreadsheet.

Along with testing cookstoves, we are also evaluating three types of solar cookers, and Seth is working on a publication that will include results.

Laboratory Test Parameters

- Fuel consumption, energy efficiency, power
- PM (particulate matter), integrated samples: gravimetric
- PM, real-time, including ultrafine particles: SMPS, APS
- CO (carbon monoxide), CO_2(carbon dioxide): infrared analyzers
- CH_4 (methane), THC (total hydrocarbons): FID analyzers
- NO_X (nitrogen oxides): chemiluminescence analyzer
- Black carbon: aethalometer, transmissometer
- Organic carbon, elemental carbon: thermal-optical analysis
- Aerosol light absorption and scattering, *in situ*: PASS-3 and nephelometer

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In the laboratory, we are measuring fuel consumption, energy efficiency, power, and emissions of air pollutants listed here. The IWA guidelines specify that measurements of only carbon monoxide and particulate matter are required for rating stoves for emissions, but we are measuring emissions of additional pollutants that may affect human health and the environment. We are measuring gaseous and particulate pollutants in real-time, as well as in some integrated measurements.

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EPA laboratory testing of biomass-fueled stoves

3 test phases, including 2 power levels (high-power cold-start, high-power hot-start, low-power simmer, per WBT)
x 2 fuel moisture content (low-moisture, high-moisture)
x 3 replications (minimum per WBT)
18 total number of test phases (usually more)

Requires a minimum of:
18 PTFE filters for gravimetric $PM_{2.5}$ (per IWA)
36 Quartz fiber filters for OC/EC
(organic carbon / elemental carbon - indicator for black carbon)

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The Water Boiling Test protocol has three test phases that include two power levels – there is a high-power cold-start, a high-power hot-start, and a low-power simmer. We test most biomass-fueled stoves with two fuel-moisture levels, and we perform at least three replications, as specified in the WBT. The total number of test phases then is at least 18, and this requires at least 18 filters for gravimetric analysis of particulate matter. Gravimetric analysis is specified in the IWA, because it is the most reliable way to measure emissions of PM mass. Analyzing a separate filter for each test phase provides useful data during different operating conditions. Filters must be carefully weighed before and after testing, and it is a time-consuming process. For each test phase, we also use two quartz fiber filters for determining organic carbon and elemental carbon in particulate matter, so we analyze at least 36 quartz filters for each stove/fuel combination. This OC/EC analysis is also a time-consuming process.

Suggestions from other researchers, testers, and manufacturers

- Test at more cooking power levels (3 or 4)
- Test with different pots (2 or 3)
- Test with different types or sizes of fuels (2 or 3)
- Test with more replications - improve ability to determine statistically significant differences between test results (7, 10, or 20)
- Test using a “burn cycle” or “drive cycle” approach

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We have heard many good suggestions for how we could expand stove testing in the future, and a few are listed here. We could test at more cooking power levels – we usually test at two power levels, as specified in the WBT, but we’ve published results that show the value of testing at more than two levels. An example of another stove-testing protocol that uses multiple power levels is the standard test for EPA-certified heating stoves in the United States - it requires four power levels. We’ve heard suggestions for three or four power levels for testing cookstoves. Other suggestions are that - we could test with more than one pot. We could test with different types, species, sizes, or shapes of fuel. We could test with more replications to improve the ability to determine statistically significant differences between test results. The number of replications needed depends on specifics of the test, but more than one research group has suggested that we generally need more replications than 3, and the numbers suggested for testing typical biomass-fueled stoves have been 7, 10, or as many as 20. Other researchers have suggested we could test using a “burn cycle” or “drive cycle” approach that would enable the lab test conditions to be more reflective of actual field conditions, and that could improve the correlation between lab and field test results.

Challenge of practical implementation in future stove testing

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Suggestions:
- Test at more power levels (**3** or 4)
- Test with different pots (**2** or 3)
- Test with different types or sizes of fuels (**2** or 3)
- Test with more replications (**7**, 10, or 20)

Now	With all suggestions included	
3	4	test phases (including **3** power levels)
x 2	x 2	fuel moisture content
	x **2**	fuel (types or sizes)
	x **2**	pot sizes
x 3	x **7**	replications
18	224	total number of test phases

Filters needed with all suggestions included:
224 Filters for gravimetric $PM_{2.5}$

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I think all of these suggestions (and some others) are good ideas, and I think many of these ideas may be incorporated in unified stove testing protocols developed through the ISO process. I think a challenge for us will be to come to a consensus on how we can integrate the best ideas in a test protocol that will be practical for testing centers to use on a routine basis. I think the example outlined in this slide illustrates the challenge. If we tested with just one more cooking power level, with two different pots, with two types of fuel, and with 7 replications, we would have a total number of test phases that would be impractical for a routine test. But we have a smart, creative, and diverse group of scientists, engineers, and stove testers from many countries who will be working on this challenge through the ISO process, and I think we can and will come to a consensus on practical unified standards and protocols.

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Considerations for future unified standards and protocols

- Test at least three cooking power levels
- Important to meet statistical requirements, but need to minimize the number of test replications
  - Control test conditions (especially fuel burning rate) at each power level
  - Specify metrics that tend to have less variation (e.g., cooking power in units of watts, rather than “time-to-boil”)
  - Use statistical analysis to minimize number of test replications
- Use data obtained from the field to:
  - Determine which parameters are most important
  - Inform lab testing conditions
  - Determine when to test different pots, fuels, fuel moisture levels, etc.
- Develop lab tests that better reflect field performance, but recognize that lab tests cannot substitute for field tests

15

There will be many more considerations for developing standards and protocols, but here are some that I think are important. I think it is a very good idea to test at least three cooking power levels. I think it is essential to meet statistical requirements, but I think we need to minimize the number of test replications, and I think we can do that by carefully controlling the test conditions (especially the fuel burning rate) at each power level tested. This is easy for some stoves (such as LPG stoves), but it is a challenge for other stoves that are more difficult to control. We can specify metrics that tend to have less variation – for example, we can specify cooking power in units of watts, rather than using the familiar “time-to-boil” that typically has a larger variation than cooking power. We can use statistical analysis to minimize the number of test replications needed. I think we can use data from the field to determine which parameters are most important, to inform lab testing conditions, and to determine when to test different pots, fuels, and fuel moisture levels. I think we can develop lab tests that better reflect field performance, but I think we must recognize that lab tests cannot substitute for field tests.

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Laboratory and Field Testing

- Laboratory Testing
  - More control of variables – less variation in results
  - Limited ability to predict usage in field
  - Provides no information on local context
  - Lower cost
  - Useful for comparing performance under controlled conditions
- Field Testing
  - Less control of variables – more variation in results
  - Ability for measuring performance and usage in the field
  - Provides valuable information on local context, but limited ability to generalize results beyond local context
  - Higher cost
  - Useful for comparing actual performance in uncontrolled conditions
- Results of laboratory and field testing may not be consistent when stoves are tested under different conditions (fuels, pots, foods, operation, burn-cycle, environment)
- ***Laboratory and field testing can be complementary***

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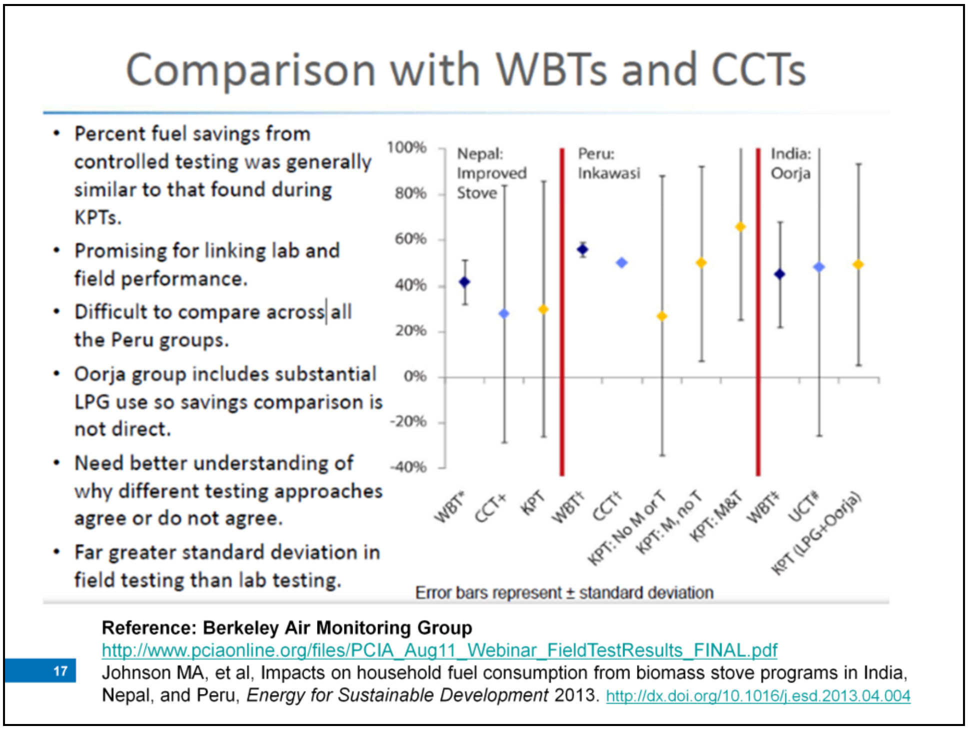
When we test stoves in the laboratory, we have more control over variables and less variation in results, compared to testing done in the field. But lab tests have very limited ability to predict how stoves are actually used in the field. The lab test provides no information on the local context, but if we have information from the field, we can better simulate field performance in the lab. Lab tests generally cost less than field tests, because field tests typically require larger sample sizes for statistical significance. Lab tests are better for comparing performance under controlled conditions, while field tests are better for comparing actual performance in uncontrolled conditions. There are many examples of disagreement between lab and field test results for stoves, but when we look at those examples, we find that stoves were tested under very different conditions in the lab and field. If we test under similar conditions, we should get similar results. On the other hand, when we test stoves under more ideal conditions in the lab, that testing can also have value, because if a stove does not perform well in a lab test, it is unlikely to perform any better in the field, and we can test a stove at lower cost in the lab before conducting field trials. The bottom line is that laboratory and field testing are both needed and can be complementary.



I think this slide beautifully illustrates the potential for lab and field tests to be complementary. Thanks to Michael Johnson and Berkeley Air Monitoring Group for permission to use this slide – the reference at the bottom includes a link to the recent publication of these results. This slide shows percent fuel savings for three different stoves tested in three different countries (the red bars separate the three different cases). The WBTs are the lab tests, the CCTs are the Controlled Cooking Tests, and the KPTs are the Kitchen Performance Tests that are done in the field. The error bars show variation in terms of plus or minus one standard deviation. Results from lab and field tests are generally similar, and the lab tests have less variation. In the Peru case, the KPT field testing provides additional valuable information – results show that fuel savings increased with stove maintenance and training (denoted by the M & T at the bottom of the chart) – this is the kind of information that is impossible to get with lab testing. I think most of us would agree with the comment on this slide that we need better understanding of why different testing approaches agree or do not agree. I think we are more likely to see agreement between lab and field tests for stoves that use processed fuels and for stoves that require less attention and manipulation by the user, but many other factors are involved.

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Introduction to EPA spreadsheet

- Based on:
  - ISO International Workshop Agreement (IWA) 11: 2012
    http://www.pciaonline.org/proceedings/iso-international-workshop-clean-and-efficient-cookstoves
  - Water Boiling Test (WBT) Version 4.2.2
    http://community.cleancookstoves.org/communities/home/22
- Includes raw data, calculations, final results
- Specific to EPA equipment and research objectives
- **NOT** intended for use by other testing labs
- **DRAFT** spreadsheet with data and results for one stove/fuel will be posted for review and comments
- Includes enhancements to WBT spreadsheet

18

And now let’s introduce our EPA spreadsheet – it is based on the IWA and the WBT. It includes the raw data, calculations, and final results. The spreadsheet is specific to EPA equipment and research purposes, and it is NOT designed for use by other testing labs. A DRAFT spreadsheet with data and results for the Mwoto stove will be posted for your review and comments. Since the results for this stove are not finalized, please do not quote or cite the results. Included in the EPA spreadsheet are some enhancements to the WBT. Some of these enhancements might be considered in the next revision of the WBT or in other protocols that are developed.

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Enhancements to WBT spreadsheet

1. Accounts for ash remaining at end of test phase, as recommended in Taylor's 2009 thesis:
   http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1534&context=etd
   - Taylor did an independent review and evaluation of the WBT
   - Taylor described limitations of WBT
   - Largest potential source of error – accounting for ash content
   - Accounting for ash important for fuels with high ash content
   - Accounting for ash in calculations enables weighing of stove with remaining char and ash at the end of the test
   - Taylor concluded: "If the test is altered to properly account for ash, the minimum method error drops to about five percent." (p. 65)

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I will describe seven enhancements to the WBT spreadsheet. First, we account for ash remaining at the end of each test phase, as recommended in Taylor's 2009 Master's thesis – a link is provided. At Iowa State University, Taylor did an independent review and evaluation of the Water Boiling Test. He described limitations of the WBT, and he found that the largest potential source of error is in failing to address the ash content in the material remaining in the stove at the end of the test phase. The error is small with fuels (such as wood) with relatively small ash content, but the error can be large with fuels (such as charcoal, some crop residues, and dung) with relatively large ash content. The error may be minimized if the ash can be physically separated from unburned fuel and char, but this is difficult with some fuels (such as rice hulls). Accounting for the ash in calculations enables us to get a more accurate measurement of the mass of remaining char when we place the stove with remaining char and ash on an electronic balance at the end of the test. When possible, placing the stove on a balance is easier and faster than dumping out the remaining char and separating the ash. Taylor concluded that "If the test is altered to properly account for ash, the minimum method error drops to about five percent." (p. 65)

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Enhancements to WBT spreadsheet

2. Provision for testing with high-moisture fuel
3. Uses measured values from fuel analyses
4. Reports additional metrics for emissions, fuel use, cooking power
5. Calculates air pollutant emissions – specific to EPA equipment
6. Corrects air velocity measurements for moisture in dilution tunnel – specific to EPA equipment
7. Calculates metrics with and without char energy included – for pyrolytic (char-producing) stoves

20

These are additional enhancements to the spreadsheet:

2. We test most biomass stoves with both low- and high-moisture fuel. When we test a stove with high-moisture fuel, low-moisture fuel is usually required to start the fire, similar to the way the stove is actually used in the field. Our spreadsheet has calculations for handling fuels with two different moisture contents during the same test.
3. We do proximate and ultimate analyses of fuel and remaining char, and we use the measured values in our calculations.
4. We report additional metrics for emissions, fuel use, and cooking power.
5. Our spreadsheet includes calculations for air pollutant emissions specific to our equipment.
6. We are using the total-capture method for quantifying emissions, so the air velocity measurements in our dilution tunnels are critical. We correct the air velocity for moisture in the air. This correction is small when there is a large ratio of dilution air to emissions, but the correction can be significant when there is a small dilution ratio.
7. We are calculating metrics both with and without the energy of the remaining char included for pyrolytic (or char-producing) stoves. We will discuss this more in a few minutes.

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What Are Pyrolytic Stoves?

- Solid biomass fuel is heated (using “primary” air) to release volatile gases that are combusted (using “secondary” air)
- Fuel may be “batch” loaded
- Char (charcoal) is produced by pyrolysis
- Char that remains after pyrolysis may be:
  - combusted in the same stove,
  - **or** saved and combusted in a different charcoal stove,
  - **or** saved and used as a soil amendment (biochar),
  - **or** discarded

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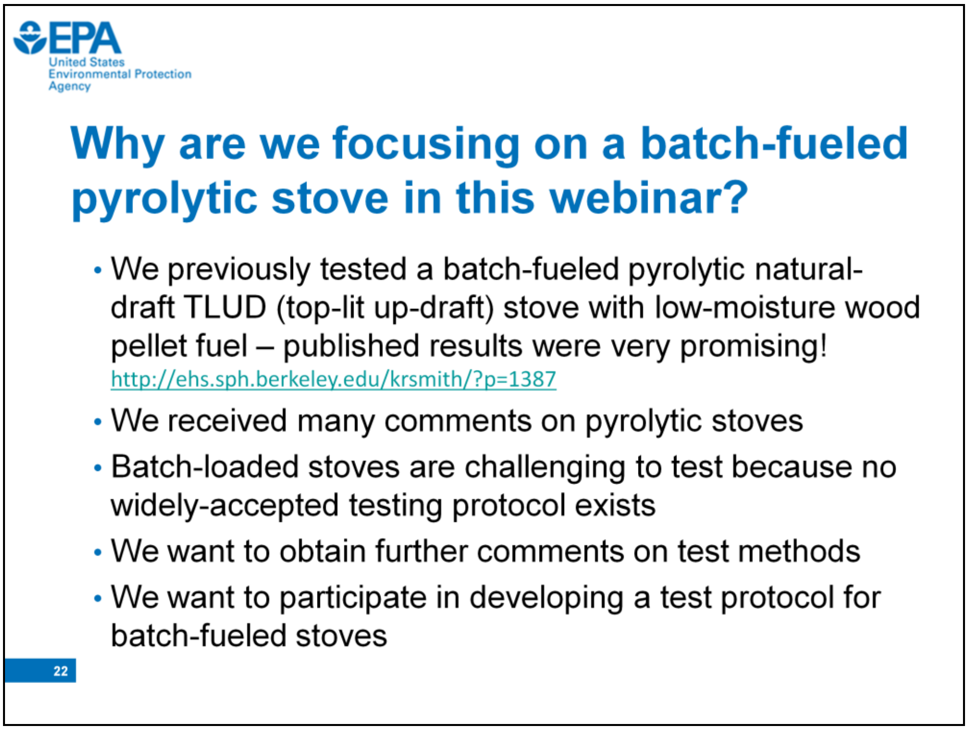
For those of you who are not familiar with pyrolytic stoves, here is a brief description. Solid fuel is heated (using “primary” air) to release volatile gases that are then combusted (using “secondary” air). The pyrolytic stoves we are testing are batch-fueled, but there are some other types of pyrolytic stoves that are fueled continuously. Pyrolysis produces char (or charcoal) that is richer in carbon content than the wood or other biomass fuel that is used in the process. Char that remains after pyrolysis may be combusted in the same stove (if the stove is designed to combust the char), **OR** the char can be saved for fuel and combusted in a different stove (ideally in a stove designed for charcoal fuel), **OR** it can be saved and used for biochar or other purposes, **OR** it may just be discarded and not used for any purpose.



In this webinar, we are focusing on a batch-fueled pyrolytic stove for several reasons. We previously tested a TLUD (top-lit up-draft) stove with low-moisture wood pellet fuel, and we published results that showed the stove had high energy efficiency and low emissions. We have received many comments on pyrolytic stoves, and there has been quite a debate going on between some of our colleagues over char-producing stoves. On one side of the debate are people who are developing or promoting char-producing stoves, and they are concerned that testing may not be adequately capturing the potential benefits of char-producing stoves. On the other side of the debate are people who are concerned that testing may not be adequately capturing the potential losses of efficiency with char-producing stoves. Here at EPA, we appreciate all your comments, and our job is to test stoves and report results in a way that is fair, unbiased, and useful. I'll come back to this topic of testing and reporting efficiency for char-producing stoves a little later in this presentation. Batch-loaded stoves are challenging to test for us, because there is no widely-accepted testing protocol. We want your further comments on test methods and we want to participate in developing a test protocol – possibly through an ISO Working Group.

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Alternative methods for testing batch-fueled pyrolytic stoves

- At the end of WBT test phase (high-power: water boils, low-power: elapsed time), extinguish fire and:
  1. Sort unburned fuel and remaining char
  2. Or, grind unburned fuel and remaining char together, analyze for energy content and composition
- Or, allow pyrolysis process to continue to completion – “burn-out” and:
  3. End test phase per WBT, and use a calibrated “burn-out” pot, as suggested by Crispin Pemberton-Pigott and described by Taylor 2009, pp. 42-44: http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1534&context=etd
  4. **Or, end the test phase at the end of the burn-cycle**

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We know of four alternative methods for testing batch-fueled pyrolytic stoves – there may be others or other variations. In Method 1, the fire is extinguished at end of the test phase, and the unburned fuel and remaining char are sorted and separated. We used this method in the past for testing stoves with pellet fuel, but it was tedious to separate the charred and uncharred pellets, and there was uncertainty with partially charred pellets. In Method 2, the fire is extinguished at the end of the test phase, and the remaining char and unburned fuel are collected and ground together to obtain a representative sample that is analyzed for heat of combustion and for composition. This method is certainly more accurate than Method 1, but it requires many fuel samples to be analyzed, because the composition of the char and remaining fuel may be different in each test replication. In Method 3, the test pot is removed at the end of the WBT test phase and is replaced with a calibrated “burn-out” pot. The pyrolysis process is allowed to continue to completion, and the energy that is left in the fuel at the end of the test phase is estimated from energy input to the “burn-out” pot. A link is provided for more details. Method 3 has the advantage of being consistent with the WBT while allowing pyrolysis to continue to completion, so there is no remaining fuel mixed with char at the end of the procedure. We think it is a good idea to allow the pyrolysis process to complete for the entire batch of fuel, because this is how stoves are actually operated in the field. We also think it is a good idea to capture emissions and measure performance over the entire burn-cycle for the batch of fuel, so we are suggesting and using Method 4. In Method 4, the test phase includes the entire burn-cycle – requires modified WBT.

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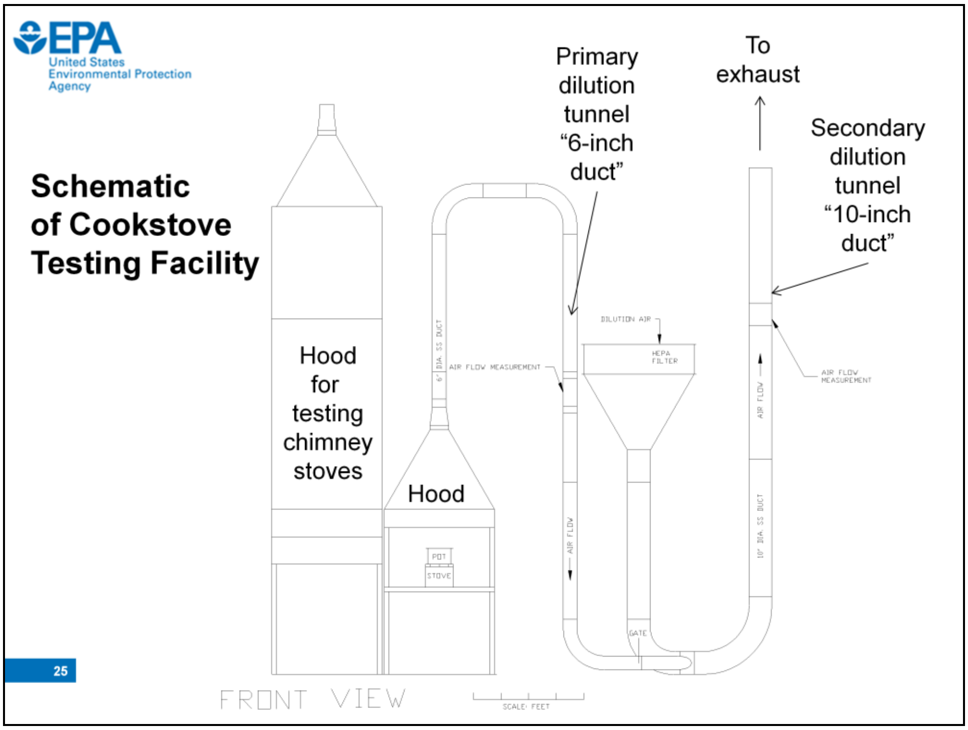
Modified WBT for pyrolytic stoves

- Load sufficient mass of fuel to complete each WBT test phase
- Allow pyrolysis process to continue to completion – “burn-out”
- Analyze samples of fuel and remaining char
  - Energy content
  - Composition
- Use results of fuel and char analyses in calculations

24

This is a brief description of our suggested modified WBT procedure for pyrolytic stoves. First, we experiment with the stove to determine approximately how much fuel is required to complete each WBT test phase. We think this is consistent with field use, as stove users learn how much fuel to load to complete a cooking task. In the high-power test phases, when the water reaches boiling temperature, we do not immediately stop the test, but we let the test continue until the pyrolysis process completes. We have done experiments that show that we measure the same energy input to the pot whether the water is boiling or not, so it does not matter if the water continues to boil at the end of the test phase. During the low-power test phase, we also allow the pyrolysis process to continue to completion. We analyze samples of fuel and remaining char. Fuel analysis results for remaining char at the end of pyrolysis are consistent between test replications, so fuel analysis is not required for every single test replication.



Before Seth begins showing you the spreadsheet, I want to show you this schematic of our cookstove testing facility. We have two hoods for collecting emissions – one is for testing stoves with tall chimneys, and one is for stoves without chimneys. The system has two dilution tunnels so we can measure air pollutant emissions at different concentrations, depending on the instruments or methods. The primary dilution tunnel has the higher concentration, and Seth may refer to this in the spreadsheet as the “6-inch duct.” The secondary dilution tunnel has the lower concentration, and Seth may refer to this as the “10-inch duct.”

EPA United States Environmental Protection Agency

Next – brief tour of EPA spreadsheet

- Reminders
  - –**NOT** intended for use by other testing labs
  - –Specific to EPA equipment and research objectives
  - –**DRAFT** spreadsheet with data and results for one stove/fuel will be posted for review and comments

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Next, Seth will give you a brief tour of our DRAFT spreadsheet. I want to remind everyone again that we are not suggesting that other labs use this spreadsheet for testing stoves, because this is specific to our EPA equipment and research purposes. We are making this draft spreadsheet available as a way to share our data and as a way to obtain feedback and comments on our testing. Seth has spent countless hours working on this, and he knows this spreadsheet better than anyone.

DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE

Stove Manufacturer & Model	Mwoto Factories Ltd., Uganda; Model 2012 (Serial Number 809)
Testing Center	EPA-RTP
Test Protocol	WBT Version 4.2.2, EPA Rev. 4
Fuel Used	Red Oak, Average Moisture Content 6.7%, Dimensions: 2 x 2 x 2-7.63 cm
Pot Used	Standard flat-bottom 7L pot w/ 5L of water
Test Dates Included in Summary	02/07/2013 02/08/2013 02/12/2013 02/19/2013

These results were obtained in accordance with ISO IWA (International Workshop Agreement) 11: 2012

		Metric	Value	Unit	Sub-Tier
Efficiency / Fuel Use					
Tier	**1**	High Power Thermal Efficiency	26	%	2
		Low Power Specific Energy Consumption	0.043	MJ / (min L)	1
Emissions					
Tier	**2**	High Power CO	3	g / $MJ_{delivered}$	4
		Low Power CO	0.04	g / (min L)	4
		High Power $PM_{2.5}$	171	mg / $MJ_{delivered}$	2
		Low Power $PM_{2.5}$	1	mg / (min L)	4
Indoor Emissions					
Tier	**2**	High Power CO	0.29	g / min	4
		Low Power CO	0.15	g / min	4
		High Power $PM_{2.5}$	15	mg / min	2
		Low Power $PM_{2.5}$	4	mg / min	3

Cooking Power (average of Cold Start and Hot Start phases)	W	1427
Fuel burning rate (average for Cold Start, based on equivalent dry fuel consumed)	g / min	16.4
Fuel burning rate (average for Hot Start, based on equivalent dry fuel consumed)	g / min	19.8
Fuel burning rate (average for Simmer, based on equivalent dry fuel consumed)	g / min	9.6

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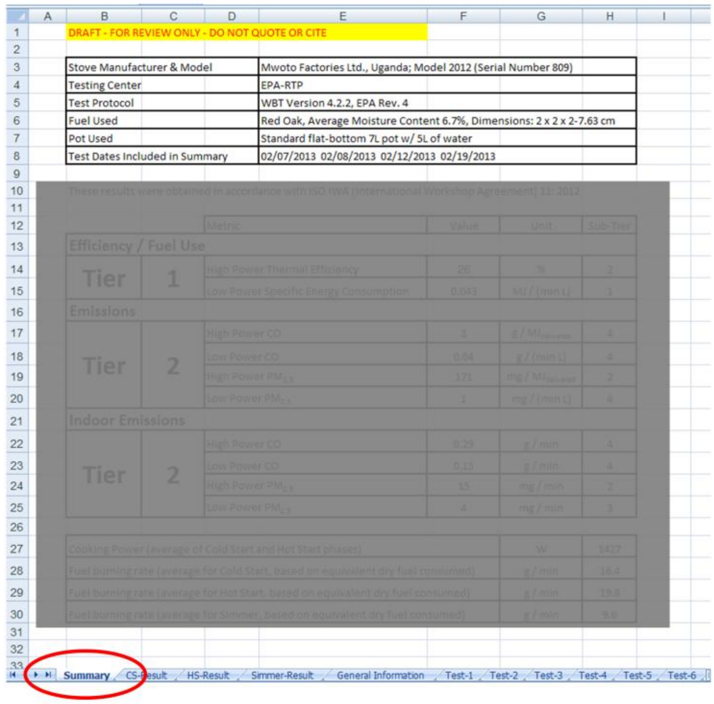
Summary | CS-Result | HS-Result | Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6

-Following are "screen shots" from the EPA – WBT spreadsheet

-Will be made available later on Alliance site

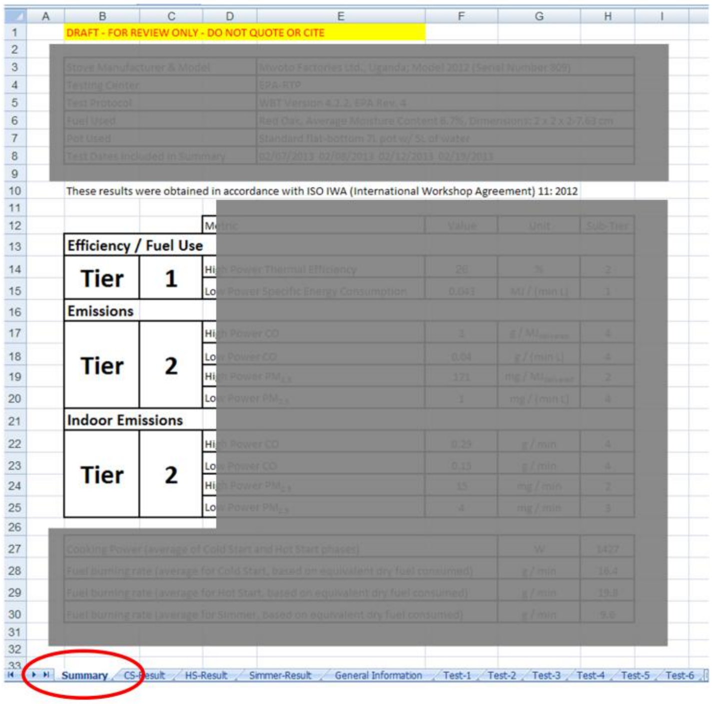
-Summary worksheet (tab circled) presents results in format specified in ISO IWA guidelines



-Starting at the top of the sheet

-Important-to-define test conditions: descriptions of stove, fuel, pot, and loading

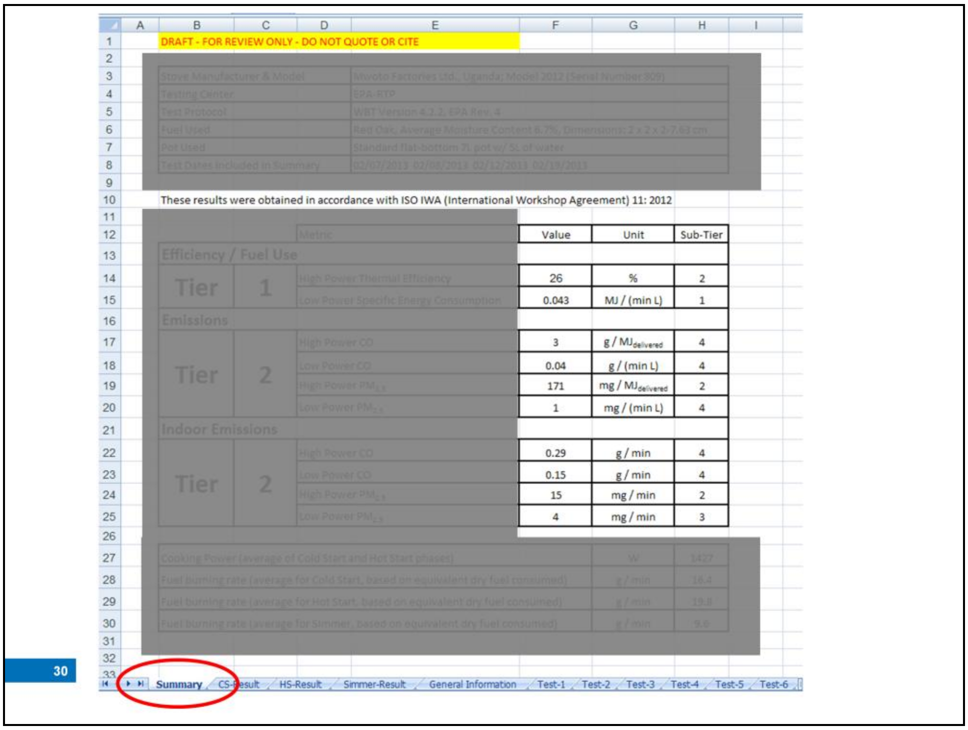
-All info on sheet filled automatically to minimize possibility of typographical errors



29

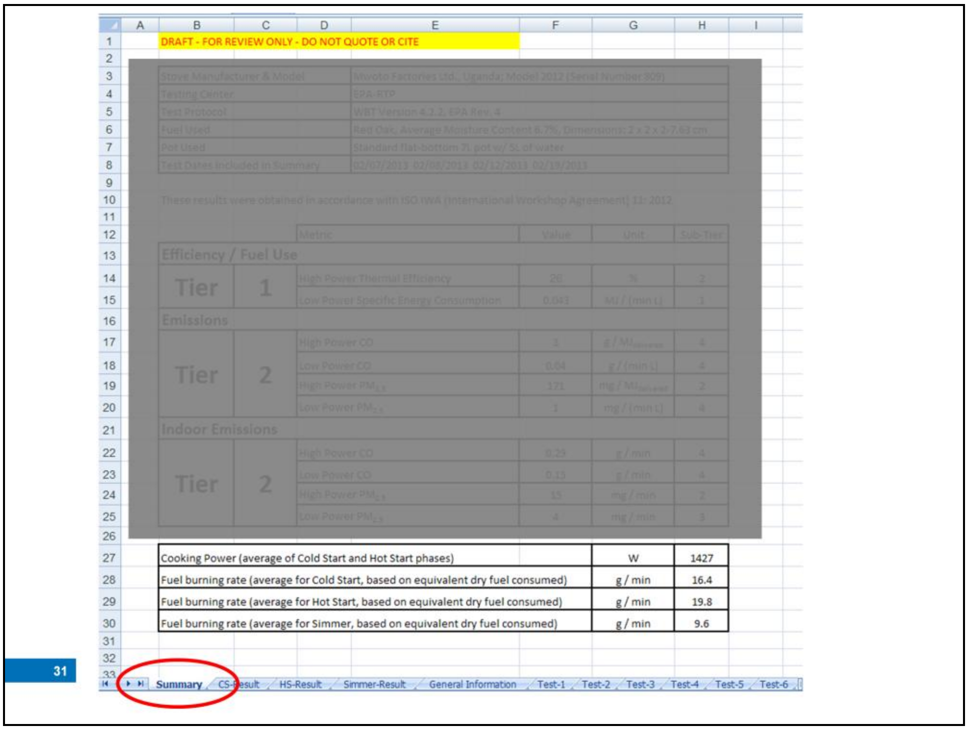
-Next section down

-Tier values on left (as defined by the IWA) . . .



-Next section down (continued)

- -And sub-tier on right. Provided to help would-be users decide if stove meets their needs based on evaluations of individual characteristics



DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE

Stove Manufacturer & Model	Mvoto Factories Ltd., Uganda; Model 2012 (Serial Number 809)
Testing Center	EPA-RTP
Test Protocol	WBT Version 4.2.2, EPA Rev. 4
Fuel Used	Red Oak; Average Moisture Content 6.7%, Dimensions: 2 x 2 x 2-7.63 cm
Pot Used	Standard flat-bottom 7L pot w/ 5L of water
Test Dates Included in Summary	02/07/2013 02/08/2013 02/12/2013 02/19/2013

These results were obtained in accordance with ISO IWA (International Workshop Agreement) 11: 2012

		Metric	Value	Unit	Sub-Tier
Efficiency / Fuel Use					
Tier	1	High Power Thermal Efficiency	26	%	2
		Low Power Specific Energy Consumption	0.043	MJ / (min L)	1
Emissions					
Tier	2	High Power CO	3	$g / MJ_{delivered}$	4
		Low Power CO	0.04	g / (min L)	4
		High Power $PM_{2.5}$	171	$mg / MJ_{delivered}$	2
		Low Power $PM_{2.5}$	1	mg / (min L)	4
Indoor Emissions					
Tier	2	High Power CO	0.29	g / min	4
		Low Power CO	0.15	g / min	4
		High Power $PM_{2.5}$	15	mg / min	2
		Low Power $PM_{2.5}$	4	mg / min	3

Cooking Power (average of Cold Start and Hot Start phases)	W	1427
Fuel burning rate (average for Cold Start, based on equivalent dry fuel consumed)	g / min	16.4
Fuel burning rate (average for Hot Start, based on equivalent dry fuel consumed)	g / min	19.8
Fuel burning rate (average for Simmer, based on equivalent dry fuel consumed)	g / min	9.6

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

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-In the final section:

-Report cooking power in units of watts (rather than reporting "time-to-boil") and fuel burning rates (to facilitate test replication)

WATER BOILING TEST - VERSION 4.2.2 - EPA VERSION 4

All white cells are linked to data worksheets, no entries are required

Stove type/model	Mwoto Model 2012
Fuel Type	Red Oak
Average Fuel Moisture	6.85%

Comments:

DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE

Test 4 not included because air control was left open as an experiment - resulting in a fuel burning rate that was higher than the other tests

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average	St Dev	CoV
Test date		02/07/13	02/08/13	02/12/13	02/19/13	01/00/00	01/00/00			
Test time		12:51:45	12:45:45	10:52:30	10:52:00	0:00:00	0:00:00	N=	3	
Include this test in calculations?		yes	yes	yes	no					
Moisture Level	%	6.66	6.80	7.11	6.04	0.00	0.00	6.85	0.23	3%
Fuel consumed (moist)	g	682.1	530.7	644.9	643.7	0.0	0.0	619.2	78.9	13%
Equivalent dry fuel consumed	g	458.4	373.7	438.4	436.0	0.0	0.0	423.5	44.3	10%
Thermal efficiency	%	25.0%	27.1%	28.2%	28.1%	0.0%	0.0%	26.7%	1.6%	6%
Burning rate	g/min	17.9	13.8	17.4	21.1	0.0	0.0	16.4	2.2	14%
Specific fuel consumption	g/liter	95.5	84.4	92.9	92.6	0.0	0.0	90.9	5.8	6%
Temp-corr sp fuel consumption	g/liter	90.3	86.5	87.7	88.6	0.0	0.0	88.2	1.9	2%
Temp-corr sp energy consumpt.	kJ/liter	1662	1593	1615	1630	0	0.0	1623	35	2%
Fire power	watts	5498	4247	5328	6473	0	0.0	5024	679	14%
Cooking power	watts	1373	1149	1500	1818	0	0.00	1341	178	13%
Carbon Balance (% difference based on fuel C)	%	5.7	-11.7	-13.5	-13.1	0.0	0.0	-6.5	10.6	
Modified combustion efficiency		0.994	0.985	0.987	0.977	0.000	0.000	0.989	0.005	0%
		yes	yes	yes	no	-	-	N=	3	
THC total mass	g	0.42	1.23	1.12	2.09	0.00	0.00	0.92	0.44	48%
Temp corr THC total mass	g	0.40	1.27	1.05	2.00	0.00	0.00	0.91	0.45	50%
THC per effective volume of water boiled	g/L	0.08	0.29	0.22	0.43	0.00	0.00	0.20	0.10	53%
THC per fuel mass (moist)	g/kg	0.61	2.33	1.73	3.25	0.00	0.00	1.56	0.87	56%
THC per fuel mass (equiv. dry fuel basis)	g/kg	0.91	3.30	2.55	4.80	0.00	0.00	2.25	1.22	54%
THC per fuel energy	g/MJ	0.05	0.18	0.14	0.26	0.00	0.00	0.12	0.07	54%
THC per energy delivered to pot	g/MJ	0.20	0.66	0.49	0.93	0.00	0.00	0.45	0.23	52%
THC per time	g/hr	0.98	2.74	2.65	6.08	0.00	0.00	2.13	0.99	47%
		yes	yes	yes	no	-	-	N=	3	
CO total mass	g	3.06	7.24	7.26	12.65	0.00	0.00	5.86	2.42	41%
Temp corr CO total mass	g	2.89	7.42	6.86	12.10	0.00	0.00	5.72	2.47	43%
CO per effective volume of water boiled	g/L	0.60	1.68	1.45	2.57	0.00	0.00	1.24	0.57	45%

Summary | CS-Result | HS-Result | Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6

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- On next tab, note "CS-Result" circled

-This and the next two sheets provide detailed results for the three WBT test phases – cold start, hot start, and simmer

-The 'Results' tabs put key parameters (measurements) in one place to evaluate all test replications

WATER BOILING TEST - VERSION 4.2.2 - EPA VERSION 4

All white cells are linked to data worksheets, no entries are required

Stove type/model	Mwoto Model 2012
Fuel Type	Red Oak
Average Fuel Moisture	6.85%

Comments:

DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE

Test 4 not included because air control was left open as an experiment - resulting in a fuel burning rate that was higher than the other tests

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average	St Dev	CoV
Test date		02/07/13	02/08/13	02/12/13	02/19/13	01/00/00	01/00/00			
Test time		12:51:45	12:45:45	10:52:30	10:52:00	0:00:00	0:00:00	N=	3	
Include this test in calculations?		yes	yes	yes	no					
Moisture Level	%	6.66	6.80	7.11	6.04	0.00	0.00	6.85	0.23	3%
Fuel consumed (moist)	g	682.1	530.7	644.9	643.7	0.0	0.0	619.2	78.9	13%
Equivalent dry fuel consumed	g	458.4	373.7	438.4	436.0	0.0	0.0	423.5	44.3	10%
Thermal efficiency	%	25.0%	27.1%	28.2%	28.1%	0.0%	0.0%	26.7%	1.6%	6%
Burning rate	g/min	17.9	13.8	17.4	21.1	0.0	0.0	16.4	2.2	14%
Specific fuel consumption	g/liter	95.5	84.4	92.9	92.6	0.0	0.0	90.9	5.8	6%
Temp-corr sp fuel consumption	g/liter	90.3	86.5	87.7	88.6	0.0	0.0	88.2	1.9	2%
Temp-corr sp energy consumpt.	kJ/liter	1662	1593	1615	1630	0	0.0	1623	35	2%
Fire power	watts	5498	4247	5328	6473	0	0.0	5024	679	14%
Cooking power	watts	1373	1149	1500	1818	0	0.00	1341	178	13%
Carbon Balance (% difference based on fuel C)	%	5.7	-11.7	-13.5	-13.1	0.0	0.0	-6.5	10.6	
Modified combustion efficiency		0.994	0.985	0.987	0.977	0.000	0.000	0.989	0.005	0%
		yes	yes	yes	no	-	-	N=	3	
THC total mass	g	0.42	1.23	1.12	2.09	0.00	0.00	0.92	0.44	48%
Temp corr THC total mass	g	0.40	1.27	1.05	2.00	0.00	0.00	0.91	0.45	50%
THC per effective volume of water boiled	g/L	0.08	0.29	0.22	0.43	0.00	0.00	0.20	0.10	53%
THC per fuel mass (moist)	g/kg	0.61	2.33	1.73	3.25	0.00	0.00	1.56	0.87	56%
THC per fuel mass (equiv. dry fuel basis)	g/kg	0.91	3.30	2.55	4.80	0.00	0.00	2.25	1.22	54%
THC per fuel energy	g/MJ	0.05	0.18	0.14	0.26	0.00	0.00	0.12	0.07	54%
THC per energy delivered to pot	g/MJ	0.20	0.66	0.49	0.93	0.00	0.00	0.45	0.23	52%
THC per time	g/hr	0.98	2.74	2.65	6.08	0.00	0.00	2.13	0.99	47%
		yes	yes	yes	no	-	-	N=	3	
CO total mass	g	3.06	7.24	7.26	12.65	0.00	0.00	5.86	2.42	41%
Temp corr CO total mass	g	2.89	7.42	6.86	12.10	0.00	0.00	5.72	2.47	43%
CO per effective volume of water boiled	g/L	0.60	1.68	1.45	2.57	0.00	0.00	1.24	0.57	45%

Summary | **CS-Result** | HS-Result | Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6

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-In this example:

-Four CS test replications were performed for this stove…

WATER BOILING TEST - VERSION 4.2.2 - EPA VERSION 4

All white cells are linked to data worksheets, no entries are required

Stove type/model	Mwoto Model 2012
Fuel Type	Red Oak
Average Fuel Moisture	6.85%

Comments:
DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE
Test 4 not included because air control was left open as an experiment - resulting in a fuel burning rate that was higher than the other tests

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average	St Dev	CoV
Test date		02/07/13	02/08/13	02/12/13	02/19/13	01/00/00	01/00/00			
Test time		12:51:45	12:45:45	10:52:30	10:52:00	0:00:00	0:00:00	N=	3	
Include this test in calculations?		yes	yes	yes	no					
Moisture Level	%	6.66	6.80	7.11	6.04	0.00	0.00	6.85	0.23	3%
Fuel consumed (moist)	g	682.1	530.7	644.[illegible]	643.7	0.0	0.0	619.2	78.9	13%
Equivalent dry fuel consumed	g	458.4	373.7	438.4	436.0	0.0	0.0	423.5	44.3	10%
Thermal efficiency	%	25.0%	27.1%	28.2%	28.1%	0.0%	0.0%	26.7%	1.6%	6%
Burning rate	g/min	17.9	13.8	17.4	21.1	0.0	0.0	16.4	2.2	14%
Specific fuel consumption	g/liter	85.5	84.4	88.9	[illegible]	0.0	0.0	86.9	5.8	6%
Temp-corr sp fuel consumption	g/liter	90.3	86.5	87.7	88.6	0.0	0.0	88.2	1.9	2%
Temp-corr sp energy consumpt.	kJ/liter	1662	1593	1615	1630	0	0.0	1623	35	2%
Fire power	watts	5498	4247	5328	6473	0	0.0	5024	679	14%
Cooking power	watts	1373	1149	1500	1818	0	0.00	1341	178	13%
Carbon Balance (% difference based on fuel C)	%	5.7	-11.7	-13.5	-13.1	0.0	0.0	-6.5	10.6	
Modified combustion efficiency		0.994	0.985	0.987	0.977	0.000	0.000	0.989	0.005	0%
		yes	yes	yes	no	-	-	N=	3	
THC total mass	g	0.42	1.23	1.12	2.09	0.00	0.00	0.92	0.44	48%
Temp corr THC total mass	g	0.40	1.27	1.05	2.00	0.00	0.00	0.91	0.45	50%
THC per effective volume of water boiled	g/L	0.08	0.29	0.22	0.43	0.00	0.00	0.20	0.10	53%
THC per fuel mass (moist)	g/kg	0.61	2.33	1.73	3.25	0.00	0.00	1.56	0.87	56%
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THC per energy delivered to pot	g/MJ	0.20	0.86	0.49	0.93	0.00	0.00	0.45	0.23	52%
THC per time	g/hr	0.98	2.74	2.65	6.08	0.00	0.00	2.13	0.99	47%
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CO total mass	g	3.06	7.24	7.26	12.65	0.00	0.00	5.86	2.42	41%
Temp corr CO total mass	g	2.89	7.42	6.86	12.10	0.00	0.00	5.72	2.47	43%
CO per effective volume of water boiled	g/L	0.60	1.08	1.45	2.57	0.00	0.00	1.24	0.57	46%

Summary | CS-Result | HS-Result | Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6

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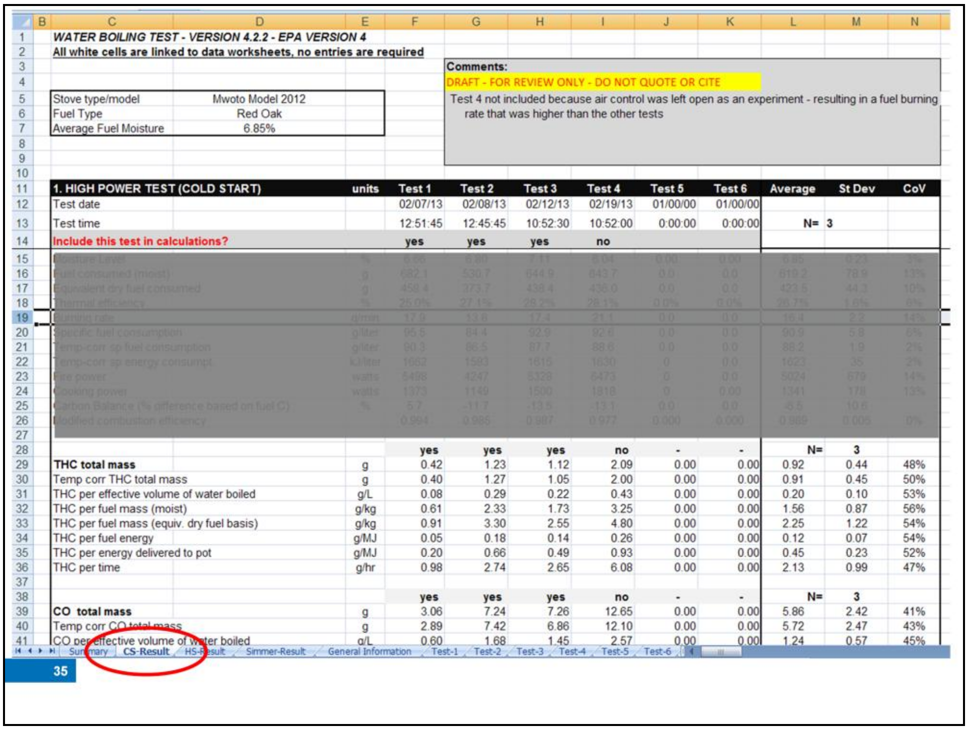
-In this example:

- -Results from the fourth replication were excluded from the final average,
- -air control was left open (as an experiment), and the fuel burning rate (Row 19 highlighted) was too high



WATER BOILING TEST - VERSION 4.2.2 - EPA VERSION 4

All white cells are linked to data worksheets, no entries are required

Stove type/model	Mwoto Model 2012
Fuel Type	Red Oak
Average Fuel Moisture	6.85%

Comments:
DRAFT - FOR REVIEW ONLY - DO NOT QUOTE OR CITE
Test 4 not included because air control was left open as an experiment - resulting in a fuel burning rate that was higher than the other tests

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average	St Dev	CoV
Test date		02/07/13	02/08/13	02/12/13	02/19/13	01/00/00	01/00/00			
Test time		12:51:45	12:45:45	10:52:30	10:52:00	0:00:00	0:00:00	N=	3	
Include this test in calculations?		yes	yes	yes	no					
[redacted]										
		yes	yes	yes	no	-	-	N=	3	
THC total mass	g	0.42	1.23	1.12	2.09	0.00	0.00	0.92	0.44	48%
Temp corr THC total mass	g	0.40	1.27	1.05	2.00	0.00	0.00	0.91	0.45	50%
THC per effective volume of water boiled	g/L	0.08	0.29	0.22	0.43	0.00	0.00	0.20	0.10	53%
THC per fuel mass (moist)	g/kg	0.61	2.33	1.73	3.25	0.00	0.00	1.56	0.87	56%
THC per fuel mass (equiv. dry fuel basis)	g/kg	0.91	3.30	2.55	4.80	0.00	0.00	2.25	1.22	54%
THC per fuel energy	g/MJ	0.05	0.18	0.14	0.26	0.00	0.00	0.12	0.07	54%
THC per energy delivered to pot	g/MJ	0.20	0.66	0.49	0.93	0.00	0.00	0.45	0.23	52%
THC per time	g/hr	0.98	2.74	2.65	6.08	0.00	0.00	2.13	0.99	47%
		yes	yes	yes	no	-	-	N=	3	
CO total mass	g	3.06	7.24	7.26	12.65	0.00	0.00	5.86	2.42	41%
Temp corr CO total mass	g	2.89	7.42	6.86	12.10	0.00	0.00	5.72	2.47	43%
CO per effective volume of water boiled	g/L	0.60	1.68	1.45	2.57	0.00	0.00	1.24	0.57	45%

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

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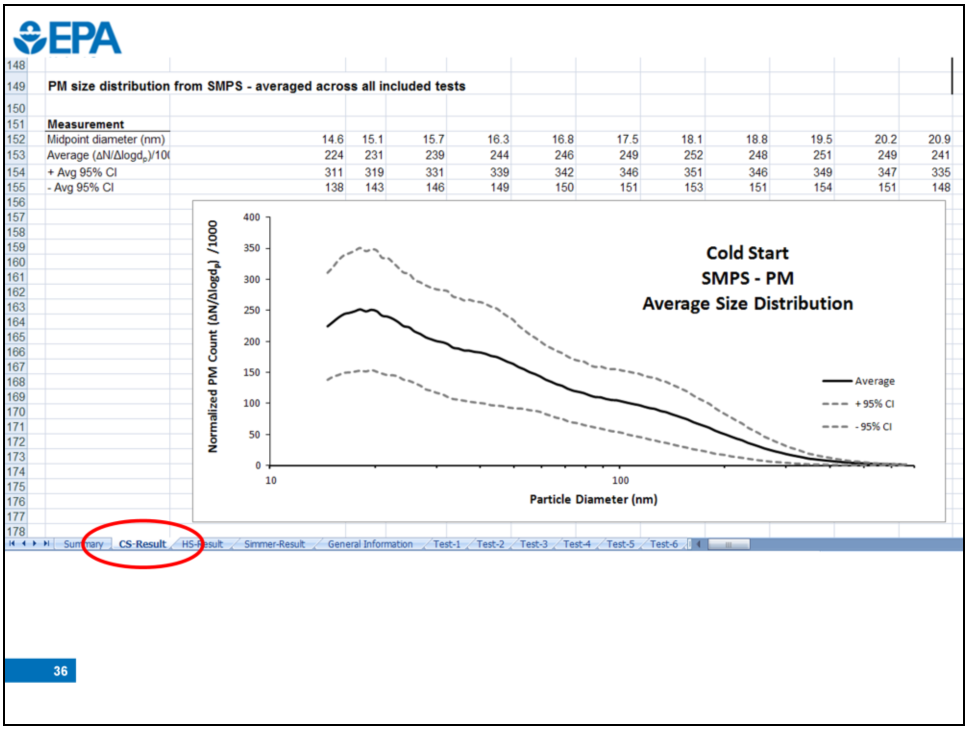
-Results for THC (total hydrocarbons) and some CO (carbon monoxide) emissions are shown at the bottom of the sheet

- -Since we chose to exclude Test 4 (for cold-start phase) all of the results for Test 4 are excluded

- Results for other air pollutant emissions are available by scrolling down on this sheet

- -emissions measurements listed by Jim in earlier slide



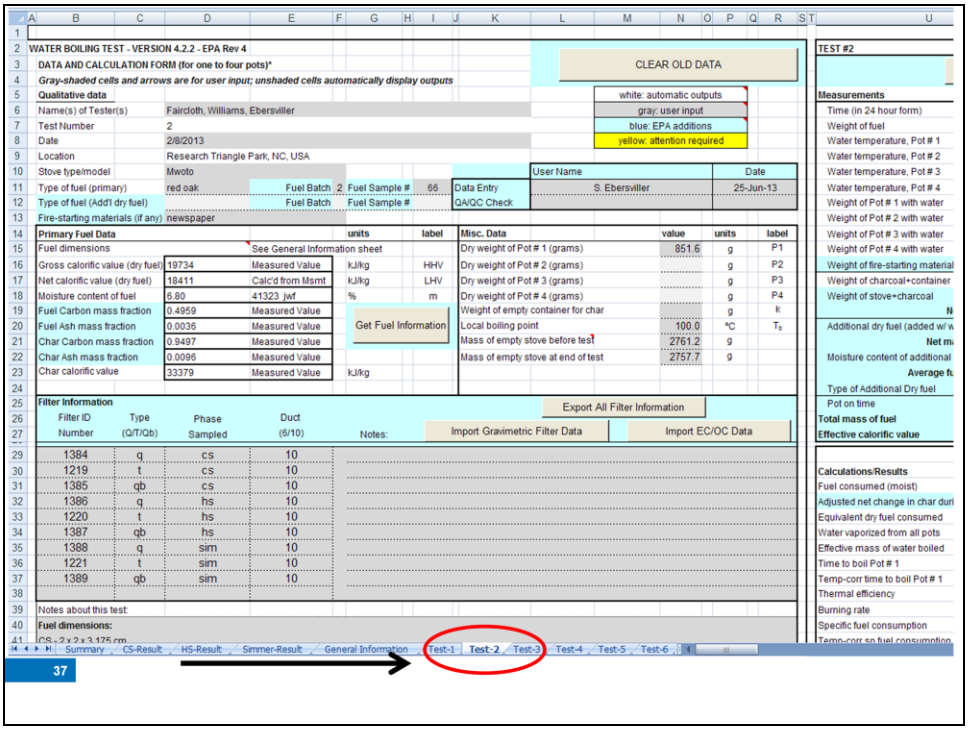
Measurement											
Midpoint diameter (nm)	14.6	15.1	15.7	16.3	16.8	17.5	18.1	18.8	19.5	20.2	20.9
Average (ΔN/Δlogd$_p$)/10(	224	231	239	244	246	249	252	248	251	249	241
+ Avg 95% CI	311	319	331	339	342	346	351	346	349	347	335
- Avg 95% CI	138	143	146	149	150	151	153	151	154	151	148

- On same tab - scrolled to the bottom of the worksheet (CS-Result tab circled)

- Average particle size distribution during test phase is shown

- Individual size distributions are provided for each test replication

-one scan every 2.5 minutes, in raw data sheets – covered later

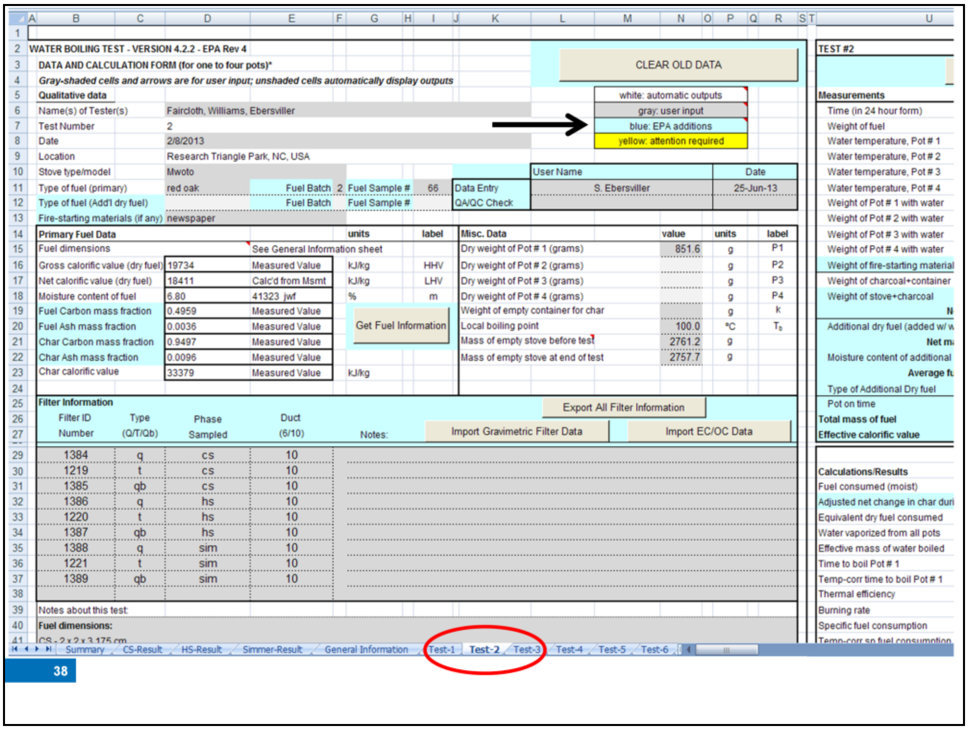


-We've skipped the other two 'Results' tabs – very similar to CS-Result

-Also skipped 'General Info' tab – mostly same as the tab from the WBT spreadsheet on the Alliance website

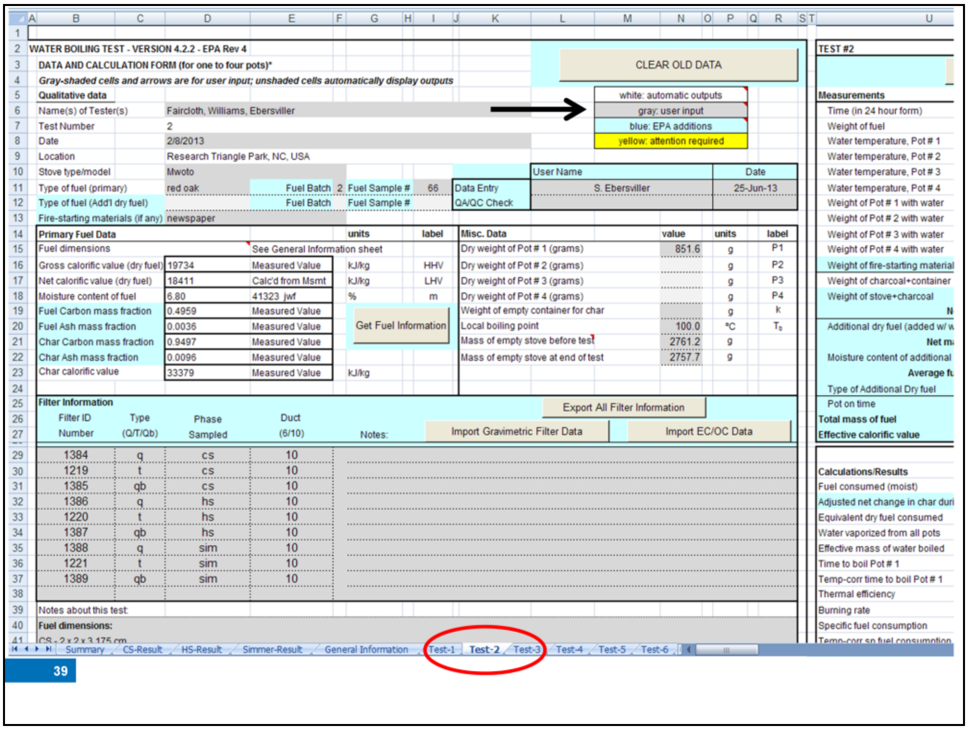
> -We HAVE moved some of the inputs to the Test tabs, because they vary from day-to-day

-This sheet (tab circled) will look very familiar to anyone who has used the WBT spreadsheet



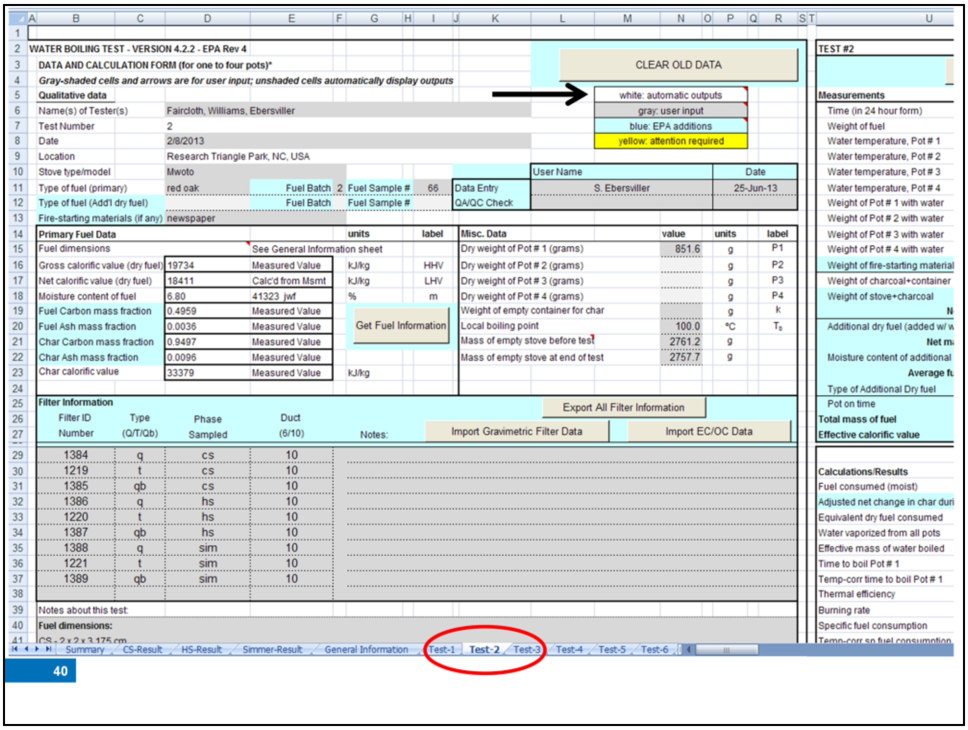
-On this sheet:

-blue-shaded cells are EPA additions, features, or enhancements to the WBT spreadsheet



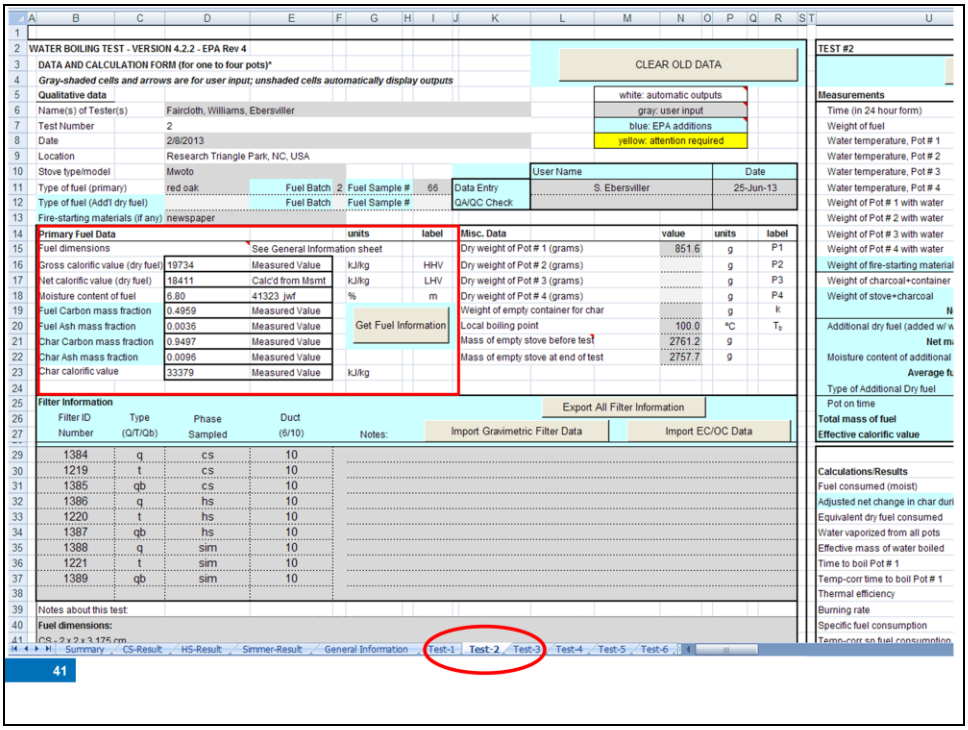
-On this sheet:

-Gray cells require user inputs, light gray are only used occasionally



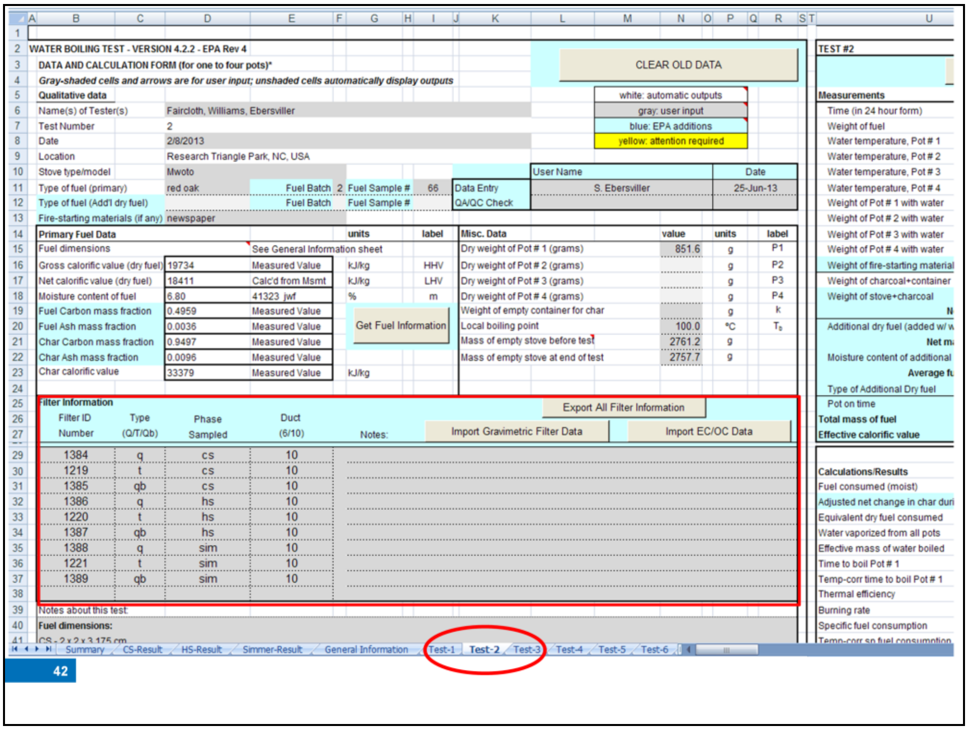
-On this sheet:

-White cells are filled automatically by either an active formula or automated code



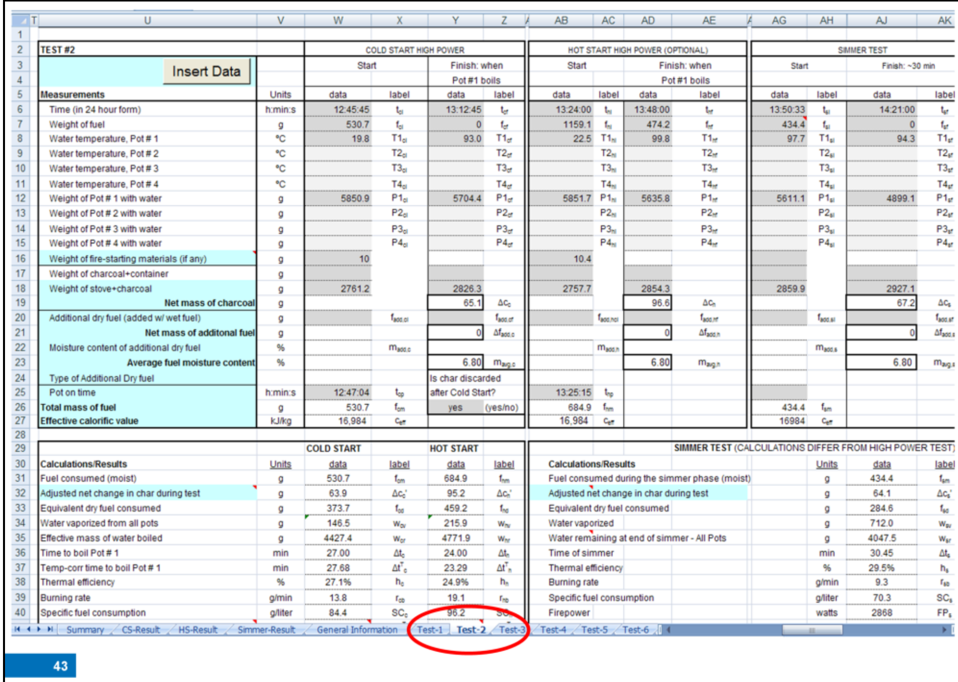
-Other enhancements on this sheet include:

 -fuel elemental analysis, moisture content, and calorific values are entered automatically when button is clicked



-Other enhancements on this sheet include:

- -PM filter identification block w/ filter ID number and parameters specific to our laboratory
    - -Helps us connect specific filters with specific tests

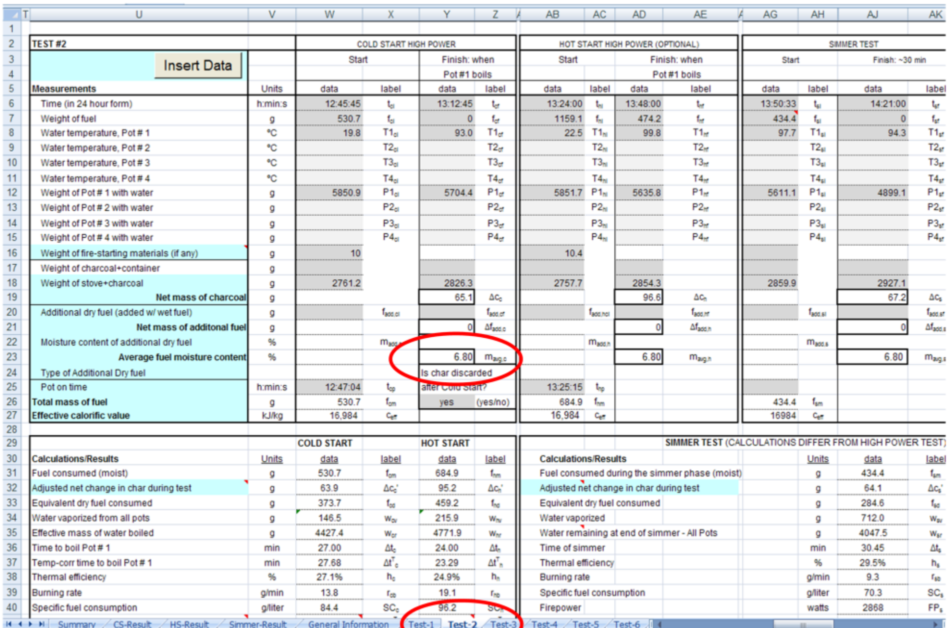


Row	U	V	W	X	Y	Z	AB	AC	AD	AE	AG	AH	AJ	AK
2	TEST #2		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
3	Insert Data		Start		Finish: when		Start		Finish: when		Start		Finish: ~30 min	
4					Pot #1 boils				Pot #1 boils					
5	Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
6	Time (in 24 hour form)	h:min:s	12:45:45	t_{ci}	13:12:45	t_{cf}	13:24:00	t_{hi}	13:48:00	t_{hf}	13:50:33	t_{si}	14:21:00	t_{sf}
7	Weight of fuel	g	530.7	f_{ci}	0	f_{cf}	1159.1	f_{hi}	474.2	f_{hf}	434.4	f_{si}	0	f_{sf}
8	Water temperature, Pot # 1	°C	19.8	$T1_{ci}$	93.0	$T1_{cf}$	22.5	$T1_{hi}$	99.8	$T1_{hf}$	97.7	$T1_{si}$	94.3	$T1_{sf}$
9	Water temperature, Pot # 2	°C		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$		$T2_{si}$		$T2_{sf}$
10	Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$		$T3_{si}$		$T3_{sf}$
11	Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$		$T4_{si}$		$T4_{sf}$
12	Weight of Pot # 1 with water	g	5850.9	$P1_{ci}$	5704.4	$P1_{cf}$	5851.7	$P1_{hi}$	5635.8	$P1_{hf}$	5611.1	$P1_{si}$	4899.1	$P1_{sf}$
13	Weight of Pot # 2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$		$P2_{si}$		$P2_{sf}$
14	Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$		$P3_{si}$		$P3_{sf}$
15	Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$		$P4_{si}$		$P4_{sf}$
16	Weight of fire-starting materials (if any)	g	10				10.4							
17	Weight of charcoal+container	g												
18	Weight of stove+charcoal	g	2761.2		2826.3		2757.7		2854.3		2859.9		2927.1	
19	Net mass of charcoal	g			65.1	Δc_c			96.6	Δc_h			67.2	Δc_s
20	Additional dry fuel (added w/ wet fuel)	g		$f_{add,ci}$		$f_{add,cf}$		$f_{add,hci}$		$f_{add,hf}$		$f_{add,si}$		$f_{add,sf}$
21	Net mass of additonal fuel	g			0	$\Delta f_{add,c}$			0	$\Delta f_{add,h}$			0	$\Delta f_{add,s}$
22	Moisture content of additional dry fuel	%		$m_{add,c}$				$m_{add,h}$				$m_{add,s}$		
23	Average fuel moisture content	%			6.80	$m_{avg,c}$			6.80	$m_{avg,h}$			6.80	$m_{avg,s}$
24	Type of Additional Dry fuel				Is char discarded									
25	Pot on time	h:min:s	12:47:04	t_{cp}	after Cold Start?		13:25:15	t_{hp}						
26	Total mass of fuel	g	530.7	f_{cm}	yes	(yes/no)	684.9	f_{hm}			434.4	f_{sm}		
27	Effective calorific value	kJ/kg	16,984	c_{eff}			16,984	c_{eff}			16984	c_{eff}		

Row	Calculations/Results	Units	COLD START data	label	HOT START data	label
31	Fuel consumed (moist)	g	530.7	f_{cm}	684.9	f_{hm}
32	Adjusted net change in char during test	g	63.9	$\Delta c_c'$	95.2	$\Delta c_h'$
33	Equivalent dry fuel consumed	g	373.7	f_{cd}	459.2	f_{hd}
34	Water vaporized from all pots	g	146.5	w_{cv}	215.9	w_{hv}
35	Effective mass of water boiled	g	4427.4	w_{cr}	4771.9	w_{hr}
36	Time to boil Pot # 1	min	27.00	Δt_c	24.00	Δt_h
37	Temp-corr time to boil Pot # 1	min	27.68	Δt^T_c	23.29	Δt^T_h
38	Thermal efficiency	%	27.1%	h_c	24.9%	h_h
39	Burning rate	g/min	13.8	r_{cb}	19.1	r_{hb}
40	Specific fuel consumption	g/liter	84.4	SC_c	96.2	SC_h

Row	SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST) Calculations/Results	Units	data	label
31	Fuel consumed during the simmer phase (moist)	g	434.4	f_{sm}
32	Adjusted net change in char during test	g	64.1	$\Delta c_s'$
33	Equivalent dry fuel consumed	g	284.6	f_{sd}
34	Water vaporized	g	712.0	w_{sv}
35	Water remaining at end of simmer - All Pots	g	4047.5	w_{sr}
36	Time of simmer	min	30.45	Δt_s
37	Thermal efficiency	%	29.5%	h_s
38	Burning rate	g/min	9.3	r_{sb}
39	Specific fuel consumption	g/liter	70.3	SC_s
40	Firepower	watts	2868	FP_s

- Same sheet – scrolled to the right (tab circled)
- This area of the sheet is also (mostly) consistent with WBT spreadsheet
- Added (blue-shaded areas)…



	TEST #2		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
			Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start		Finish: ~30 min	
5	Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
6	Time (in 24 hour form)	h:min:s	12:45:45	t_{ci}	13:12:45	t_{cf}	13:24:00	t_{hi}	13:48:00	t_{hf}	13:50:33	t_{si}	14:21:00	t_{sf}
7	Weight of fuel	g	530.7	f_{ci}	0	f_{cf}	1159.1	f_{hi}	474.2	f_{hf}	434.4	f_{si}	0	f_{sf}
8	Water temperature, Pot # 1	°C	19.8	$T1_{ci}$	93.0	$T1_{cf}$	22.5	$T1_{hi}$	99.8	$T1_{hf}$	97.7	$T1_{si}$	94.3	$T1_{sf}$
9	Water temperature, Pot # 2	°C		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$		$T2_{si}$		$T2_{sf}$
10	Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$		$T3_{si}$		$T3_{sf}$
11	Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$		$T4_{si}$		$T4_{sf}$
12	Weight of Pot # 1 with water	g	5850.9	$P1_{ci}$	5704.4	$P1_{cf}$	5851.7	$P1_{hi}$	5635.8	$P1_{hf}$	5611.1	$P1_{si}$	4899.1	$P1_{sf}$
13	Weight of Pot # 2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$		$P2_{si}$		$P2_{sf}$
14	Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$		$P3_{si}$		$P3_{sf}$
15	Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$		$P4_{si}$		$P4_{sf}$
16	Weight of fire-starting materials (if any)	g	10				10.4							
17	Weight of charcoal+container	g												
18	Weight of stove+charcoal	g	2761.2		2826.3		2757.7		2854.3		2859.9		2927.1	
19	Net mass of charcoal	g			65.1	Δc_c			96.6	Δc_h			67.2	Δc_s
20	Additional dry fuel (added w/ wet fuel)	g		$f_{add,ci}$		$f_{add,cf}$		$f_{add,hci}$		$f_{add,hf}$		$f_{add,si}$		$f_{add,sf}$
21	Net mass of additonal fuel	g			0	$\Delta f_{add,c}$			0	$\Delta f_{add,h}$			0	$\Delta f_{add,s}$
22	Moisture content of additional dry fuel	%		$m_{add,c}$				$m_{add,h}$				$m_{add,s}$		
23	Average fuel moisture content	%			6.80	$m_{avg,c}$			6.80	$m_{avg,h}$			6.80	$m_{avg,s}$
24	Type of Additional Dry fuel				Is char discarded									
25	Pot on time	h:min:s	12:47:04	t_{cp}	after Cold Start?		13:25:15	t_{hp}						
26	Total mass of fuel	g	530.7	f_{cm}	yes	(yes/no)	684.9	f_{hm}			434.4	f_{sm}		
27	Effective calorific value	kJ/kg	16,984	c_{eff}			16,984	c_{eff}			16984	c_{eff}		

			COLD START		HOT START	
30	Calculations/Results	Units	data	label	data	label
31	Fuel consumed (moist)	g	530.7	f_{cm}	684.9	f_{hm}
32	Adjusted net change in char during test	g	63.9	$\Delta c_c'$	95.2	$\Delta c_h'$
33	Equivalent dry fuel consumed	g	373.7	f_{cd}	459.2	f_{hd}
34	Water vaporized from all pots	g	146.5	w_{cv}	215.9	w_{hv}
35	Effective mass of water boiled	g	4427.4	w_{cr}	4771.9	w_{hr}
36	Time to boil Pot # 1	min	27.00	Δt_c	24.00	Δt_h
37	Temp-corr time to boil Pot # 1	min	27.68	Δt^T_c	23.29	Δt^T_h
38	Thermal efficiency	%	27.1%	h_c	24.9%	h_h
39	Burning rate	g/min	13.8	r_{cb}	19.1	r_{hb}
40	Specific fuel consumption	g/liter	84.4	SC_c	96.2	SC_h

	SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)			
30	Calculations/Results	Units	data	label
31	Fuel consumed during the simmer phase (moist)	g	434.4	f_{sm}
32	Adjusted net change in char during test	g	64.1	$\Delta c_s'$
33	Equivalent dry fuel consumed	g	284.6	f_{sd}
34	Water vaporized	g	712.0	w_{sv}
35	Water remaining at end of simmer - All Pots	g	4047.5	w_{sr}
36	Time of simmer	min	30.45	Δt_s
37	Thermal efficiency	%	29.5%	h_s
38	Burning rate	g/min	9.3	r_{sb}
39	Specific fuel consumption	g/liter	70.3	SC_s
40	Firepower	watts	2868	FP_s

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

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-Added (blue-shaded areas):

- -Accounting for mixture of low-moisture and high-moisture fuel
- -Automatically filled by active formulas in worksheet

	U	V	W	X	Y	Z	AB	AC	AD	AE	AG	AH	AJ	AK
1														
2	TEST #2		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
3	Insert Data		Start		Finish: when		Start		Finish: when		Start		Finish: ~30 min	
4					Pot #1 boils				Pot #1 boils					
5	**Measurements**	Units	data	label	data	label	data	label	data	label	data	label	data	label
6	Time (in 24 hour form)	h:min:s	12:45:45	t_{ci}	13:12:45	t_{cf}	13:24:00	t_{hi}	13:48:00	t_{hf}	13:50:33	t_{si}	14:21:00	t_{sf}
7	Weight of fuel	g	530.7	f_{ci}	0	f_{cf}	1159.1	f_{hi}	474.2	f_{hf}	434.4	f_{si}	0	f_{sf}
8	Water temperature, Pot # 1	°C	19.8	$T1_{ci}$	93.0	$T1_{cf}$	22.5	$T1_{hi}$	99.8	$T1_{hf}$	97.7	$T1_{si}$	94.3	$T1_{sf}$
9	Water temperature, Pot # 2	°C		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$		$T2_{si}$		$T2_{sf}$
10	Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$		$T3_{si}$		$T3_{sf}$
11	Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$		$T4_{si}$		$T4_{sf}$
12	Weight of Pot # 1 with water	g	5850.9	$P1_{ci}$	5704.4	$P1_{cf}$	5851.7	$P1_{hi}$	5635.8	$P1_{hf}$	5611.1	$P1_{si}$	4899.1	$P1_{sf}$
13	Weight of Pot # 2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$		$P2_{si}$		$P2_{sf}$
14	Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$		$P3_{si}$		$P3_{sf}$
15	Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$		$P4_{si}$		$P4_{sf}$
16	Weight of fire-starting materials (if any)	g	10				10.4							
17	Weight of charcoal+container	g												
18	Weight of stove+charcoal	g	2761.2		2826.3		2757.7		2854.3		2859.9		2927.1	
19	**Net mass of charcoal**	g			65.1	Δc_c			96.6	Δc_h			67.2	Δc_s
20	Additional dry fuel (added w/ wet fuel)	g		$f_{add,ci}$		$f_{add,cf}$		$f_{add,hci}$		$f_{add,hf}$		$f_{add,si}$		$f_{add,sf}$
21	**Net mass of additonal fuel**	g			0	$\Delta f_{add,c}$			0	$\Delta f_{add,h}$			0	$\Delta f_{add,s}$
22	Moisture content of additional dry fuel	%		$m_{add,c}$				$m_{add,h}$				$m_{add,s}$		
23	**Average fuel moisture content**	%			6.80	$m_{avg,c}$			6.80	$m_{avg,h}$			6.80	$m_{avg,s}$
24	Type of Additional Dry fuel				Is char discarded									
25	Pot on time	h:min:s	12:47:04	t_{cp}	after Cold Start?		13:25:15	t_{hp}						
26	**Total mass of fuel**	g	530.7	f_{cm}	yes	(yes/no)	684.9	f_{hm}			434.4	f_{sm}		
27	**Effective calorific value**	kJ/kg	16,984	c_{eff}			16,984	c_{eff}			16984	c_{eff}		
28														

			COLD START		HOT START		SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)			
30	**Calculations/Results**	Units	data	label	data	label	**Calculations/Results**	Units	data	label
31	Fuel consumed (moist)	g	530.7	f_{cm}	684.9	f_{hm}	Fuel consumed during the simmer phase (moist)	g	434.4	f_{sm}
32	Adjusted net change in char during test	g	63.9	$\Delta c_c'$	95.2	$\Delta c_h'$	Adjusted net change in char during test	g	64.1	$\Delta c_s'$
33	Equivalent dry fuel consumed	g	373.7	f_{cd}	459.2	f_{hd}	Equivalent dry fuel consumed	g	284.6	f_{sd}
34	Water vaporized from all pots	g	146.5	w_{cv}	215.9	w_{hv}	Water vaporized	g	712.0	w_{sv}
35	Effective mass of water boiled	g	4427.4	w_{cr}	4771.9	w_{hr}	Water remaining at end of simmer - All Pots	g	4047.5	w_{sr}
36	Time to boil Pot # 1	min	27.00	Δt_c	24.00	Δt_h	Time of simmer	min	30.45	Δt_s
37	Temp-corr time to boil Pot # 1	min	27.68	Δt^T_c	23.29	Δt^T_h	Thermal efficiency	%	29.5%	h_s
38	Thermal efficiency	%	27.1%	h_c	24.9%	h_h	Burning rate	g/min	9.3	r_{sb}
39	Burning rate	g/min	13.8	r_{cb}	19.1	r_{hb}	Specific fuel consumption	g/liter	70.3	SC_s
40	Specific fuel consumption	g/liter	84.4	SC_c	96.2	SC_h	Firepower	watts	2868	FP_s

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

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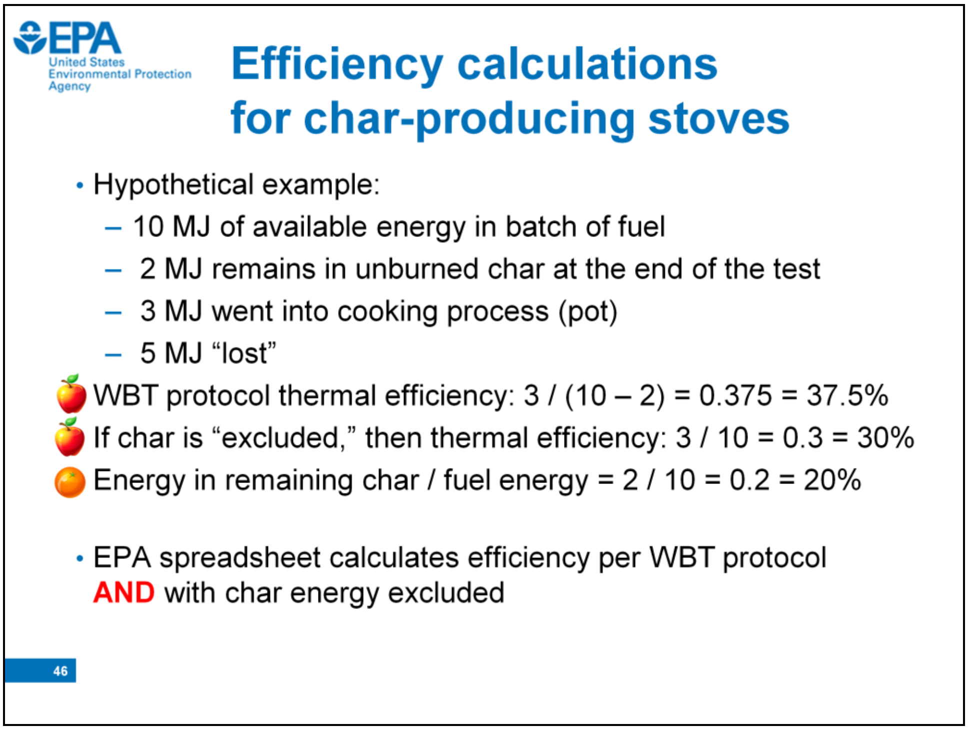
-Added (blue-shaded areas):

- Accounting for ash content of fuel and remaining char
  - Especially useful for charcoal stoves/stoves that aren't emptied between phases
  - AND Char-producing stoves



Now let's discuss efficiency calculations for char-producing stoves. As I mentioned before, there has been debate on this topic, and our goal at EPA is to report efficiency in a way that is fair and is clear to all stakeholders. I think it is easiest to explain the calculations using this hypothetical example. Let's say we begin with a batch of fuel with 10 MJ of available energy. We find 2 MJ of energy remains in the unburned char at the end of the test, and 3 MJ went into the cooking process. 5 MJ of energy was "lost" to the surroundings. Let's look at the first apple on the slide – the efficiency calculation specified in the WBT protocol gives full credit for the energy in the remaining char – the 2 MJ of char energy is subtracted from the 10 MJ of total energy – there is an assumption that the energy in the char represents unused energy that can be used later. In this example, thermal efficiency is 37.5%. Now let's look at the second apple – efficiency can also be calculated with the char energy "excluded," and this would apply only if the char is discarded or is used for some purpose other than for fuel (such as for biochar). Now let's look at the orange on the slide – we can calculate the ratio of the energy in the remaining char to the total available fuel energy – in this case, it is 20%. You may want to maximize this number if an objective of your stove program is to produce char (whether it is for fuel, biochar, carbon credits, or other purposes). But if your stove program is in an area where people actually discard the char, then you may consider this number as a loss of potential energy from the fuel. On the other hand, if your fuel is some type of waste biomass (such as waste rice hulls) the loss may not matter anyway. Let's look at the two apples on the slide again – we CAN compare thermal efficiencies with and without the char energy credit. However, we cannot add the numbers for the second apple and the orange – we cannot say the stove in this example is 50% efficient because the thermal efficiency is 30% and the char energy is 20%. While there is a common denominator (the 10 MJ of available energy), the numerators cannot be added, because they are different – they are useful energy versus potential energy. We are planning to report efficiencies both ways (the two apples) and to report the ratio of energy in char to fuel energy (the orange). We think this will provide complete information, and please let us know what you think.

Now Seth will continue with the tour of the spreadsheet, picking up with the efficiency calculations for this example with the char-producing stove.

United States Environmental Protection Agency

Calculations/Results	Units	COLD START data	label	HOT START data	label
Fuel consumed (moist)	g	530.7	f_{cm}	731.7	f_{hm}
Adjusted net change in char during test	g	63.9	$\Delta c_c'$	142.3	$\Delta c_h'$
Equivalent dry fuel consumed	g	373.7	f_{cd}	417.0	f_{hd}
Water vaporized from all pots	g	146.5	w_{cv}	215.9	w_{hv}
Effective mass of water boiled	g	4427.4	w_{cr}	4771.9	w_{hr}
Time to boil Pot # 1	min	27.00	Δt_c	24.00	Δt_h
Temp-corr time to boil Pot # 1	min	27.68	Δt^T_c	23.29	Δt^T_h
Thermal efficiency	%	27.1%	h_c	27.4%	h_h
Burning rate	g/min	13.8	r_{cb}	17.4	r_{hb}
Specific fuel consumption	g/liter	84.4	SC_c	87.4	SC_h
Temp-corr sp fuel consumption	g/liter	86.5	SC^T_c	84.8	SC^T_h
Temp-corr sp energy consumpt.	kJ/liter	1593	SE^T_C	1561	SE^T_H
Fire power	watts	4247	FP_c	5331	FP_h
Cooking power	watts	1149	CP_c	1462	CP_h

SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST) Calculations/Results	Units	data	label
Fuel consumed during the simmer phase (moist)	g	384.8	f_{sm}
Adjusted net change in char during test	g	14.0	$\Delta c_s'$
Equivalent dry fuel consumed	g	329.6	f_{sd}
Water vaporized	g	712.0	w_{sv}
Water remaining at end of simmer - All Pots	g	4047.5	w_{sr}
Time of simmer	min	30.45	Δt_s
Thermal efficiency	%	25.5%	h_s
Burning rate	g/min	10.8	r_{sb}
Specific fuel consumption	g/liter	81.4	SC_s
Firepower	watts	3322	FP_s
Turn down ratio	--	1.28	TDR
Specific Energy Consumption	kJ/liter	1499	SE_s
T-corrected Fuel Benchmark to Complete 5L WBT	g	835	BF
T-corrected Energy Benchmark to Complete 5L WBT	kJ	15,381	BE

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

48

- Same sheet we've been looking at (tab circled)
  - -This is the section of the sheet that contains typical fuel use and efficiency calculations from the WBT spreadsheet
  - -These calculations include the energy contained in the char
- -Next are the results with the char energy excluded . . .

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CHAR ENERGY EXCLUDED		COLD START	HOT START
Calculations/Results	Units	data	data
Fuel consumed (moist)	g	530.7	684.9
Adjusted net change in char during test	g	0.0	0.0
Equivalent dry fuel consumed	g	489.6	631.8
Water vaporized from all pots	g	146.5	215.9
Effective mass of water boiled	g	4427.4	4771.9
Time to boil Pot # 1	min	27.00	24.00
Temp-corr time to boil Pot # 1	min	27.68	23.29
Thermal efficiency	%	20.7%	18.1%
Burning rate	g/min	18.1	26.3
Specific fuel consumption	g/liter	110.6	132.4
Temp-corr sp fuel consumption	g/liter	113.3	128.5
Temp-corr sp energy consumpt.	kJ/liter	2087	2365
Fire power	watts	4247	5871
Cooking power	watts	1149	1462
Energy in char / Energy in equiv dry fuel	%	24%	27%

CHAR ENERGY EXCLUDED		SIMMER
Calculations/Results	Units	data
Fuel consumed during the simmer phase (mo	g	434.4
Adjusted net change in char during test phase	g	0.0
Equivalent dry fuel consumed	g	400.7
Water vaporized	g	712.0
Water remaining at end of simmer - All Pots	g	4047.5
Time of simmer	min	30.45
Burning rate	g/min	13.2
Specific fuel consumption	g/liter	99.0
Firepower	watts	2868
Turn down ratio	--	1.48
Specific Energy Consumption	kJ/liter	1823
Energy in char / Energy in equiv dry fuel	%	29%

= results affected by excluding char energy

Summary / CS-Result / HS-Result / Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6

49

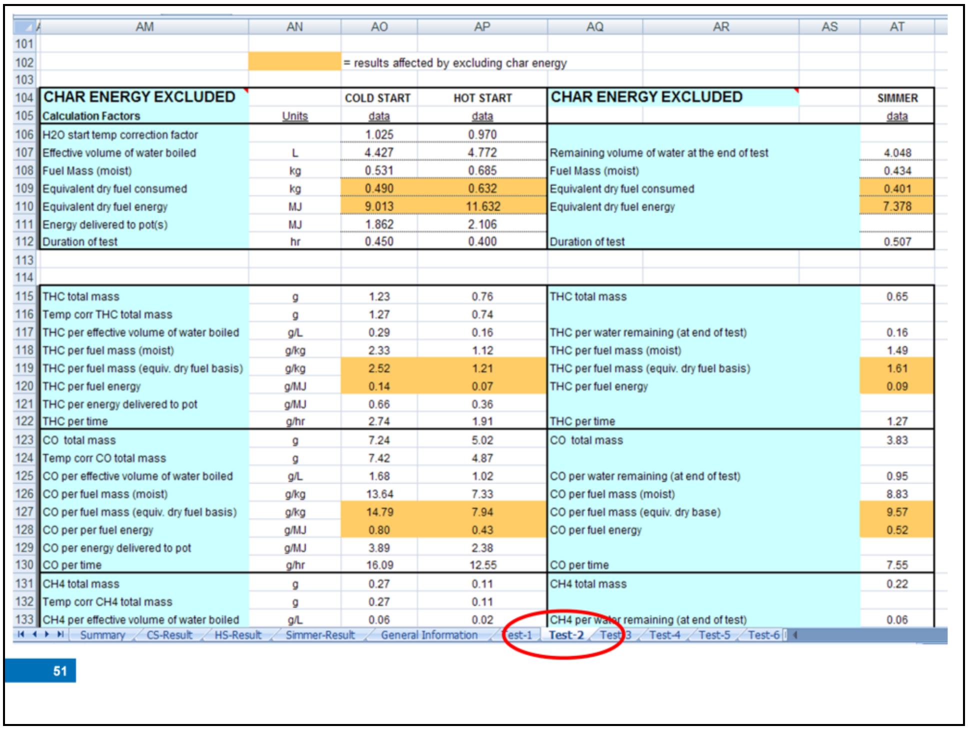
- Same sheet (tab circled) scrolled to right
- Added calculations for Char Energy Excluded
- These results apply ONLY if char (remaining at the end of the burn-cycle) is discarded or is used for a different purpose (such as for biochar)
- Energy in remaining char is not credited in thermal efficiency and fuel-use calculations
- Orange-shaded cells – results affected by excluding char energy

	U	V	W	X	Y	Z	AB–AE	AH	AJ
103									
104	**Values used in calculations of emissions**		**COLD START**		**HOT START**		**SIMMER TEST** (CALCULATIONS DIFFER FROM HIGH POWER TEST)		
105	**(below)**	Units	data	label	data	label		Units	data
106	H2O start temp correction factor		1.025		0.970				
107	Effective volume of water boiled	L	4.427		4.772		Remaining volume of water at the end of test	liter	4.048
108	Fuel Mass (moist)	kg	0.531		0.685		Fuel Mass (moist)	Kg	0.434
109	Equivalent dry fuel consumed	kg	0.374		0.459		Equivalent dry fuel consumed	Kg	0.285
110	Equivalent dry fuel energy	MJ	6.879		8.454		Equivalent dry fuel energy	MJ	5.240
111	Energy delivered to pot(s)	MJ	1.862	$E_{D,c}$	2.106	$E_{D,h}$			
112	Duration of test	hr	0.450		0.400		Duration of test	hr	0.507
113									
114	**Air Pollutant Emissions**								
115	THC total mass	g	1.23		0.76		THC total mass	g	0.65
116	Temp corr THC total mass	g	1.27		0.74				
117	THC per effective volume of water boiled	g/L	0.29		0.16		THC per water remaining (at end of test)	g/L	0.16
118	THC per fuel mass (moist)	g/kg	2.33		1.12		THC per fuel mass (moist)	g/kg	1.49
119	THC per fuel mass (equiv. dry fuel basis)	g/kg	3.30		1.66		THC per fuel mass (equiv. dry fuel basis)	g/kg	2.27
120	THC per fuel energy	g/MJ	0.18		0.09		THC per fuel energy	g/MJ	0.12
121	THC per energy delivered to pot	g/MJ	0.66		0.36				
122	THC per time	g/hr	2.74		1.91		THC per time	g/hr	1.27
123	CO total mass	g	7.24		5.02		CO total mass	g	3.83
124	Temp corr CO total mass	g	7.42		4.87				
125	CO per effective volume of water boiled	g/L	1.68		1.02		CO per water remaining (at end of test)	g/L	0.95
126	CO per fuel mass (moist)	g/kg	13.64		7.33		CO per fuel mass (moist)	g/kg	8.83
127	CO per fuel mass (equiv. dry fuel basis)	g/kg	19.38		10.93		CO per fuel mass (equiv. dry base)	g/kg	13.47
128	CO per per fuel energy	g/MJ	1.05		0.59		CO per fuel energy	g/MJ	0.73
129	CO per energy delivered to pot	g/MJ	3.89		2.38				
130	CO per time	g/hr	16.09		12.55		CO per time	g/hr	7.55
131	CH4 total mass	g	0.27		0.11		CH4 total mass	g	0.22
132	Temp corr CH4 total mass	g	0.27		0.11				
133	CH4 per effective volume of water boiled	g/L	0.06		0.02		CH4 per water remaining (at end of test)	g/L	0.06
134	CH4 per fuel mass (moist)	g/kg	0.50		0.16		CH4 per fuel mass (moist)	g/kg	0.52
135	CH4 per fuel mass (equiv. dry fuel basis)	g/kg	0.71		0.24		CH4 per fuel mass (equiv. dry base)	g/kg	0.79
136	CH4 per fuel energy	g/MJ	0.04		0.01		CH4 per fuel energy	g/MJ	0.04
137	CH4 per energy delivered to pot	g/MJ	0.14		0.05				
138	CH4 per time	g/hr	0.59		0.28		CH4 per time	g/hr	0.44
139	NOx total mass	g	0.31		0.29		NOx total mass	g	0.30
140	Temp corr NOx total mass	g	0.31		0.28				
141	NOx per effective volume of water boiled	g/L	0.07		0.06		NOx per water remaining (at end of test)	g/L	0.07
142	NOx per fuel mass (moist)	g/kg	0.58		0.42		NOx per fuel mass (moist)	g/kg	0.69

Summary | CS-Result | HS-Result | Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6

50

- Still same sheet – scrolled down and to the left (tab circled)
- Added (blue-shaded areas)
    - -Results for emissions for this test replication
    - -Some of these values are used in the IWA Tier evaluations, but many others are interesting/important to us (at the EPA), but are not currently included in the stove evaluations as outlined by the current IWA



	AM	AN	AO	AP	AQ	AT
101						
102			= results affected by excluding char energy			
103						
104	CHAR ENERGY EXCLUDED		COLD START	HOT START	CHAR ENERGY EXCLUDED	SIMMER
105	Calculation Factors	Units	data	data		data
106	H2O start temp correction factor		1.025	0.970		
107	Effective volume of water boiled	L	4.427	4.772	Remaining volume of water at the end of test	4.048
108	Fuel Mass (moist)	kg	0.531	0.685	Fuel Mass (moist)	0.434
109	Equivalent dry fuel consumed	kg	0.490	0.632	Equivalent dry fuel consumed	0.401
110	Equivalent dry fuel energy	MJ	9.013	11.632	Equivalent dry fuel energy	7.378
111	Energy delivered to pot(s)	MJ	1.862	2.106		
112	Duration of test	hr	0.450	0.400	Duration of test	0.507
113						
114						
115	THC total mass	g	1.23	0.76	THC total mass	0.65
116	Temp corr THC total mass	g	1.27	0.74		
117	THC per effective volume of water boiled	g/L	0.29	0.16	THC per water remaining (at end of test)	0.16
118	THC per fuel mass (moist)	g/kg	2.33	1.12	THC per fuel mass (moist)	1.49
119	THC per fuel mass (equiv. dry fuel basis)	g/kg	2.52	1.21	THC per fuel mass (equiv. dry fuel basis)	1.61
120	THC per fuel energy	g/MJ	0.14	0.07	THC per fuel energy	0.09
121	THC per energy delivered to pot	g/MJ	0.66	0.36		
122	THC per time	g/hr	2.74	1.91	THC per time	1.27
123	CO total mass	g	7.24	5.02	CO total mass	3.83
124	Temp corr CO total mass	g	7.42	4.87		
125	CO per effective volume of water boiled	g/L	1.68	1.02	CO per water remaining (at end of test)	0.95
126	CO per fuel mass (moist)	g/kg	13.64	7.33	CO per fuel mass (moist)	8.83
127	CO per fuel mass (equiv. dry fuel basis)	g/kg	14.79	7.94	CO per fuel mass (equiv. dry base)	9.57
128	CO per per fuel energy	g/MJ	0.80	0.43	CO per fuel energy	0.52
129	CO per energy delivered to pot	g/MJ	3.89	2.38		
130	CO per time	g/hr	16.09	12.55	CO per time	7.55
131	CH4 total mass	g	0.27	0.11	CH4 total mass	0.22
132	Temp corr CH4 total mass	g	0.27	0.11		
133	CH4 per effective volume of water boiled	g/L	0.06	0.02	CH4 per water remaining (at end of test)	0.06

- Scrolled to the right on same sheet (tab circled)
- Added calculations for emissions for Char Energy Excluded
- These results apply ONLY if char is discarded or is used for a different purpose (such as for biochar)
- Energy in remaining char is not credited in emissions calculations
- Orange-shaded cells – results affected by excluding char energy

	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
1										
2										
3	**Wood - Red Oak (Quercus Rubra)**									
4	BATCH #	1	1	2	3	4	5			
5	Laboratory	G	S	S	S	S	S			
6	BASIS	dry		dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**
7	VOLATILE	86.60%		87.52%	87.43%	86.82%	86.98%	87.07%	0.39%	0.005
8	FIXED CARBON	12.31%		12.12%	12.28%	12.94%	12.41%	12.41%	0.31%	0.025
9	ASH	1.09%		0.36%	0.29%	0.24%	0.61%	0.52%	0.35%	0.676
10	SULFUR	<0.5%		0.02%	0.01%	0.01%	0.28%	0.07%	0.12%	1.624
11	CARBON	49.44%		49.59%	49.41%	49.60%	49.54%	49.52%	0.09%	0.002
12	HYDROGEN	5.92%		6.06%	5.97%	5.95%	6.22%	6.10%	0.15%	0.025
13	NITROGEN	<0.5%		3.90%	0.48%	0.37%	0.04%	1.20%	1.81%	1.513
14	OXYGEN	43.54%		43.58%	43.84%	43.83%	43.31%	43.62%	0.22%	0.005
15	BTU/LB		8176	8484	8432	8440	8349	8376	122	0.015
16	HHV (kJ/kg)		19017	19734	19613	19631	19420	19483	284	0.015
17	LHV (kJ/kg; calc'd)		17645	18411	18310	18333	18062	18152	312	0.017
18	MAF BTU/LB			8515	8457	8460	8397	8457	48	0.006
19	LBS OF SO2 PER MILLION BTU			0.05	0.02	0.02	0.67	0.19	0.32	1.686
20										
21	**Charcoal**									
22	BATCH #	1	1	1	1					
23	Laboratory	G	S	S	S					
24	BASIS	dry								
25	VOLATILE	19.59%								
26	FIXED CARBON	76.16%								
27	ASH	4.25%								
28	SULFUR	0.15%								
29	CARBON	80.75%								
30	HYDROGEN	2.90%								
31	NITROGEN	0.74%								
32	OXYGEN	10.89%				**Average**	**Std. Dev.**	**CV**		
33	BTU/LB		13076	12651	13263	12997	313.618	0.024		
34	HHV (kJ/kg)		30415	29426	30850	30230	729.476	0.024		
35	LHV (kJ/kg; calc'd)		29782	28793	30217	29597	729.476	0.025		
36										

Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6 / **Fuel Info** / Test-1-data / Test-2-

52

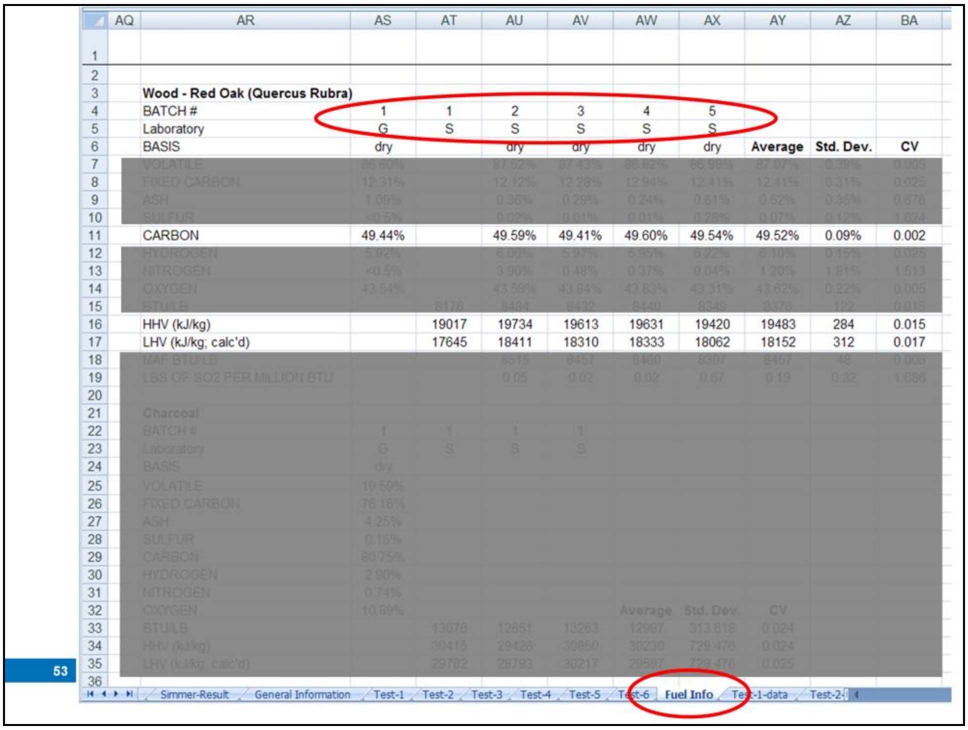
-Return to tour of the enhancements and modifications made in the EPA spreadsheet

-Now moved to Fuel Info sheet (tab circled)

- Includes information from “Calorific values” tab on WBT spreadsheet (not shown in this slide)

- Includes additional fuel analysis results (partially shown) from current round of stove testing

-All analyses done by external, independent labs



	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
1										
2										
3	**Wood - Red Oak (Quercus Rubra)**									
4	BATCH #	1	1	2	3	4	5			
5	Laboratory	G	S	S	S	S	S			
6	BASIS	dry		dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**
7	VOLATILE	86.60%		87.52%	87.43%	86.82%	86.98%	87.07%	0.39%	0.005
8	FIXED CARBON	12.31%		12.12%	12.28%	12.94%	12.41%	12.41%	0.31%	0.025
9	ASH	1.09%		0.36%	0.29%	0.24%	0.61%	0.52%	0.35%	0.676
10	SULFUR	<0.5%		0.02%	0.01%	0.01%	0.28%	0.07%	0.12%	1.624
11	CARBON	49.44%		49.59%	49.41%	49.60%	49.54%	49.52%	0.09%	0.002
12	HYDROGEN	5.92%		6.06%	5.97%	5.95%	6.22%	6.10%	0.15%	0.025
13	NITROGEN	<0.5%		3.90%	0.48%	0.37%	0.04%	1.20%	1.81%	1.513
14	OXYGEN	43.54%		43.58%	43.84%	43.83%	43.31%	43.62%	0.22%	0.005
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18	MAF BTU/LB			8515	8457	8460	8397	8457	48	0.006
19	LBS OF SO2 PER MILLION BTU			0.05	0.02	0.02	0.67	0.19	0.32	1.686
20										
21	**Charcoal**									
22	BATCH #	1	1	1	1					
23	Laboratory	G	S	S	S					
24	BASIS	dry								
25	VOLATILE	19.59%								
26	FIXED CARBON	76.16%								
27	ASH	4.25%								
28	SULFUR	0.15%								
29	CARBON	80.75%								
30	HYDROGEN	2.90%								
31	NITROGEN	0.74%								
32	OXYGEN	10.89%				**Average**	**Std. Dev.**	**CV**		
33	BTU/LB		13076	12651	13263	12997	313.818	0.024		
34	HHV (kJ/kg)		30415	29426	30850	30230	729.476	0.024		
35	LHV (kJ/kg; calc'd)		29782	28793	30217	29597	729.476	0.025		
36										

-Same sheet (Fuel Info; tab circled)

-We have had all 5 'batches' of the wood fuel we're using analyzed

- -Each 'batch' is made of an entire log (5 different trees, not all purchased at the same time)

-Note consistent values for 5 batches of wood fuel

- -Both C-content and energy content
- -Tells us that, at least regionally, the composition of this fuel is very consistent

	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
1											
2											
3		Wood - Red Oak (Quercus Rubra)									
4		BATCH #	1	1	2	3	4	5			
5		Laboratory	G	S	S	S	S	S			
6		BASIS	dry		dry	dry	dry	dry	Average	Std. Dev.	CV
7		VOLATILE	86.60%		87.52%	87.43%	86.82%	86.98%	87.07%	0.39%	0.005
8		FIXED CARBON	12.31%		12.12%	12.28%	12.94%	12.41%	12.41%	0.31%	0.025
9		ASH	1.09%		0.36%	0.29%	0.24%	0.61%	0.52%	0.35%	0.676
10		SULFUR	<0.5%		0.02%	0.01%	0.01%	0.28%	0.07%	0.12%	1.624
11		CARBON	49.44%		49.59%	49.41%	49.60%	49.54%	49.52%	0.09%	0.002
12		HYDROGEN	5.92%		6.06%	5.97%	5.95%	6.22%	6.10%	0.15%	0.025
13		NITROGEN	<0.5%		3.90%	0.48%	0.37%	0.04%	1.20%	1.81%	1.513
14		OXYGEN	43.54%		43.58%	43.84%	43.83%	43.31%	43.62%	0.22%	0.005
15		BTU/LB		8176	8484	8432	8440	8349	8376	122	0.015
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17		LHV (kJ/kg; calc'd)		17645	18411	18310	18333	18062	18152	312	0.017
18		MAF BTU/LB			8515	8457	8460	8397	8457	48	0.006
19		LBS OF SO2 PER MILLION BTU			0.05	0.02	0.02	0.67	0.19	0.32	1.686
20											
21		**Charcoal**									
22		BATCH #	1	1	1	1					
23		Laboratory	G	S	S	S					
24		BASIS	dry								
25		VOLATILE	19.59%								
26		FIXED CARBON	76.16%								
27		ASH	4.25%								
28		SULFUR	0.15%								
29		CARBON	80.75%								
30		HYDROGEN	2.90%								
31		NITROGEN	0.74%								
32		OXYGEN	10.89%				**Average**	**Std. Dev.**	**CV**		
33		BTU/LB		13076	12651	13263	12997	313.618	0.024		
34		HHV (kJ/kg)		30415	29426	30850	30230	729.476	0.024		
35		LHV (kJ/kg; calc'd)		29782	28793	30217	29597	729.476	0.025		
36											

Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6 / **Fuel Info** / Test-1-data / Test-2-

54

-Same sheet (Fuel Info; tab circled)

-We have 1 large ‘batch’ of charcoal

-Purchased many commercially-available bags from the same supplier & combined into one batch

-Took 3 random samples from different parts of the batch…

	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
1											
2											
3		**Wood - Red Oak (Quercus Rubra)**									
4		BATCH #	1	1	2	3	4	5			
5		Laboratory	G	S	S	S	S	S			
6		BASIS	dry		dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**
7		VOLATILE	86.60%		87.52%	87.43%	86.82%	86.98%	87.07%	0.39%	0.005
8		FIXED CARBON	12.31%		12.12%	12.28%	12.94%	12.41%	12.41%	0.31%	0.025
9		ASH	1.09%		0.36%	0.29%	0.24%	0.61%	0.52%	0.35%	0.676
10		SULFUR	<0.5%		0.02%	0.01%	0.01%	0.28%	0.07%	0.12%	1.624
11		CARBON	49.44%		49.59%	49.41%	49.60%	49.54%	49.52%	0.09%	0.002
12		HYDROGEN	5.92%		6.06%	5.97%	5.95%	6.22%	6.10%	0.15%	0.025
13		NITROGEN	<0.5%		3.90%	0.48%	0.37%	0.04%	1.20%	1.81%	1.513
14		OXYGEN	43.54%		43.58%	43.84%	43.83%	43.31%	43.62%	0.22%	0.005
15		BTU/LB		8176	8484	8432	8440	8349	8376	122	0.015
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17		LHV (kJ/kg, calc'd)		17645	18411	18310	18333	18062	18152	312	0.017
18		MAF BTU/LB			8515	8457	8460	8397	8457	48	0.006
19		LBS OF SO2 PER MILLION BTU			0.05	0.02	0.02	0.67	0.19	0.32	1.686
20											
21		**Charcoal**									
22		BATCH #	1	1	1	1					
23		Laboratory	G	S	S	S					
24		BASIS	dry								
25		VOLATILE	19.59%								
26		FIXED CARBON	76.16%								
27		ASH	4.25%								
28		SULFUR	0.15%								
29		CARBON	80.75%								
30		HYDROGEN	2.90%								
31		NITROGEN	0.74%								
32		OXYGEN	10.89%				**Average**	**Std. Dev.**	**CV**		
33		BTU/LB		13076	12651	13263	12997	313.618	0.024		
34		HHV (kJ/kg)		30415	29426	30850	30230	729.476	0.024		
35		LHV (kJ/kg; calc'd)		29782	28793	30217	29597	729.476	0.025		
36											

55

Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6 / **Fuel Info** / Test-1-data / Test-2-

-Same sheet (Fuel Info; tab circled)

-Took 3 random samples from different parts of the batch for analysis

-Note consistent values for charcoal fuel from the same batch

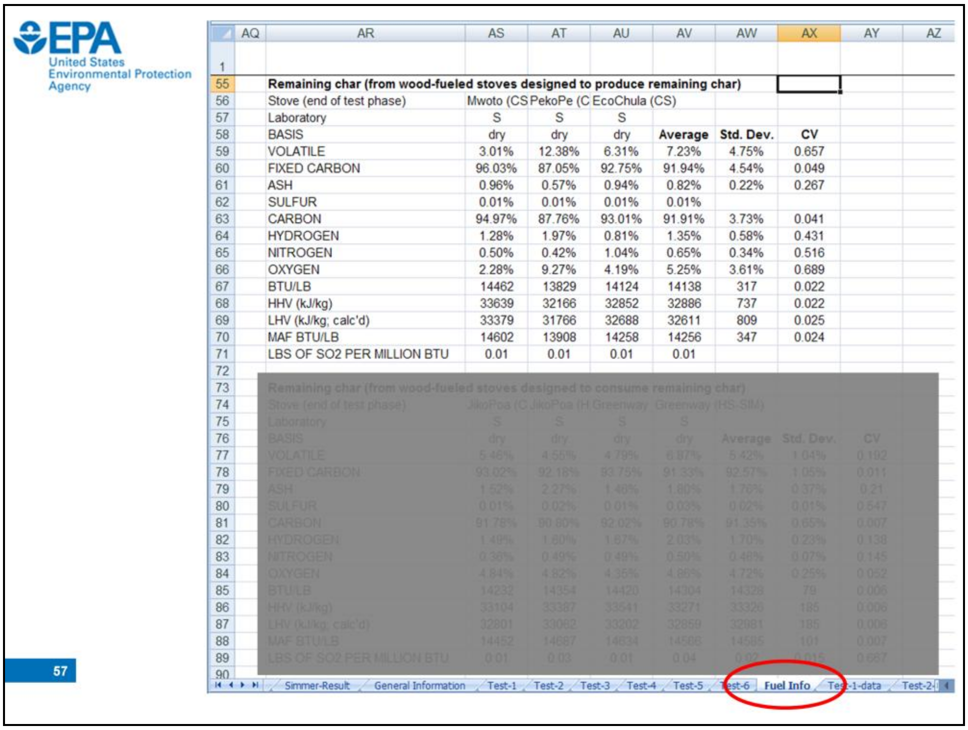
United States Environmental Protection Agency

	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ
1										
55		**Remaining char (from wood-fueled stoves designed to produce remaining char)**								
56		Stove (end of test phase)	Mwoto (CS	PekoPe (C	EcoChula (CS)					
57		Laboratory	S	S	S					
58		BASIS	dry	dry	dry	**Average**	**Std. Dev.**	**CV**		
59		VOLATILE	3.01%	12.38%	6.31%	7.23%	4.75%	0.657		
60		FIXED CARBON	96.03%	87.05%	92.75%	91.94%	4.54%	0.049		
61		ASH	0.96%	0.57%	0.94%	0.82%	0.22%	0.267		
62		SULFUR	0.01%	0.01%	0.01%	0.01%				
63		CARBON	94.97%	87.76%	93.01%	91.91%	3.73%	0.041		
64		HYDROGEN	1.28%	1.97%	0.81%	1.35%	0.58%	0.431		
65		NITROGEN	0.50%	0.42%	1.04%	0.65%	0.34%	0.516		
66		OXYGEN	2.28%	9.27%	4.19%	5.25%	3.61%	0.689		
67		BTU/LB	14462	13829	14124	14138	317	0.022		
68		HHV (kJ/kg)	33639	32166	32852	32886	737	0.022		
69		LHV (kJ/kg; calc'd)	33379	31766	32688	32611	809	0.025		
70		MAF BTU/LB	14602	13908	14258	14256	347	0.024		
71		LBS OF SO2 PER MILLION BTU	0.01	0.01	0.01	0.01				
72										
73		**Remaining char (from wood-fueled stoves designed to consume remaining char)**								
74		Stove (end of test phase)	JikoPoa (C	JikoPoa (H	Greenway	Greenway (HS-SIM)				
75		Laboratory	S	S	S	S				
76		BASIS	dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**	
77		VOLATILE	5.46%	4.55%	4.79%	6.87%	5.42%	1.04%	0.192	
78		FIXED CARBON	93.02%	92.18%	93.75%	91.33%	92.57%	1.05%	0.011	
79		ASH	1.52%	2.27%	1.46%	1.80%	1.76%	0.37%	0.21	
80		SULFUR	0.01%	0.02%	0.01%	0.03%	0.02%	0.01%	0.547	
81		CARBON	91.78%	90.80%	92.02%	90.78%	91.35%	0.65%	0.007	
82		HYDROGEN	1.49%	1.60%	1.67%	2.03%	1.70%	0.23%	0.138	
83		NITROGEN	0.36%	0.49%	0.49%	0.50%	0.46%	0.07%	0.145	
84		OXYGEN	4.84%	4.82%	4.35%	4.86%	4.72%	0.25%	0.052	
85		BTU/LB	14232	14354	14420	14304	14328	79	0.006	
86		HHV (kJ/kg)	33104	33387	33541	33271	33326	185	0.006	
87		LHV (kJ/kg; calc'd)	32801	33062	33202	32859	32981	185	0.006	
88		MAF BTU/LB	14452	14687	14634	14566	14585	101	0.007	
89		LBS OF SO2 PER MILLION BTU	0.01	0.03	0.01	0.04	0.02	0.015	0.667	
90										

Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6 / **Fuel Info** / Test-1-data / Test-2-

56

- Still on ‘Fuel Info’ sheet – scrolled down (tab circled)
- Fuel analysis results for remaining char (end of test phase)
  - -Analyses also done by independent labs



	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ
1										
55		**Remaining char (from wood-fueled stoves designed to produce remaining char)**								
56		Stove (end of test phase)	Mwoto (CS	PekoPe (C	EcoChula (CS)					
57		Laboratory	S	S	S					
58		BASIS	dry	dry	dry	**Average**	**Std. Dev.**	**CV**		
59		VOLATILE	3.01%	12.38%	6.31%	7.23%	4.75%	0.657		
60		FIXED CARBON	96.03%	87.05%	92.75%	91.94%	4.54%	0.049		
61		ASH	0.96%	0.57%	0.94%	0.82%	0.22%	0.267		
62		SULFUR	0.01%	0.01%	0.01%	0.01%				
63		CARBON	94.97%	87.76%	93.01%	91.91%	3.73%	0.041		
64		HYDROGEN	1.28%	1.97%	0.81%	1.35%	0.58%	0.431		
65		NITROGEN	0.50%	0.42%	1.04%	0.65%	0.34%	0.516		
66		OXYGEN	2.28%	9.27%	4.19%	5.25%	3.61%	0.689		
67		BTU/LB	14462	13829	14124	14138	317	0.022		
68		HHV (kJ/kg)	33639	32166	32852	32886	737	0.022		
69		LHV (kJ/kg; calc'd)	33379	31766	32688	32611	809	0.025		
70		MAF BTU/LB	14602	13908	14258	14256	347	0.024		
71		LBS OF SO2 PER MILLION BTU	0.01	0.01	0.01	0.01				
72										
73		**Remaining char (from wood-fueled stoves designed to consume remaining char)**								
74		Stove (end of test phase)	JikoPoa (C	JikoPoa (H	Greenway	Greenway (HS-SIM)				
75		Laboratory	S	S	S	S				
76		BASIS	dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**	
77		VOLATILE	5.46%	4.55%	4.79%	6.87%	5.42%	1.04%	0.192	
78		FIXED CARBON	93.02%	92.18%	93.75%	91.33%	92.57%	1.05%	0.011	
79		ASH	1.52%	2.27%	1.46%	1.80%	1.76%	0.37%	0.21	
80		SULFUR	0.01%	0.02%	0.01%	0.03%	0.02%	0.01%	0.547	
81		CARBON	91.78%	90.80%	92.02%	90.78%	91.35%	0.65%	0.007	
82		HYDROGEN	1.49%	1.60%	1.67%	2.03%	1.70%	0.23%	0.138	
83		NITROGEN	0.36%	0.49%	0.49%	0.50%	0.46%	0.07%	0.145	
84		OXYGEN	4.84%	4.82%	4.35%	4.86%	4.72%	0.25%	0.052	
85		BTU/LB	14232	14354	14420	14304	14328	79	0.006	
86		HHV (kJ/kg)	33104	33387	33541	33271	33326	185	0.006	
87		LHV (kJ/kg; calc'd)	32801	33062	33202	32859	32981	185	0.006	
88		MAF BTU/LB	14452	14687	14634	14566	14585	101	0.007	
89		LBS OF SO2 PER MILLION BTU	0.01	0.03	0.01	0.04	0.02	0.015	0.667	
90										

Simmer-Result / General Information / Test-1 / Test-2 / Test-3 / Test-4 / Test-5 / Test-6 / **Fuel Info** / Test-1-data / Test-2-

-We have separated:

-Remaining char from wood-fueled, designed to PRODUCE char

United States Environmental Protection Agency

	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ
1										
55–71		[redacted]								
72										
73		**Remaining char (from wood-fueled stoves designed to consume remaining char)**								
74		Stove (end of test phase)	JikoPoa (C	JikoPoa (H	Greenway	Greenway (HS-SIM)				
75		Laboratory	S	S	S	S				
76		BASIS	dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**	
77		VOLATILE	5.46%	4.55%	4.79%	6.87%	5.42%	1.04%	0.192	
78		FIXED CARBON	93.02%	92.18%	93.75%	91.33%	92.57%	1.05%	0.011	
79		ASH	1.52%	2.27%	1.46%	1.80%	1.76%	0.37%	0.21	
80		SULFUR	0.01%	0.02%	0.01%	0.03%	0.02%	0.01%	0.547	
81		CARBON	91.78%	90.80%	92.02%	90.78%	91.35%	0.65%	0.007	
82		HYDROGEN	1.49%	1.60%	1.67%	2.03%	1.70%	0.23%	0.138	
83		NITROGEN	0.36%	0.49%	0.49%	0.50%	0.46%	0.07%	0.145	
84		OXYGEN	4.84%	4.82%	4.35%	4.86%	4.72%	0.25%	0.052	
85		BTU/LB	14232	14354	14420	14304	14328	79	0.006	
86		HHV (kJ/kg)	33104	33387	33541	33271	33326	185	0.006	
87		LHV (kJ/kg; calc'd)	32801	33062	33202	32859	32981	185	0.006	
88		MAF BTU/LB	14452	14687	14634	14566	14585	101	0.007	
89		LBS OF SO2 PER MILLION BTU	0.01	0.03	0.01	0.04	0.02	0.015	0.667	
90										

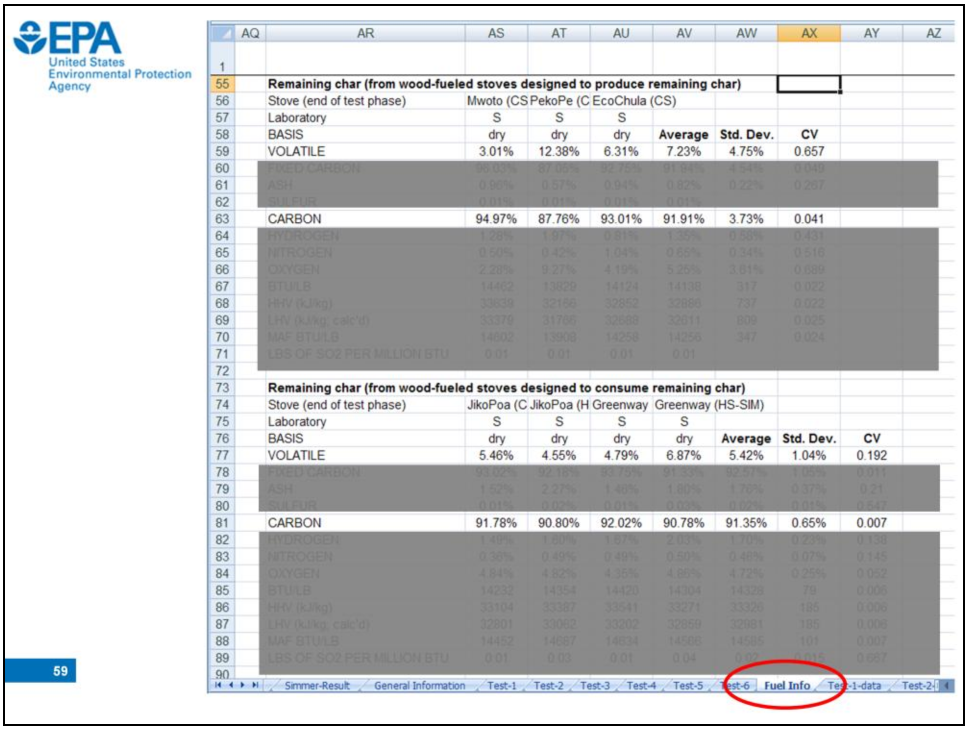
Simmer-Result | General Information | Test-1 | Test-2 | Test-3 | Test-4 | Test-5 | Test-6 | **Fuel Info** | Test-1-data | Test-2

58

-We have separated:

-Separately, wood-fueled, designed to CONSUME char

-Designed to operate differently, not good to lump together

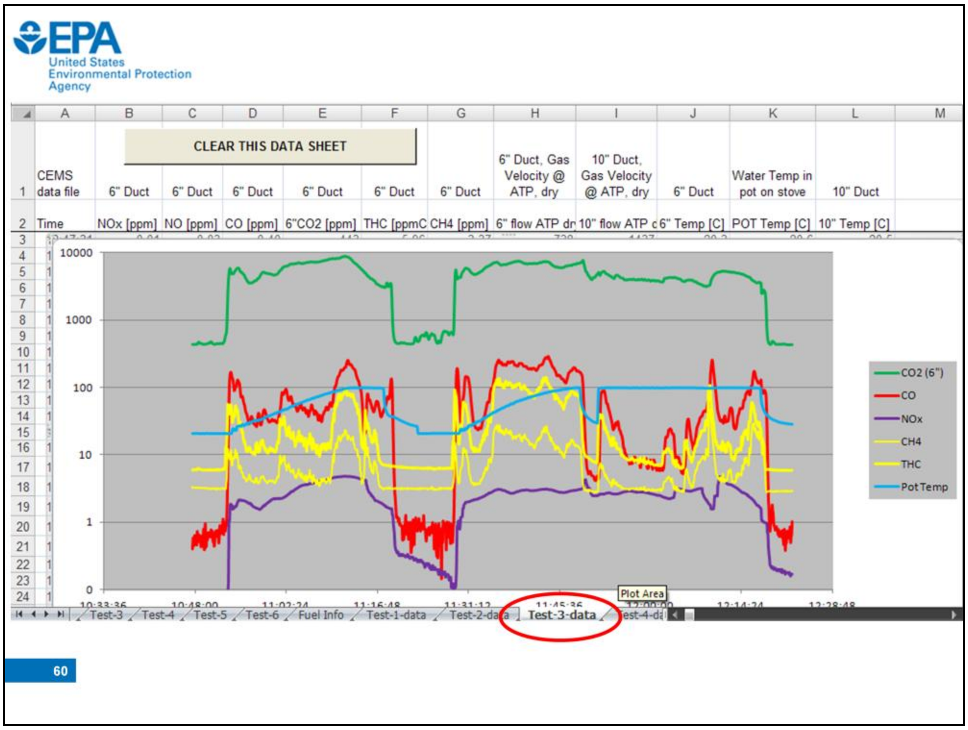


	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ
1										
55		**Remaining char (from wood-fueled stoves designed to produce remaining char)**								
56		Stove (end of test phase)	Mwoto (CS	PekoPe (C	EcoChula (CS)					
57		Laboratory	S	S	S					
58		BASIS	dry	dry	dry	**Average**	**Std. Dev.**	**CV**		
59		VOLATILE	3.01%	12.38%	6.31%	7.23%	4.75%	0.657		
60–62		[redacted]								
63		CARBON	94.97%	87.76%	93.01%	91.91%	3.73%	0.041		
64–72		[redacted]								
73		**Remaining char (from wood-fueled stoves designed to consume remaining char)**								
74		Stove (end of test phase)	JikoPoa (C	JikoPoa (H	Greenway	Greenway (HS-SIM)				
75		Laboratory	S	S	S	S				
76		BASIS	dry	dry	dry	dry	**Average**	**Std. Dev.**	**CV**	
77		VOLATILE	5.46%	4.55%	4.79%	6.87%	5.42%	1.04%	0.192	
78–80		[redacted]								
81		CARBON	91.78%	90.80%	92.02%	90.78%	91.35%	0.65%	0.007	
82–89		[redacted]								
90										

-Note:

char produced by stoves has higher carbon content (80.7% C vs near-or-above 90%; and lower volatile content:~20% in commercial char coal) than charcoal fuel produced by commercial supplier

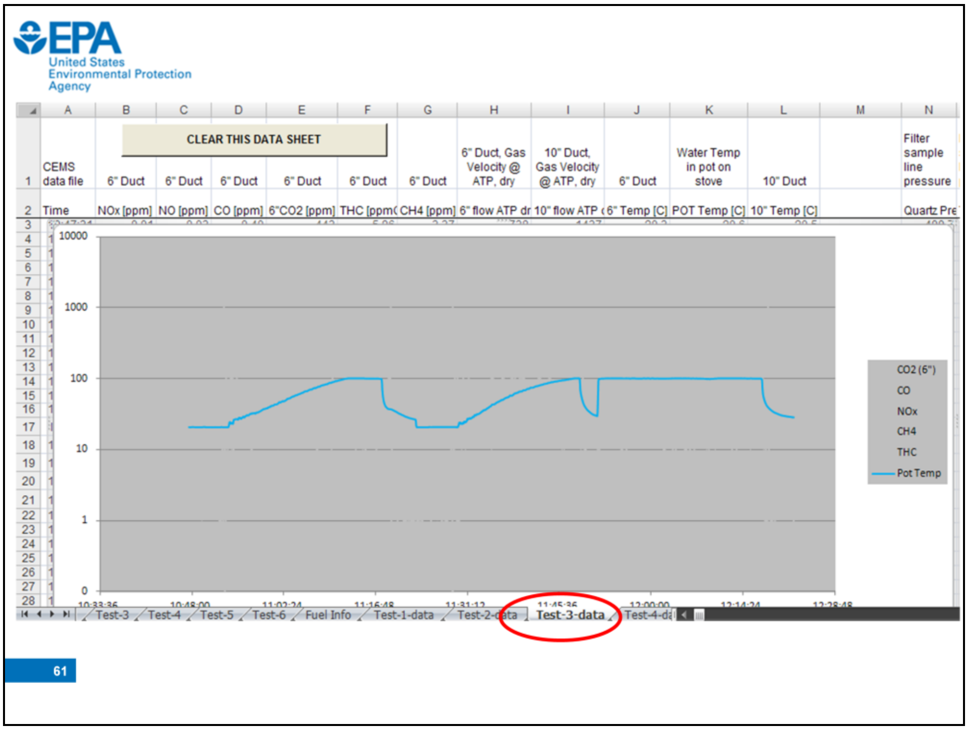
- Fuel analysis results for liquid fuels (kerosene and denatured alcohol) and remaining char from charcoal-fueled stoves also included (not shown – also on 'Fuel Info' sheet)



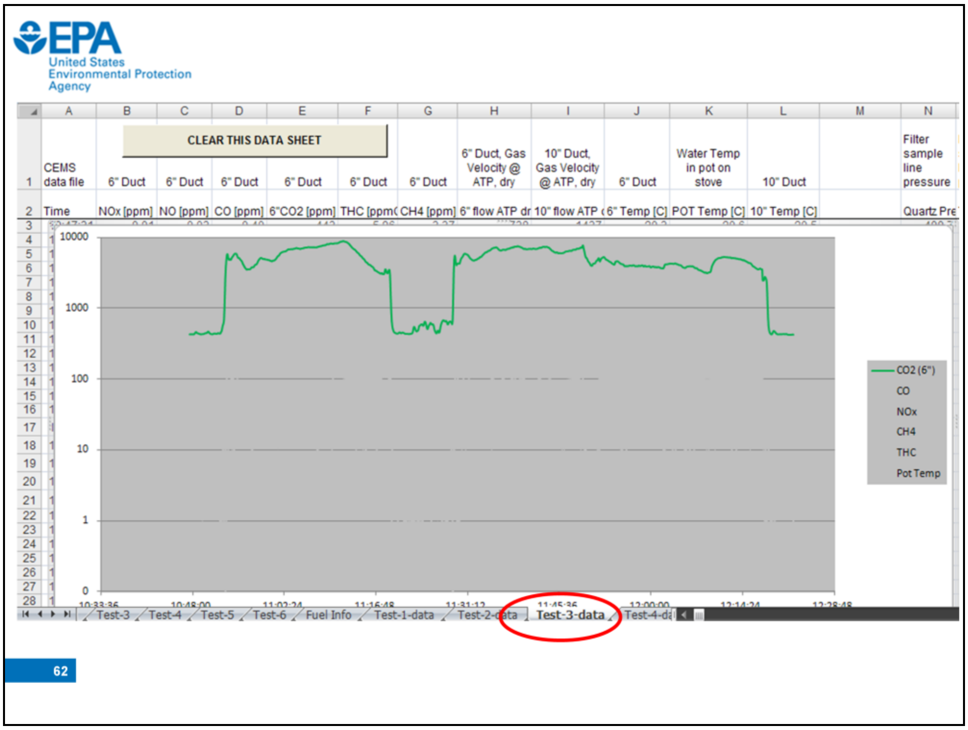
- Now looking at raw data for one test replication (Test 3; tab circled)

- Column headings include identification of 6-inch or 10-inch ducts (primary and secondary dilution tunnels, specific to EPA test facility), the measurement made, and units

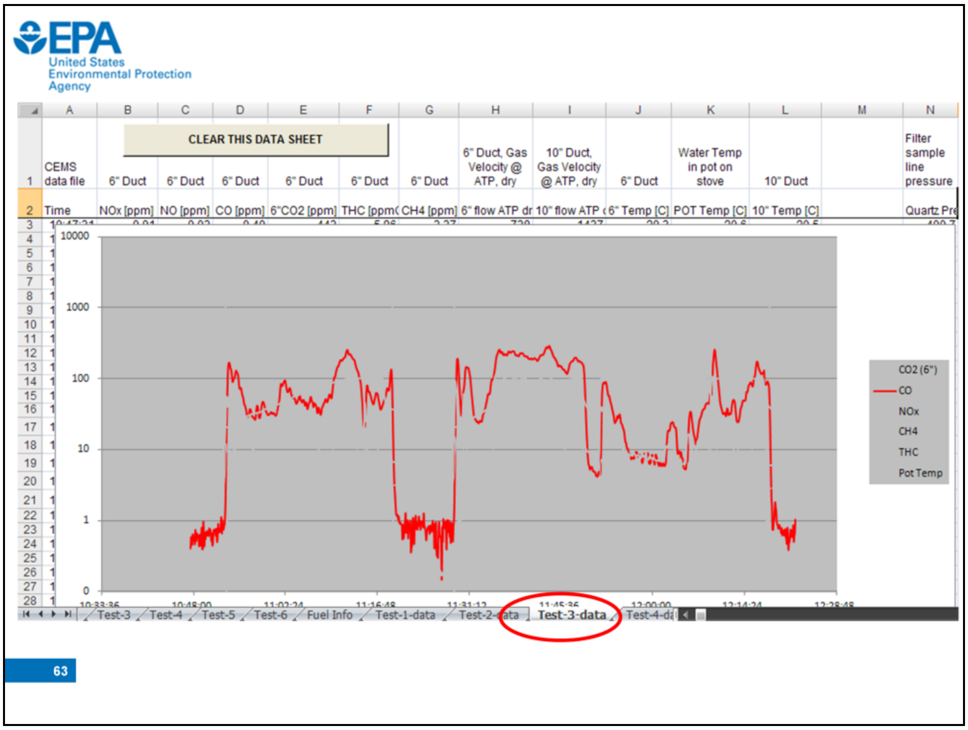
- Graph of (some) real-time data is shown for each replication



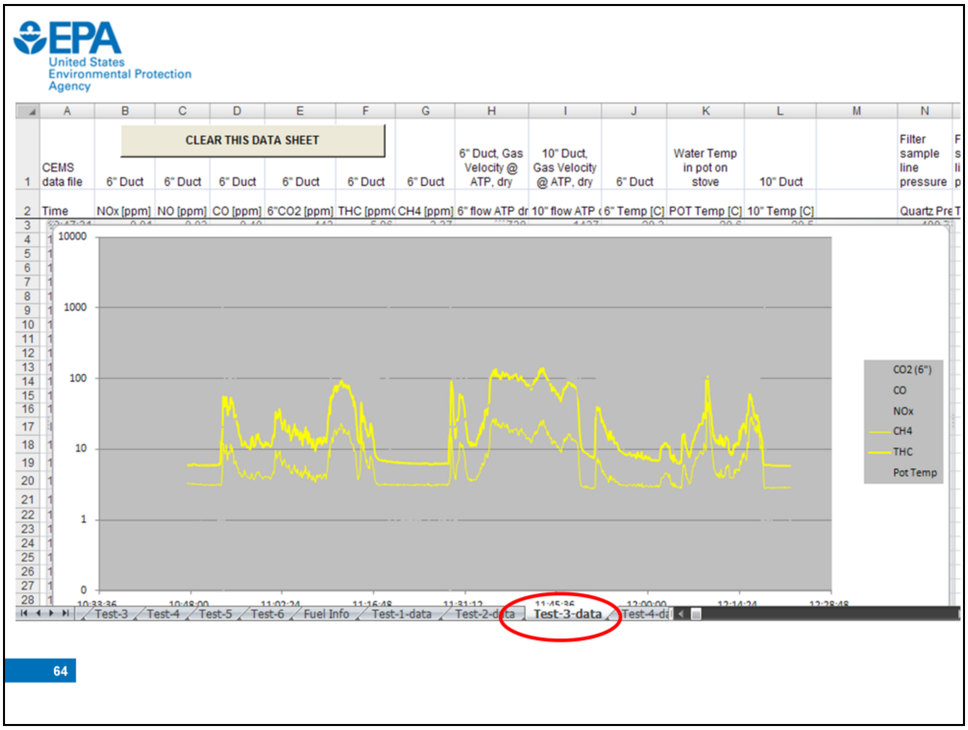
-Blue line is temperature of water in pot – indicates test phase



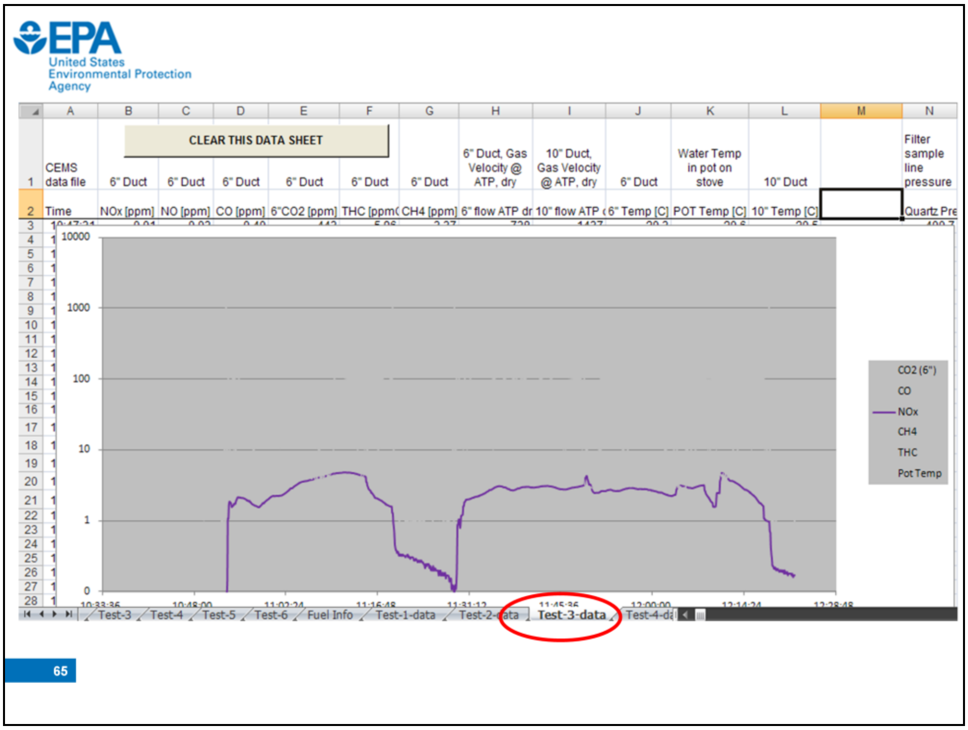
-Green line is (carbon dioxide) concentration – indicates fuel burning-rate



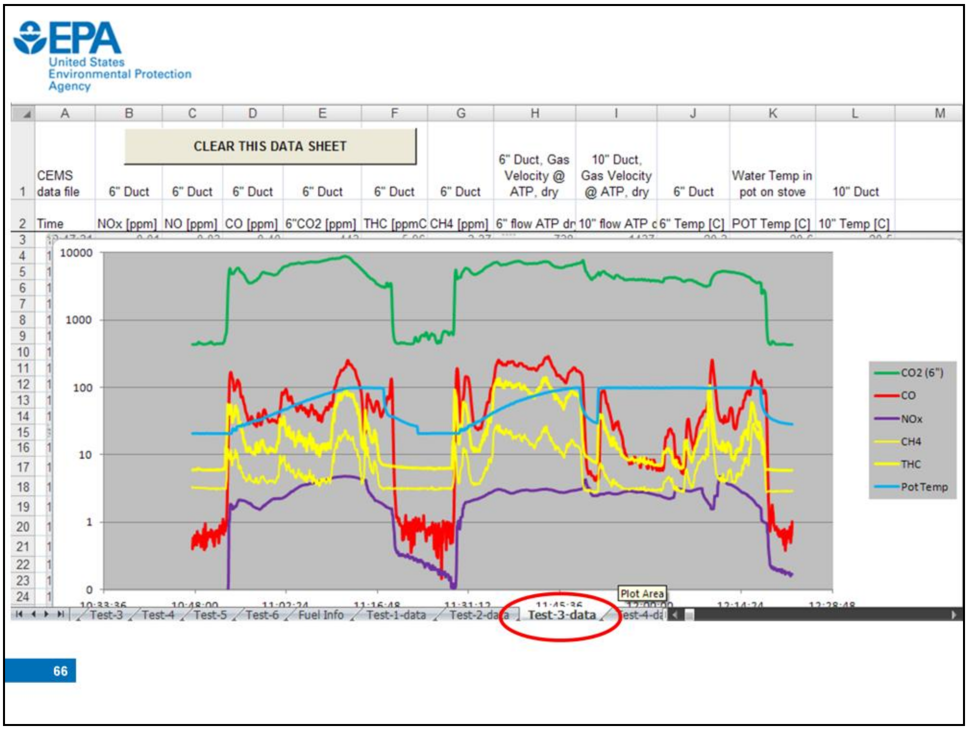
-Red line is CO (carbon monoxide) concentration



-Yellow lines are THC (total hydrocarbon) and CH4 (methane) concentrations



-Purple line is NOX (nitrogen oxides) concentration



- Looking at raw data like this helps us see how measurements fit together, and spot issues

CLEAR THIS DATA SHEET

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	CEMS data file	6" Duct	6" Duct	6" Duct	6" Duct	6" Duct	6" Duct	6" Duct, Gas Velocity @ ATP, dry	10" Duct, Gas Velocity @ ATP, dry	6" Duct	Water Temp in pot on stove	10" Duct		Filter sample line pressure	Filter sample line pressure
2	Time	NOx [ppm]	NO [ppm]	CO [ppm]	6"CO2 [ppm]	THC [ppmC	CH4 [ppm]	6" flow ATP dr	10" flow ATP c	6" Temp [C]	POT Temp [C]	10" Temp [C]		Quartz Pre	Teflon Pressure
50	10:51:26	0.03	-0.03	0.61	456	5.90	3.08	735	1433	20.3	20.5	20.3		243.9	230.3
51	10:51:31	0.02	-0.02	0.76	455	5.91	3.19	732	1441	20.2	20.6	20.4		244.0	230.8
52	10:51:36	0.02	-0.02	0.60	453	6.01	3.17	735	1433	20.2	20.5	20.4		244.2	231.3
53	10:51:41	0.02	-0.02	0.49	451	5.92	3.20	735	1433	20.3	20.6	20.4		244.3	231.7
54	10:51:46	0.03	-0.02	0.64	450	6.03	3.21	738	1433	20.3	20.6	20.5		244.4	232.2
55	10:51:51	0.00	-0.01	0.89	454	5.89	3.12	735	1429	20.3	20.5	20.5		246.1	232.7
56	10:51:56	0.01	-0.02	0.67	459	6.01	3.13	735	1433	20.3	20.5	20.5		399.2	345.6
57	10:52:01	0.01	-0.01	0.76	461	5.95	3.17	735	1429	20.4	20.5	20.5		401.1	398.6
58	10:52:06	0.02	-0.02	0.69	458	5.99	3.18	735	1433	20.3	20.5	20.4		401.1	398.6
59	10:52:11	0.00	-0.01	0.69	455	6.05	3.19	735	1437	20.3	20.5	20.6		401.1	398.6
60	10:52:16	0.01	-0.01	0.88	454	5.94	3.26	735	1433	20.4	20.5	20.5		401.1	398.6
61	10:52:21	0.02	-0.02	1.10	457	6.04	3.23	735	1433	20.3	20.6	20.6		401.1	398.6
62	10:52:26	-0.03	-0.02	0.65	478	6.30	3.30	735	1433	20.3	20.5	20.5		401.1	398.6
63	10:52:31	0.03	-0.03	0.99	488	6.21	3.12	732	1433	20.5	20.6	20.5		401.1	398.6
64	10:52:36	0.03	-0.01	0.77	524	6.07	3.15	735	1437	20.3	20.6	20.4		394.0	389.3
65	10:52:41	0.03	0.00	0.74	574	6.74	3.18	735	1433	20.4	20.6	20.4		389.8	383.0
66	10:52:46	0.03	-0.01	0.84	610	12.97	3.15	737	1437	20.6	20.5	20.4		389.4	382.6
67	10:52:51	0.03	-0.01	0.87	645	11.77	3.13	740	1437	21.4	20.5	20.7		389.3	382.5
68	10:52:56	0.03	-0.01	1.16	778	15.06	3.92	739	1437	22.6	20.5	20.8		389.3	382.5
69	10:53:01	0.05	-0.01	2.34	1290	24.95	4.75	741	1444	23.9	20.5	21.0		389.3	382.4
70	10:53:06	0.06	0.02	8.07	2416	55.62	9.63	739	1440	25.6	20.5	21.2		389.3	382.4
71	10:53:11	0.09	0.05	23.18	3739	39.68	12.21	734	1439	27.1	20.6	21.5		389.3	382.4
72	10:53:16	0.14	0.11	53.54	4890	54.54	9.60	733	1435	28.3	20.5	21.7		389.3	382.3
73	10:53:21	1.08	0.65	106.61	5759	47.07	9.66	732	1442	29.2	20.5	21.6		389.3	382.3
74	10:53:26	1.06	0.67	151.98	6014	40.16	8.59	731	1438	29.8	20.6	21.8		389.3	382.3
75	10:53:31	1.71	0.62	165.02	5683	51.28	9.60	731	1430	30.4	20.5	21.9		389.3	382.3
76	10:53:36	1.87	0.61	166.05	5150	55.16	11.72	728	1434	31.2	20.5	22.0		389.3	382.3
77	10:53:41	1.84	0.50	151.42	4977	44.06	11.32	728	1430	31.7	20.6	22.0		389.3	382.3
78	10:53:46	1.80	0.44	138.48	5095	31.03	7.65	728	1434	31.7	21.6	21.9		389.2	382.2
79	10:53:51	1.74	0.44	133.96	5106	30.27	6.95	732	1434	31.7	23.9	21.8		389.2	382.2
80	10:53:56	1.56	0.49	123.93	4976	40.06	9.01	730	1435	31.7	24.3	21.9		389.2	382.2
81	10:54:01	1.58	0.49	103.60	5012	37.44	8.56	730	1431	31.8	23.0	21.9		389.2	382.2
82	10:54:06	1.62	0.68	89.22	5238	36.32	9.07	730	1431	32.1	23.0	22.0		389.2	382.2
83	10:54:11	1.62	0.68	90.90	5419	40.35	8.77	733	1435	32.2	23.7	21.9		389.2	382.1
84	10:54:16	1.71	0.74	98.08	5521	52.39	10.30	736	1439	32.5	23.7	22.1		389.2	382.1
85	10:54:21	1.74	0.76	100.61	5653	53.66	11.95	736	1431	32.8	22.8	22.0		389.2	382.1
86	10:54:26	1.71	0.77	103.60	5838	45.53	11.01	736	1435	33.2	23.0	22.0		389.2	382.0
87	10:54:31	1.73	0.76	114.28	5982	43.92	9.09	736	1439	33.6	25.9	22.1		389.2	382.0
88	10:54:36	1.85	0.86	126.69	6057	46.33	10.63	733	1431	33.9	26.2	22.3		389.2	381.9
89	10:54:41	1.96	0.91	128.11	6090	40.27	9.51	730	1431	34.2	26.0	22.2		389.2	381.9

Test-1 Test-2 Test-3 Test-4 Test-5 Test-6 Fuel Info Test-1-data Test-2-data **Test-3-data** Test-4-data Test-

67

Same sheet (tab circled)

– scrolled down

– shows columns of raw (unmodified) data

– keeps record of raw data in the same workbook as analysis, facilitates manual calculations (quality checks)

	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG
1	SMPS													
2														
19														
20	Date	Start Time		14.6	15.1	15.7	16.3	16.8	17.5	18.1	18.8	19.5	20.2	20.
21	2/12/2013	10:32:07		0	0	0	0	0	0	0	0	0	0	
22	2/12/2013	10:34:37		0	0	0	0	2	0	0	0	1	0	
23	2/12/2013	10:37:07		0	0	0	0	2	0	0	0	0	0	
24	2/12/2013	10:39:37		0	0	0	0	0	0	0	0	3	0	
25	2/12/2013	10:42:07		0	0	0	0	0	0	0	0	0	0	
26	2/12/2013	10:44:37		0	0	0	0	0	0	0	0	0	0	
27	2/12/2013	10:47:08		0	0	0	0	0	0	0	0	0	0	
28	2/12/2013	10:49:38		0	0	0	2	0	0	0	0	1	2	
29	2/12/2013	10:52:08		0	0	0	0	0	0	0	0	1	0	
30	2/12/2013	10:54:38		593	638	653	667	697	717	800	773	807	829	85
31	2/12/2013	10:57:08		2072	2324	2292	2517	2603	2674	2567	2588	2635	2477	255
32	2/12/2013	10:59:38		1098	1049	1033	1090	1096	1036	1084	1058	1085	1046	101
33	2/12/2013	11:02:08		3213	3551	3529	3760	3894	4186	4331	4658	5115	5244	540
34	2/12/2013	11:04:38		5385	5590	6076	6259	6864	7072	7243	7373	7438	7335	719
35	2/12/2013	11:07:08		5207	5182	5298	5452	5158	4985	4790	4275	4077	3791	346
36	2/12/2013	11:09:38		1363	1424	1349	1382	1337	1337	1206	1179	1185	1062	98
37	2/12/2013	11:12:08		876	1011	1046	1241	1385	1576	1872	2046	2273	2513	270
38	2/12/2013	11:14:38		6833	7156	7884	8339	8765	9187	9492	9502	9548	9710	930
39	2/12/2013	11:17:08		2353	2594	2580	2967	3211	3573	3759	3738	3787	3969	399
40	2/12/2013	11:19:38		142	133	127	160	161	98	128	175	126	114	13
41	2/12/2013	11:22:08		36	56	39	38	60	50	37	40	52	60	4
42	2/12/2013	11:24:38		4	8	14	17	7	12	10	20	15	11	2
43	2/12/2013	11:27:08		9	4	3	10	2	10	10	10	8	3	
44	2/12/2013	11:29:38		396	466	590	729	1000	1327	1705	2170	2697	3010	342
45	2/12/2013	11:32:08		1222	1295	1435	1378	1412	1373	1379	1334	1301	1246	118
46	2/12/2013	11:34:38		3189	3392	3199	3321	3607	3584	3686	3776	3988	4130	417
47	2/12/2013	11:37:08		1611	1818	2000	1956	2109	2181	2246	2567	2540	2805	295
48	2/12/2013	11:39:38		1208	1424	1561	1800	1948	2190	2442	2655	2997	3398	346
49	2/12/2013	11:42:08		2117	2202	2593	2640	3156	3072	3631	3745	4130	4380	469
50	2/12/2013	11:44:38		1732	2136	2261	2461	2778	2991	3424	3816	4110	4609	484
51	2/12/2013	11:47:09		2538	2874	3053	3328	3597	4068	4258	4487	4753	5127	536
52	2/12/2013	11:49:39		9306	9494	9623	9322	8811	8551	7851	7412	6661	6144	516
53	2/12/2013	11:52:09		2646	2580	2537	2403	2370	2315	2147	2320	2298	2295	235
54	2/12/2013	11:54:39		3111	2981	2965	2987	2967	2795	2747	2631	2541	2471	216
55	2/12/2013	11:57:09		4080	4233	4046	3963	3706	3462	3325	3029	2839	2583	233
56	2/12/2013	11:59:39		5520	5200	4953	4540	4360	3906	3597	3230	2773	2506	212
57	2/12/2013	12:02:09		5628	5512	5427	[illegible]	5360	5089	4884	4930	4761	4756	435

Test-1 Test-2 Test-3 Test-4 Test-5 Test-6 Fuel Info Test-1-data Test-2-data Test-3-data Test-4-data Test-

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- Still raw data sheet for Test 3 (tab circled; sheet scrolled to the right)

- Shown is raw data for the online PM sizing instrument (SMPS) that was included in graph shown on earlier slide

- Also raw data for:

    -aethalometer, black carbon emissions (real-time, 1 s resolution)

    - nephelometer, particle light scattering (real-time, 1 s resolution)

    - PASS-3 (photo-acoustic soot spectrometer, 3-wavelength), particle light absorption (real-time, 1 s resolution)

    - PM2.5 and EC/OC (elemental carbon/organic carbon) filters (integrated samples, whole test phase)

    - SMPS (scanning mobility particle sizer), fine particle size distribution (semi-real-time, 2-2.5 min resolution)

    - APS (aerodynamic particle sizer), course particle size distribution (semi-real-time, 20 s resolution)

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Summary

- Discussed test methods
- Suggested procedure for testing batch-fueled stoves
- Presented a spreadsheet for sharing data
- Reminder: Spreadsheet is **NOT** intended for use by other labs
- Interested in your further comments on methods, spreadsheet, and data sharing

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In summary, we discussed test methods and suggested a procedure for testing batch-fueled stoves. We presented a spreadsheet for sharing data, and one reminder (again) is that the spreadsheet is not intended for use by other testing labs. We are very interested in your further comments on the methods, spreadsheet, and data sharing. At EPA, we have learned so much about stoves and stove testing from many of you – we thank you for sharing your information, knowledge, and ideas.

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Next Steps

- EPA spreadsheet will be posted for review: http://community.cleancookstoves.org/communities/home/22
- Collect comments for 3 weeks: jetter.jim@epa.gov
- Post responses to comments
- Complete current round of stove testing
- Complete EPA quality assurance and administrative reviews
- Post results and data for all stoves and solar cookers
- Publish results and analyses in peer-reviewed literature

United States Environmental Protection Agency

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Next: Questions…

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Questions

- A major advantage to char-making stoves is requiring much less time for fire-tending. Present testing allows continuous second-by-second adjustment of fuels, which does not simulate the real world. What are plans to add test results (such as percent time away from the stove) that address this issue?

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Questions

- Some stoves might be either too small or too large to perform well with the standard (possibly 5 kg water) test requirement - but might do exceedingly well with some other non-standard task. Will future protocols allow a manufacturer's recommended non-standard test?

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Comment & Question

- It would help everyone if Jim Jetter and similar expert testers could make very general observations to stove builders on how to get better stoves and stove test results.
- How can the testing results give suggestion to the stove designer?

Questions

- Plans to standardize fuel for testing + associated question re: how useful/practical that is.
- How best can a stove tester perfect on their work?
- How to deal with the limitation that a stove might not have enough batch size in one filling to complete boiling plus 45 min simmer, if the stove is designed to have a spare fuel container to continue cooking?

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Questions

- Char-using stoves generally use char made badly if not illegally. What are GACC plans for showing data for both the best and worst use of different biomass feedstocks in the production of char and how that should influence stated efficiencies of char-using stoves?

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Questions

- There are countries giving zero credit for char production in their present national stove testing protocols (viewing char as a problem not a benefit) Will this continue or be changed in those countries receiving GACC funding?