United States Environmental Protection Agency

Process for Developing Improved Cordwood Test Methods for Wood Heaters

Discussion Paper

March 2016

Prepared by
U.S. EPA Office of Air Quality Planning and Standards (OAQPS)

Notice

The EPA promulgated the "Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces" on February 3, 2015. The final rule was published on March 16, 2015 in **80 FR 13702** for subpart AAA – Standards of Performance for New Residential Wood Heaters and in **80 FR 13715** for subpart QQQQ – Standards of Performance for New Residential Hydronic Heaters and Forced-Air Furnaces. A complete copy of the final rule, including Preamble, can be found in the *Federal Register* (Volume 80, Number 50) at **https://federalregister.gov/a/2015-03733**.

This Discussion Paper puts forth the history and current state-of-the-science regarding cordwood test methods relevant to the wood heaters regulated under the Standards of Performance cited above. The paper also suggests a process for transitioning to test methods that are more representative of how cordwood fueled heaters are used in people's homes.

Most importantly, this Discussion Paper seeks input from any interested party – from regulators, manufacturers, laboratories, third-party certifiers, academia, environmental and health organizations and the general public. The Agency seeks a wide range of participation in order to further the science. Input on how to improve current cordwood test methods and balance representation of in-home use with precision and variability concerns will be useful to EPA as the Agency considers the development of a reference method.

The EPA has established a non-rulemaking docket for any input, questions or suggestions relevant to this Discussion Paper under Docket ID No. EPA-HQ-OAR-2016-0130. All documents in the docket are listed in the www.regulations.gov index. If you want your input to be considered in the process, please send by June 30, 2016 to Docket ID No. EPA-HQ-OAR-2016-0130, by one of the following methods:

- www.regulations.gov: Follow the on-line instructions for submitting comments.
- Email: a-and-r-docket@epa.gov, Attention Docket ID No. EPA-HQ-OAR-2016-0130.
- Mail: U.S. Postal Service to EPA Docket Center, EPA West (Air Docket), Attention Docket ID Number EPA-HQ-OAR-2016-0130, U.S. Environmental Protection Agency, Mailcode: 28221T, 1200 Pennsylvania Ave., NW, Washington, DC 20004.

The EPA will post all submitted non-CBI information to this publicly available website. If you need to submit CBI material, please contact Amanda Aldridge, EPA, Office of Air Quality Planning and Standards (OAQPS) for instructions at telephone number (919) 541-5268, or aldridge.amanda@epa.gov.

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1.0 Introduction

In August 2014, the Hearth Patio and Barbecue Association (HPBA), the Northeast States for Coordinated Air Use Management (NESCAUM) and the Western States Air Resources Council (WESTAR) presented consensus recommendations to EPA on the subject of test methods for wood-burning residential heaters. One such recommendation was: "Wood heater emission limits should be based on tests that correlate better with actual in-use emissions than the current test. There is a common interest among the parties to transition from the current crib-based wood heater certification test to a cordwood-based certification test by first establishing appropriate and efficient test methods, then using those methods to build a robust database to inform EPA's determination of BSER for wood heaters based on cordwood testing." They also agreed on the following approach for developing this test method: "A workgroup comprised of experts from industry, state/local air quality agencies, and EPA will develop protocols for cordwood testing that are sufficiently accurate and reproducible to reliably predict emissions from wood heaters throughout the device's burning cycle."[1]

This document discusses a process to achieve this joint stakeholder recommendation. It brings experts together to advance the current science of wood heater testing to better reflect in-home use. The dissemination of this Discussion Paper serves as an open invitation to a broad range of stakeholders to contribute their expertise and perspective to this endeavor – including regulators, manufacturers, laboratories, third-party certifiers, academia, environmental and health organizations, and the general public.

Section 2 highlights the importance of advancing the science of cordwood testing by briefly reviewing the health and environmental impacts of wood smoke. Section 3 discusses the history, current status and direction of wood heater appliance testing. Included in Section 3 is an overview of the regulating and certifying of wood heaters; the test methods currently prescribed in the 2015 NSPS; the transition from crib wood to cordwood testing; what we know about in-home device use; and how to capture some of the most important aspects of in-home wood heater operation in improved test methods based on cordwood. Section 4 describes the EPA process for approving alternative test methods under the current NSPS. Section 5 is a brief summary of the process for adopting a new EPA reference test method.

Section 6 outlines a suggested process for improving cordwood test methods and how EPA will continue to approve alternative test methods during this process, including methods based on cordwood. This section discusses the process as overseen by a Steering Committee and led by state multi-jurisdiction organizations (MJOs). It will include expert participation from a wide range of stakeholders in two technical workgroups. One technical workgroup will focus on improvements to the particulate matter (PM) measurement method and the other technical workgroup will focus on improvements to the fueling and operational protocol of the cordwood based method. The input from these two expert workgroups will inform improvements in cordwood test methods for wood heaters and the possible development of an EPA reference test method based on cordwood. The goal of cordwood methods is to reflect in-home use, improve the precision of wood heater testing, and be protective of human health and the environment as the cornerstone of the NSPS certification program.

Section 7 includes suggested topics for further consideration. Endnotes for all sections are listed in Section 8. Finally, Section 9 is an Appendix that includes tables describing the parameters of current cordwood based test methods used in the U.S. and in other countries.

Table 1. Explanation of Acronyms and Abbreviations

Acronym	Explanation
1988 NSPS	The New Source Performance Standards (rule) promulgated in 1988 regulating residential wood stoves
2015 NSPS	The New Source Performance Standards (rule) promulgated in 2015 regulating residential wood heaters that supersedes the 1988 NSPS
AP-42	Air pollution emission factors compilation, published by EPA since 1972
ASTM	American Society for Testing and Materials (now ASTM International)
Btu	British Thermal Unit
CFR	Code of Federal Regulations
CO	Carbon Monoxide
cordwood	Split logs resembling what a typical homeowner would use for wood fuel
crib wood	Douglas Fir dimensional lumber used in many current certification methods
CSA	Canadian Standards Association
EN	European Standard
EPA	U.S. Environmental Protection Agency
FR	Federal Register
g/hr	Grams per hour
HAP	Hazardous Air Pollutants
IBR	Incorporated by reference
lb/MMBtu	Pounds per million British thermal unit
MJOs	Multi-Jurisdiction Organizations
MTG	Measurement Technology Group (USEPA)
NAAQS	National Ambient Air Quality Standards
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOx	Nitrogen Oxides
NSPS	New Source Performance Standards
NYSERDA	New York State Energy and Research Development Authority
OAQPS	Office of Air Quality Planning & Standards (USEPA)
OAR	Office of Air and Radiation (USEPA)
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter with diameter $\leq$ 2.5 micrometers ("fine particles")
POM	Polycyclic Organic Matter
Subpart AAA	The subpart of this rule that regulates new wood stoves (including adjustable burn rate stoves, single burn rate stoves and pellet stoves)
Subpart QQQQ	The subpart of this rule that regulates new hydronic heaters and new forced-air furnaces
VOC	Volatile Organic Compounds
WESTAR	Western States Air Resources Council

2.0 Why is Wood Smoke Important?

This section discusses the importance of regulating wood smoke – including wood smoke's significant contribution to particulate matter (PM) pollution, wood smoke's presence within many neighborhoods and homes, and wood smoke's considerable health impacts.

2.1 Contribution to PM

Particulate pollution from wood heaters is a significant national air pollution problem and human health issue. For almost all of the residential wood heaters currently on the market, there are substantial particulate emissions which are composed largely of unburnt carbon and organic compounds. Even when the heaters are operated ideally, a fraction of the wood fuel is volatilized but is not completely combusted and so condenses to form PM, along with carbon monoxide (CO) and some air toxics.[2] Also, many users restrict the air flow in order to achieve a longer burn which further increases emissions. Under these operating conditions, the combustion quality is reduced even further and emissions can be 10 or 20 fold greater per unit of fuel compared to adequate air flow conditions.[3]

Residential wood smoke contains fine particles (primarily with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$)), CO, toxic air pollutants (*e.g.*, benzene and formaldehyde), and climate-forcing emissions (*e.g.*, methane and black carbon). Each year, smoke from wood stoves and fireplaces contributes over 382,000 tons of fine particles throughout the country – mostly during the winter months.[4] Nationally, residential wood combustion also accounts for 20 percent of total stationary and mobile polycyclic organic matter (POM) emissions.[5]

In addition, residential wood smoke causes many counties in the U.S. to either exceed or almost exceed the EPA's health-based national ambient air quality standards (NAAQS) for $PM_{2.5}$.[6] In places such as Keene, New Hampshire; Sacramento, California; Tacoma, Washington; and Fairbanks, Alaska; residential wood combustion can contribute over 50 percent of daily wintertime $PM_{2.5}$ emissions.[7] It may be difficult for these and other areas to meet or continue to meet the $PM_{2.5}$ standards without taking steps to significantly reduce residential wood smoke. Furthermore, studies have shown that $PM_{2.5}$ concentrations in proximity to a typical outdoor hydronic heater (a.k.a. outdoor wood boiler) can exceed the 24-hour $PM_{2.5}$ NAAQS.[8]

The National Association of Clean Air Agencies (NACAA), the Environmental Council of States (ECOS), NESCAUM, WESTAR, and the Lake Michigan Air Directors Consortium (LADCO) have advocated that more stringent standards for new wood heating devices would provide a much needed tool for states and local communities to use in addressing the growth of pollution from these sources.[9] In advance of the wood heater 2014 NSPS proposal and 2015 NSPS final rule, EPA received many letters, including from NESCAUM, WESTAR, other MJOs, health and environmental organizations, concerned citizens, and the HPBA urging the Agency to update and develop regulations for wood heating devices.[10] A joint letter from NESCAUM and WESTAR cited concerns that many communities are measuring ambient conditions above or very close to the $PM_{2.5}$ NAAQS and that, in many instances, emissions from wood smoke are a large contributor to those high $PM_{2.5}$ levels.[11] WESTAR, for example, asserted "Residential wood combustion is a leading cause of unhealthy levels of fine particulate and air toxics and the primary source of non-attainment with the 24 hour $PM_{2.5}$ NAAQS in airsheds throughout the West."[12]

In addition, areas currently attaining the $PM_{2.5}$ NAAQS will experience health benefits from reduced residential wood smoke emissions. This is because there is no known threshold below which $PM_{2.5}$ does not cause adverse health effects. Even though the health-based standards are set to provide an adequate margin of safety, the standards are not set at a level of zero risk. Thus, the EPA recognizes that reducing the emissions level in those areas will have health benefits.

2.2 Local Source of Pollution

Wood heaters create significant air quality problems in localities where they are used in large numbers. Residential wood smoke can contribute to unhealthy levels of $PM_{2.5}$ in many neighborhoods nationwide, including in minority and low-income neighborhoods, and impact people in their homes. The concerns are heightened because wood stoves, hydronic heaters, and other wood heaters are often used around the clock in many residential areas. As summarized in EPA's 1987 listing of residential wood heaters for development of the New Source Performance Standards: residential wood combustion PM emissions are increasing; they include compounds which are carcinogens; and they are released at low heights in residential areas, resulting in relatively high levels of exposure to human populations. Emissions from residential wood heating devices occur near ground level in residential communities across the country.

The PM from wood heaters is primarily condensed organic materials as opposed to fly ash. (Fly ash is one of the residues of coal combustion.) Unlike large industrial point sources, with sophisticated controls such as electrostatic precipitators and with more elevated emission release heights, there are millions of residential chimneys emitting wood smoke immediately into their surroundings and ultimately into neighbors' homes. In winter, air pollution is trapped close to the ground – in breathing space – because of stagnant air and temperature inversions which limit air movement.[13]

Furthermore, wood smoke fine particles not only remain in the breathing space air for long periods of time, but also readily enter homes and pollute indoor as well as outdoor air. The median amount of outdoor fine particle pollution that penetrated indoors was estimated to be 64 percent in one study.[14] Consequently, even homes that do not burn wood have higher indoor wood smoke levels if their neighbors burn wood.[15] For example, significant indoor $PM_{2.5}$ concentrations and resulting health impacts were found in a study conducted by Environment and Human Health, regarding the indoor air in homes located in the vicinity of outdoor wood heaters (*e.g.*, hydronic heaters).[16] In response to the 2014 NSPS proposal, the Agency received numerous comments describing the impact of fine PM and other wood smoke constituents resulting from wood smoke emissions, including many personal stories of specific harm to health from their own or a neighbor's wood smoke emissions.

2.3 Health Impacts

There is overwhelming recognition of the health impacts of particle pollution, to which wood smoke is a contributing factor in many areas. Residential wood combustion in the U.S. accounts for nearly 50 percent of all area source air toxics cancer risks and 8 percent of noncancer respiratory effects.[17] Wood smoke contains a mixture of gases and fine particles that can cause immediate health effects, including burning eyes, runny nose and bronchitis. Exposure to fine particles has been associated with a range of more serious health effects, including aggravation of heart or respiratory problems (as indicated by increased hospital admissions and emergency department visits), changes in lung function and increased respiratory symptoms, as well as premature death. Populations that are at greater risk for experiencing health effects related to fine particle exposures include older adults, children and individuals with pre-existing heart or lung disease.

Residential wood smoke can increase $PM_{2.5}$ to levels that cause significant health concerns.[18] More than 80 percent of the PM emissions from wood heaters are smaller than 2.5 micrometers and almost all particles are less than 10 micrometers. PM of this size can penetrate to the tracheo-bronchial and alveolar regions of the lung. Multiple studies have shown clear associations between $PM_{2.5}$ exposure and increased mortality. There is also growing evidence for the biological mechanisms, which include increased risk of ventricular arrhythmia and thrombotic processes, increased system inflammation and oxidative stress, increased blood pressure, decreased plaque stability, and lower lung function. Recent studies have suggested that risks from PM exposure may extend below the current NAAQS and may not have a threshold.[19] Furthermore, numerous recent health studies considered in the review of the PM NAAQS confirm the impacts on public health. The latest information on the PM NAAQS reviews is at **http://www.epa.gov/pm/actions.html**.

There is also concern about the health effects of other pollutants found in wood smoke. Wood heaters contribute significantly to PM pollution and these appliances also emit CO, volatile organic compounds (VOC), nitrogen oxides (NOx) and hazardous air pollutants (HAP). Health effects from CO include:

- Interference with the blood's ability to carry oxygen to the brain, which impairs thinking and reflexes;
- Heart pain;
- Lower birth weights and increased deaths in newborns; and
- Death.

Nitrogen oxides can irritate the eyes and respiratory system, may damage the immune system by impairing the body's ability to fight respiratory infection and can affect lung function.[20]

Residential wood combustion emissions contain potentially carcinogenic (cancer-causing) HAP including formaldehyde, polycyclic aromatic hydrocarbons (PAHs), benzene and dioxin.[21] Health effects from formaldehyde and other organic gases include:

- Irritation of eyes, nose, and throat;
- Inflammation of mucous membranes, irritation of the throat and sinuses;
- Interference with lung function;
- Allergic reactions;
- Nose and throat cancer in animals; and
- Cancer in humans.

As discussed in the preambles for the 2014 NSPS proposal and the 2015 NSPS final rule, emission reductions associated with the requirements of this rule will generate substantial health benefits by reducing emissions of $PM_{2.5}$ and HAP, as well as criteria pollutants and their precursors, including CO and VOC. (VOCs are precursors of $PM_{2.5}$ and ozone.) The quantified health benefits of the reduction in directly emitted $PM_{2.5}$ alone is substantial – over 100 times the estimated cost to manufacturers to design cleaner devices.

3.0 The History and Direction of Wood Heater Appliance Testing

This section discusses the history of wood heater appliance testing, including the types of wood heaters that are required to undergo certification testing, the test methods used for certification testing, and the reason that crib wood has been the basis to-date for certification testing. This section also provides an overview of what we know about in-home device use and discusses several important aspects of in-home heater use including: fuel species and moisture content variability, low and high burn rates, firebox load, and start-up and refueling emissions.

3.1 Regulating and Certifying Heating Devices

Regulated appliances. The development of the residential wood heater regulations began in the mid-1980s in response to the growing recognition that wood smoke contributes to ambient air quality-related health problems. The 1988 NSPS regulated catalytic and non-catalytic wood stoves. The 2015 NSPS updated the emission standards for catalytic and non-catalytic wood stoves and also applied emission standards to pellet stoves and single burn rate stoves, as well as to wood-fired residential central heaters including hydronic heaters (a.k.a. outdoor wood boilers) and forced-air furnaces (a.k.a. warm-air furnaces). Generally speaking, the 2015 NSPS regulates all wood-fired residential heaters, including cordwood, wood pellet and wood chip fueled devices. Subpart AAA of the 2015 NSPS regulates "room heaters" that warm the space surrounding the heater. Subpart QQQQ regulates "central heaters" that warm spaces other than the space where the heater is located, by the distribution of heated air through ducts or heated liquid through pipes.

Residential Wood Heater Certification program. Because these regulations apply to mass-produced residential consumer items, the residential wood heater NSPS allows compliance for model lines to be certified "pre-sale" by the manufacturers. To avoid unreasonable cost impacts, both the 1988 and 2015 NSPS were designed to allow manufacturers of wood heaters to use a certification program to test representative wood heaters on a model line basis. Once a model line is certified, all of the individual units within the model line are subject to labeling, operational and other requirements. Manufacturers are then required to conduct a quality assurance program, which is overseen and verified by a third-party certifier, to ensure that appliances produced within a model line conform to the certified design and meet the applicable emission limits. There are also provisions in the 2015 NSPS for the third-party certifier and for the EPA to conduct unannounced audits to ensure compliance under the certification program. At the heart of the current certification program are the test methods prescribed in the 2015 NSPS. These test methods are discussed in the next subsection.

3.2 Test Methods Prescribed in Current NSPS

The 1988 NSPS regulated PM emissions from wood stoves and expressed the emission limit in grams per hour (g/hr). The test methods used to establish the PM emission value of the wood heaters undergoing certification testing include both fueling and operating protocols and sampling and analytical PM measurement methods.

Fueling and operating protocol. The EPA developed the wood heater fueling and operating protocol in Method 28 as part of the efforts on the 1988 NSPS. In 1987, manufacturers, laboratories, and some states provided input to the Agency on the protocol under development. Oregon Method 7 was the starting point for Method 28; thus, Method 28 has many aspects similar to Oregon Method 7. The details on the history and development of Method 28 are contained in the February 18, 1987 proposal in the *Federal Register* (52 FR 5003) and the February 26, 1988 final rule in the *Federal Register* (53 FR 5866).

The standardized fueling protocol specified fuel species (Douglas Fir dimensional "crib" lumber), and the allowable moisture content range prescribed in Method 28 serve the purpose of providing a common basis for comparing emission performance among wood heaters for certification testing purposes. As explained in the 1988 NSPS, standardized test methods are necessary to achieve objective comparison among heaters and comparison of emission performance of individual heaters to a specified regulatory limit. There are multiple parameters, some of which are routinely varied by the operator, that affect the burn rate and combustion quality of natural draft wood heaters. Ideally, a standardized test method creates reproducible test conditions that are necessary for comparing performance of one heater to another. Furthermore, manufacturers, laboratories, states and the EPA have more than 25 years of experience with Method 28, and it has been very useful for certifying hundreds of model lines of wood heaters/stoves. In addition, EPA Method 28 WHH (for wood-fired hydronic heaters) is based on Method 28 and has been used for qualification testing of hydronic heaters in the EPA voluntary partnership program and numerous state regulations.

Nonetheless, the EPA and stakeholders widely agree that improved test methods for residential wood heaters are needed in order to better reflect wood heater operation in homes across the country. Prior to the 2014 NSPS proposal, the EPA asked the manufacturers, EPA-accredited laboratories and states for their insights on Method 28. Many stakeholders agreed that changes needed to be made to improve the reproducibility and repeatability of the test procedures and to address concerns about how to best ensure protection across the entire U.S. when various operating scenarios are used and various wood species and densities are used. The test methods prescribed by the Agency in the 2015 NSPS – including a revised Method 28 and several other fueling and operating protocols depending on the type of wood heater to be certified – include some of these improvements. However, the fueling and operating test methods prescribed by the 2015 NSPS (listed in Table 2) represent a step in the process toward better test methods, rather than the end goal. There is still room for improvement, as discussed in this document.

<u>Sampling and analytical PM measurement</u>. Procedures for measuring particulate emissions from wood heaters involve measurement of exhaust gas flow rate and emission concentration. These measurements can be made either in the wood heater stack or in a dilution tunnel. A dilution tunnel is a device which captures wood heater stack emissions and introduces outside air for the purpose of maintaining constant measurable gas velocities for sampling. The 1988 NSPS required either Method 5G (using a dilution tunnel sampling location) or Method 5H (using a stack sampling location) to measure PM, with a conversion factor to better equate 5H and 5G PM results in order to establish a device's emissions while undergoing certification testing. The adjustment between Methods 5G and 5H has resulted in as high as a 30 percent difference in certification values. Furthermore, Houck *et.al*. note that "[i]t is generally agreed that a dilution tunnel approach collects particles in a more realistic fashion and more closely simulates the formation of particles once emissions from chimneys mix and cool in the ambient air than a method such as Method 5H based on the old industrial stack sampling Method 5."[22] This is because a dilution tunnel allows the flue gas to cool and the PM to condense. By the time the gas reaches the filter (at ≤ 90 degrees), PM has formed that much closer approximates actual residential near-flue conditions than sampling directly in the flue would via Method 5H. For these reasons, Method 5H is no longer allowed to be used for certification under the 2015 NSPS.

The Agency continues to recognize – as it did in the 1988 NSPS – that test methods are an integral part of any regulation and that the emission limit is related directly to the method. This is especially true for PM because PM is not an absolute quantity, but rather is defined by the measurement method (*i.e.*, it is an operationally defined quantity). Different methods produce different PM emission results because wood combustion particles (formed by condensed organic compounds) are trapped with different efficiencies depending on the PM sampling method used.[23] Application of more than one measurement test method could needlessly complicate enforcement and may even result in unequal enforcement of the standards. Because of these considerations, in the 2015 NSPS the Agency requires the use of one PM test method (ASTM E2515-11, a dilution tunnel method) for the measurement of PM across all devices, using the prescribed fueling and operating protocols with the exception of test method EN 303-5. While Method 5G is not prescribed in the 2015 NSPS, it is not prohibited from being used in an alternative test method if prior approval is received from the EPA. For example, the EPA would consider the existing Method 5G for use with the draft ASTM Cordwood method, if requested. However, in that instance, the EPA would likely include several caveats upon approval to align it with EPA's current approach to cordwood PM measurement from wood stoves (*i.e.*, ASTM 2515 with some modifications). Section 4 describes the EPA's process for approval of alternatives and modifications to test methods and testing procedures.

Efficiency and CO reporting. Stakeholders have pointed out the usefulness of reporting to consumers the efficiency of each wood heater on the market, based on a common metric, so that consumers have the information necessary to choose a heater needing less fuel. In addition, stakeholders and the EPA continue to recognize the importance of measuring and reporting CO emissions from all regulated wood heaters, due to the immediate health dangers to consumers and the negative environmental effects of emitted CO. The 2015 NSPS, therefore, prescribes a common test method (CSA B415.1-10) across all devices for measuring efficiency and CO emissions.

Test methods prescribed in the 2015 residential wood heater NSPS. Table 2 lists all the test methods prescribed in the 2015 NSPS – both fueling and operating protocols, as well as sampling and analytical measurement methods. The table includes a brief description of each method, the applicable residential wood heating device(s), and information regarding how each protocol or sampling method prescribed in the 2015 NSPS handles the following parameters:

- Fuel species and density;
- Moisture content;
- Fueling protocol;
- PM measurement;
- Efficiency measurement; and
- CO measurement.

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Fueling & Operating Test Methods for Adjustable & Single Burn Rate Stoves and Pellet Stoves under Subpart AAA				
EPA Method 28R for Certification and Auditing of Wood Heaters	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for measuring PM emissions from wood-fired room heaters and fireplace inserts. Four burn rate categories (kg/hr of wood fuel burned) are used to calculate the weighted average emission rate, based on a hot-to-hot (no cold start) test cycle. The method incorporates the provisions of ASTM E2780-10 except that the startup, burn rate categories, low burn rate requirement and weightings of Method 28 must be used. Knowledge of EPA Methods 1, 2, 3, 4, 5, 5G, 5H, 6, 6C and 16A is assumed. ASTM E871-82 may be used as an alternative to the moisture content determination procedures in Method 5H and Method 28 for particulate wood fuel.	Catalytic and non-catalytic adjustable burn rate stoves, using g/hr metric based on a weighted average. (References ASTM E2780-10 which contains an appendix for the fueling & operating protocol for single burn rate stoves.)	"Crib Wood" dimensional lumber, Douglas Fir, untreated, certified C grade or better, air-dried with a 16-20% wet basis (19-25% dry basis) moisture content	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. CSA B415.1-10 must be used to measure efficiency (stack loss method), CO and heat output.
ASTM E2779-10 Standard Test Method for Determining Particulate Matter Emissions from Pellet Heaters	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for determining PM emissions from pellet or other granular or particulate biomass burning room heaters and fireplace inserts. An integrated hot-to-hot (no cold start) test run is conducted including 3 burn rate segments ranging from low to maximum. A separate test run is required for each fuel type specified by the manufacturer. If more than one grade of pellets is listed for the heater, the lowest recommended grade is used as test fuel.	Incorporated by reference (IBR) in NSPS for pellet stoves, using a g/hr metric based on an average emission rate (total emissions divided by length of full test run)	Pellet fuel with the fuel type(s) specified by the manufacturer; Douglas Fir is allowed; NSPS requires pellets to be graded and licensed	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. CSA B415.1-10 must be used to measure efficiency (stack loss method), CO and heat output.

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Fueling & Operating Test Methods for Adjustable & Single Burn Rate Stoves and Pellet Stoves under Subpart AAA				
ASTM E871-82 (Reapproved 2013) Standard Test Method for Moisture Analysis of Particulate Wood Fuels	**Moisture Analysis Determination** – This method covers the determination of the total mass basis moisture in the analysis sample of particulate wood fuel. IBR in NSPS as an acceptable alternative to EPA Methods 5H and 28 for moisture analysis of particulate wood fuel. It is also used in ASTM E2779-10 for testing of pellet heaters.	Any heater regulated under Subpart AAA if using any of fuel types listed under "Allowable Fuel Species"	Sanderdust, sawdust, pellets, green tree chips, hogged fuel, or other particulate wood fuel with max particle volume of 1 in^3	This is a moisture analysis method based on total mass
ASTM E2780-10 Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for determining PM emissions from wood-burning room heaters and fireplace inserts. The fuel load specified is a lumber crib of uniform dimensions, identical to that specified in EPA Method 28 and each test run is a hot-to-hot (no cold start) cycle. NSPS stipulates that Method 28 burn rate categories must be used (instead of low, medium and maximum rates of method). This method also includes Annex A1 which provides a fueling procedure using cordwood.	Catalytic and non-catalytic adjustable burn rate stoves, using a g/hr metric based on a weighted average. IBR in Method 28R, although the startup, burn rate categories, low burn rate requirement and weightings in Method 28 must be used. Appendix in method also contains protocol for single burn rate stoves.	"Crib Wood" dimensional lumber (standard grade or better Douglas Fir); method allows 15-25% moisture content (wet basis); specifies an average density of 25-36 lb/ft^3. Method also includes Annex with cordwood protocol.	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. CSA B415.1-10 must be used to measure efficiency (stack loss method), CO and heat output.

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Fueling & Operating Test Methods for Hydronic Heaters under Subpart QQQQ				
EPA Method 28WHH for Measurement of Particulate Emissions & Heating Efficiency of Wood-Fired Hydronic Heating Appliances	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for measuring PM emissions at specified heat output rates (Btu/hr) based on the rated heating capacity. Procedures for determining burn rates, and particulate emissions rates and for reducing data are provided. Method 28, ASTM E2515-11 and CSA B415.1-10 are referenced. Heater is operated on a hot-to-hot (no cold start) test cycle and the four test categories / burn rates are as follows: Category I = heat output of ≤ 15% capacity; Category II = 16-24% capacity; Category III = 25-50% capacity; Category IV = heat output capacity	Indoor and outdoor hydronic heaters, both pressurized and non-pressurized, using an annual average lb/MMBtu output metric	"Crib Wood" dimensional lumber composed of red or white oak, with a 19-25% dry basis moisture content	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. Thermal efficiency (stack loss method) and CO emissions must be measured using CSA B415.1-10
EPA Method 28WHH-PTS for Certification of Cordwood-Fired Hydronic Heating Appliances with Partial Thermal Storage	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for measuring PM emissions at specified heat output rates (Btu/hr) referenced against the rated heating capacity. Procedures for determining heat output rates, PM and CO emissions, and efficiency and for reducing data are provided. Methods 28, 28WHH and CSA B415.1-10 are referenced. The four test categories are the same as in Method 28WHH, but the Category III and IV runs use a hot-to-hot test cycle, while the Category I and II runs use a cold start. Category I and II runs must be done with thermal storage; Category III and IV runs may be done with or without thermal storage. Three burn cycle phases: start-up (from the start of the test until 15 percent of the test fuel charge is consumed); steady-state (from the end of the start-up phase to a point at which 80 percent of the test fuel charge is consumed); and end phase.	Indoor and outdoor hydronic heaters equipped with external partial thermal storage, both pressurized & non-pressurized, using an annual average lb/MMBtu output metric. Note that method produces a PM emission rate (g/hr) based on start-up, steady state and end phases of the burn cycle.	Cordwood composed of red or white oak, with a 19-25% dry basis moisture content with cross section dimensions and weight limits as defined in CSA B415.1-10. Dimensional lumber is not allowed by this test method.	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. Thermal efficiency (stack loss method) and CO emissions must be measured using CSA B415.1-10

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Fueling & Operating Test Methods for Hydronic Heaters under Subpart QQQQ				
ASTM E2618-13 Standard Test Method for Measurement of Particulate Matter Emissions and Heating Efficiency of Outdoor Solid Fuel-Fired Hydronic Heating Appliances	**Fueling & Operating Protocol** - This method covers the fueling and operating procedures for measuring PM emissions at specified heat output rates based on the heater's rated heating capacity. Heater is operated on a hot-to-hot test cycle for the same four test categories used in Method 28WHH (above). Method references ASTM E2515-11 and CSA B415.1-10. NSPS requires use of this method for continuously fed biomass hydronic heaters. Annex A1 of method applies to full thermal storage hydronic heaters and Annex A2 applies to partial thermal storage hydronic heaters; cold start is incorporated in method for heaters with thermal storage.	Indoor and outdoor hydronic heaters, both pressurized and non-pressurized, including no, partial and full thermal storage heaters, using an annual average lb/MMBtu output metric.	Cordwood and automatically fed biomass fuel, any wood species within specified density range allowed with a 19-25% dry basis moisture content, Douglas Fir (crib wood) also allowed	PM emissions must be measured by the dilution tunnel method specified in ASTM E2515-11. Thermal efficiency (stack loss method) and CO emissions must be measured using CSA B415.1-10
EN 303-5 Heating boilers for solid fuels, manually and automatically stoked nominal heat output of up to 500 kW	**Fueling & Operating Protocol** - This European standard provides a fueling and operating procedure for measuring PM emissions that is allowed to certify to the 2015 hydronic heater standard for units sold with thermal storage only; it is not allowed to certify to the 2020 standard. Emissions from manually fed heaters using this method are based on the average from 2 consecutive combustion periods, with the mean value based on time elapsed only, without regard to the flue gas flow rate. In the method, mean values are measured in ppm which are then converted to mg/m^3 based on provided conversion factors.	Hydronic heaters up to 500 kW size, manually or automatically stoked, using a mg/m^3 output metric (converted to lb/MMBtu for the NSPS) based on an average over 2 periods at full load	Cordwood with option of beech, birch, oak, spruce or hornbeam with a moisture content of 12-20% (as received basis)	In-stack measurement of PM with the addition of organic gases. Thermal efficiency (stack loss method) and CO emissions must be measured using CSA B415.1-10

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Fueling & Operating Test Methods for Forced-Air Furnaces under Subpart QQQQ				
CSA B415.1-10 Performance Testing of Solid-fuel-burning Heating Appliances	**Fueling & Operating Protocol** - This Canadian Standard is a method covering the fueling and operating procedures for measuring PM emissions, CO emissions, heat output, appliance efficiency, and flue gas flow rates. (The method itself points to procedures in ASTM E2515 to determine PM emissions.) This method has provisions for both manually and automatically fueled room and central wood heaters, but does not cover masonry heaters or fireplaces. The method applies to wood fuels and biomass- and grain-based fuels, but not coal. Note: This method uses 4 different burn rate categories than the 4 burn rate categories used in Method 28WHH; but the burn rate categories in Method 28WHH must be used to certify to the 2020 forced-air furnace standard, with results reported per burn rate category.	Forced-air furnaces using a simple average lb/MMBtu output metric	Cordwood, wood chips, sawdust, firelogs, wood and biomass pellets – must certify to fuel in user's manual. Cordwood specific gravity of 0.60 to 0.73 (dry basis, various species) and a moisture content of 18 to 28% (dry basis).	PM emissions are to be measured by the dilution tunnel method specified in ASTM E2515-11. Thermal efficiency (stack loss method) and CO emissions (dilution tunnel method) are measured using CSA B415.1-10.

Table 2. Descriptions of Test Methods Prescribed in 2015 Residential Wood Heater NSPS

Test Method Name	Type - Description	Applicable Heating Devices & Metric	Allowable Fuel Species	Measurement Methods
Sampling & Analytical Test Methods used in Conjunction with Fueling & Operating Protocols under Subparts AAA & QQQQ				
ASTM E2515-11 Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel	**Sampling & Analytical Measurement** – This method is used for measuring PM emissions from wood heaters including all heaters regulated under this NSPS – adjustable and single burn rate wood stoves, pellet stoves, hydronic heaters and forced-air furnaces – as well as fireplaces and masonry heaters. The total flue-gas exhaust from the wood heater is collected along with ambient dilution air with a collection hood. Duplicate sampling trains are used to extract gas samples from the dilution tunnel for determination of PM concentrations. Each sample train has two glass fiber filters in series, although Teflon membrane filters or Teflon-coated glass fiber filters may be used. Four-inch filters may be used. The NSPS also requires that the first hour of PM emissions for each test run be measured, using a separate filter in one of the two parallel trains.	PM measurement for all wood heaters regulated under NSPS. Total PM emissions are measured in grams. Test results for the first hour must be reported separately and also included in the total PM emissions per run.	Any solid-fuel including all wood species	This is a dilution tunnel PM measurement method
CSA B415.1-10 Performance Testing of Solid-fuel-burning Heating Appliances	**Sampling & Analytical Measurement** – This Canadian Standard includes methods for measuring heat outputs, appliance efficiencies, and CO emission levels from wood heaters. The method references other methods including ASTM E2515, ASTM E2618, and EPA Methods 1, 2, 5G, 28, 28A. The NSPS requires that the burn rates specified in Method 28WHH must be used for hydronic heaters and for the 2020 forced-air furnace standard. CO is measured every 10 minutes during the test run.	CO measurement, thermal efficiency & heat output for all wood heaters regulated under NSPS. CO emissions are measured in grams, thermal efficiency is a percentage (%); and heat output is measured in MJ (converted to Btu)	Any wood species, density or moisture content allowed by fueling & operating protocols (listed above), including Douglas fir “crib” dimensional lumber	CO emissions are measured via the dilution tunnel method. Thermal efficiency is based on the stack loss method.

3.3 Transition from the 1988 Crib Wood based NSPS to Cordwood

The pros of crib wood-based testing. Fuel characteristics and loading arrangements affect PM emissions from wood heaters. To provide a common basis for comparing emission performance among wood heaters for certification testing purposes, the EPA prescribed a standardized wood fuel as well as a standardized wood loading procedure in Method 28 for the 1988 NSPS. "Crib wood" is a specified configuration and quality of Douglas Fir dimensional lumber and spacers, which was intended to improve the repeatability of the test method in 1988. "Cordwood" is a different specified configuration and quality of wood that more closely resembles what a typical homeowner would use. In 1988, the EPA deemed the repeatability concerns of the test method underlying certification to favor the use of crib wood over cordwood. It was reasoned that cordwood testing would have caused greater variability and, thereby, would have been problematic as the basis of a certification program.

The pros of cordwood-based testing and the transition to cordwood-based requirements. While dimensional lumber creates a standardized fuel charge, it is not reflective of the type of fuel used in homes. One of the critical variables of testing is the air flow and air-to-fuel surface ratio. This standardized crib has allowed manufacturers to adjust the air flow to minimize emissions during certification testing. The adjusted air flow for cribs has the potential to decrease emissions performance with cordwood, which has a different physical configuration, and therefore the air flow through the unit will be considerably different with cordwood. Based on that hypothesis, many believe that use of cordwood for emissions testing is a better measure of how the heaters will perform in homes. Finally, some data suggest the repeatability of cribs is no better than cordwood, as indicated by hydronic heater and forced-air furnace tests conducted by Environment Canada.[24]

The EPA's intention at the time of the 2014 NSPS proposal was to transition to cordwood as the basis for certification. Public comment on this issue in 2014 ranged from complete support for the proposed cordwood testing requirements to complete opposition to requiring cordwood testing. Nonetheless, as noted above, stakeholders overwhelmingly agreed that tuning heaters for crib wood certification tests often results in poorer performance in homes. As Dr. James E. Houck has stated "Wood heaters, out of practical commercial necessity, are designed for optimal performance with NSPS test conditions."[25] Recognizing this, the 2014 NSPS proposal required testing with cordwood for compliance with the 2020 Step 2 emissions limits based on: (1) the existence of a viable draft cordwood test method and the expectation that the ASTM test method for wood stoves using cordwood would be complete soon after the NSPS proposal; and (2) that significant testing of wood heaters adjusted ("re-tuned") to perform well on cordwood would occur before promulgation of the 2015 final rule. In that final rule, the EPA continued to encourage manufacturers to design wood heaters that best represent in-home performance on cordwood that consumers use. However, the ASTM cordwood test method was not completed in time for the 2015 final rule and only limited testing using the draft methods occurred.

In addition, the EPA received numerous comments from noncatalytic stove manufacturers, laboratories and some states with concerns about when the cordwood test methods would be ready and how quickly noncatalytic stoves could be redesigned to perform well with cordwood certification testing (that the Agency proposed for Step 2 in 2020, *i.e.*, 5 years after the rule's effective date). As the EPA discussed in the 2014 Notice of Data Availability (NODA), by May 2014 the Agency had test data for three catalytic or hybrid wood heaters/stoves that performed very well on cordwood. However, considering all of the above, the Agency determined that it was premature to set a cordwood-based emission limit because it did not have sufficient data (in 2014-2015) to support a regulatory requirement for cordwood testing (except for forced-air furnaces for which CSA B415.1–10 already specifies cordwood as the test fuel). Instead, the EPA provided an alternative compliance option (not a requirement) based on cordwood.

In the 2015 NSPS final rule, the EPA expressed the expectation that many manufacturers would choose the alternative cordwood compliance testing option so that consumers would have more opportunities to purchase stoves that are tuned for in-home use. The Agency noted that many public comments indicated a critical need for test methods that reflect in-home use with cordwood, cold starts, cycling, moisture, heat demand and shorter averaging periods. It should be noted that the 2015 NSPS did provide cordwood test methods for hydronic heater and forced-air-furnaces; however, while these tests do use cordwood, they do not provide emission data on many of the operational parameters requested by commenters. The EPA stated strong agreement with these needs and noted that the Agency would consider alternative cordwood test method requests on a case-by-case basis until convinced that improved test methods have been sufficiently demonstrated that they can be relied upon for regulatory purposes.

The EPA also stated in the 2015 NSPS preamble (section V.F. Test Methods) that for the time being it would be receptive to alternative test method requests that use the current ASTM draft cordwood method for wood stoves ("Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters using Cordwood Test Fuel"). The Agency noted that the draft ASTM test method was sufficient to be used, upon request, for the cordwood alternative compliance option until better test methods could be developed. The EPA furthermore stated that it would be receptive to other alternative method requests that are sufficiently demonstrated, ideally using the EPA Method 301 validation procedures. The Agency pointed out that there are some manufacturers who already achieve the cordwood emission level and many more manufacturers were expected to take this option and submit data that would inform development of a required cordwood certification test in a future rulemaking. The EPA expressed hope that enough cordwood test data would be submitted within the next few years to enable the Agency to establish revised certification requirements based on cordwood testing.

Test methods based on cordwood for wood stoves and central heaters, that were developed in the U.S. as well as other countries, are listed in the Appendix tables. These tables compare various parameters of each method listed.

3.4 What We Know About In-Home Device Use

It is widely recognized by stakeholders that the current test method fueling protocols for certification do not reflect the range of in-home device use, not merely due to the use of crib wood instead of cordwood, but also related to the variability in other fuel properties and operational parameters. James Houck, Lyrik Pitzman, and Paul Tiegs summarized some of the reasons for this in 2008:[26]

> *Due to the large number of variables associated with residential wood heaters and their operation, all common operational scenarios could not be incorporated into the testing procedures. In addition, the need for reproducibility in the certification methods necessitated divergence from some real-world operational scenarios. Finally, due to the paucity of relevant data prior to the 1988 promulgation of standards, some aspects of*

the testing methods do not simulate the real-world usage as well as they could based on our current understanding. The net effect of these issues is that while the NSPS for wood heaters, did and continues to, provide a commercial and regulatory expediency for the issue of air emissions from wood heaters, the emission data generated do not predict actual emission factors well and the certification methods could be refined considerably to allow for a more realistic target around which new technology wood heaters could be designed…. Regional differences due to climate and socio-demographic factors which include such parameter as burn rates, hot versus cold starts, wood moisture content, hardwood versus softwood fuel, the age distribution of wood heaters, and the level of reliance on wood heaters (main heat source vs. secondary heat source) can all cause differences in emission factors from region to region.

All stakeholders, including industry, have noted that certification values do not correlate well with in-home performance of wood heaters. As noted earlier, HPBA, NESCAUM and WESTAR have jointly recommended that "wood heater emission limits should be based on tests that correlate better with actual in-use emissions than the current test. There is a common interest among the parties to transition from the current crib-based wood heater certification test to a cordwood-based certification test…"[27] The most significant problem with the certification test methods not reflecting the range of in-home fueling and operation is that manufacturers design and adjust their wood heaters to the test method in order to pass the applicable certification test; but emissions may be higher when placed in operation. It should be noted that this is different than other stationary source rules, where additional emission reductions can be obtained at a later date when modifications are made. This is a natural consequence of regulating with a laboratory certification test and underscores the far-reaching importance of the test methods.

Improved certification test methods could not only better predict actual emissions, but also drive the industry to design and adjust ("tune") their wood heaters to perform well (*i.e.*, emit less PM and burn more efficiently) in homes across the country, rather than primarily in the test laboratory. As NESCAUM has stated, "The use of appropriate test methods that challenge a unit to perform its best under a variety of conditions is critical to ensuring clean burning units in field operations."[28] Fueling protocol test methods more reflective of in-home device use would thereby better protect human health and the environment and also move the state of the science in the direction of cleaner devices.

Thus, it is important to catalog what we know about in-home device use. The following list includes aspects of in-home wood heater use that improved fueling protocols should address:

- Fuel species, fuel density and fuel moisture of the cordwood (not crib wood) used in wood heaters vary greatly from region-to-region and consumer-to-consumer and can impact emissions significantly;

- Consumer operation of wood heaters at low burn rates may be more common than is currently represented in the fueling protocol weighting schemes. Low burn rates result in higher PM per mass of wood burned (emission factors), while high burn rates can result in higher stack rates (emission rates). This means that emissions at the lowest and highest burn rates tend to be the most problematic, rather than emissions at the middle burn rates;

- Consumers often overload fireboxes, beyond what is ideal for efficient and lower-emitting burning. This overloading is not captured by most fueling protocols; and

- High-level, short-term PM emissions from wood heaters (*i.e*., during start-up and re-fuel) are not captured by the current test methods which average emissions over a full fuel charge.

3.5 Capturing Fuel Species Variability including Moisture Content

Fuel species and density. The type of fuel species used by consumers varies from region to region of the country, based on the wood species most prevalent in each region. Deciduous hardwoods such as oak, maple, hickory and birch dominate wood fuel in the Eastern and Midwestern U.S. Evergreen softwoods such as Douglas Fir and various pine species dominate wood fuel in the Western U.S., although hardwoods are also common fuel in the West. NESCAUM has claimed that for the country overall there is "a 50-50 split between softwood and hardwood burners", based on formal and informal surveys.[29]

In general, hardwood provides longer burning fires, is denser, and contains more total heat per volume (cord) but less total heat per unit of mass compared to softwood; while softwood, although less dense, has a higher heat content per unit of mass because it contains more resin than hardwood.[30] NESCAUM has claimed that the use of oak as the test fuel for hydronic heaters can significantly underestimate emissions compared to other, less dense woods.[31] In one study, testing data indicates that emission rates from hydronic heaters are 200% to 500% greater for softwoods than hardwoods.[32]

For wood stoves, studies are conflicted regarding which wood species provides the cleaner burn. This may be related to differences in the moisture content and/or the density of the wood fuel used in the studies (that can vary for a given species). The exact difference that wood (tree) species makes in certification testing is unknown; therefore, regulators cannot yet have an informed opinion regarding whether or not the manufacturer should be allowed to choose the species used in certification testing. Consequently, NESCAUM has suggested that EPA adopt a single cordwood fuel type with specified allowable species and densities, for testing all residential wood heater devices, and furthermore that the fuel density be reported in all test reports.[33]

In order to better reflect in-home device use, it is important for the certification test methods to represent the range of fuel species and densities used across the country, while still maintaining a level playing field for comparing emissions across devices. How this can be accomplished – through prescribing fuel species and densities across devices, or through merely requiring that the density of the test fuel be reported – needs to be analyzed further.

Moisture content of wood fuel. The moisture content of wood fuel should not be confused with laboratory terms such as "dry wood" and "wet wood", which are constructs used in developing AP-42 emission factors. These terms refer to the use of a mathematical operation to remove the weight of moisture in the fuel (or not), so that all tests are on an equal basis.[34] Consumers, however, more commonly understand the terms "dry wood" and "wet wood" in terms of moisture content and its effect on combustion.

Moisture content refers to the percentage of moisture in the wood fuel, reported either as a dry basis (db) or wet basis (wb). The dry basis moisture content is determined by dividing the weight of the water in the wood fuel by the weight of the dry wood, while the wet basis moisture content is the weight of the water in the wood fuel divided by the total weight of the wood including the water weight. When comparing the moisture content of wood fuel it is important to use a consistent metric. For certification methods, the basis of the moisture content is explicitly defined as either dry basis or wet basis.

Both wood with very low moisture content and wood with very high moisture content produce higher PM emissions compared to wood fuel with a moisture content near the center of the range (approximately 15-25 percent).[35] The technical reasons for this were understood and explained by experts in wood heater combustion in the 1980's:

> *Higher moisture contents increase the amount of heat required to dry the fuel. This in turn lowers the firebox temperature, increasing particulate and CO emissions. Conversely, very low moisture levels … can also increase emissions because volatile fuel gases are generated at a faster rate than they can be efficiently combusted.*[36]

However, for in-home wood heater fueling, increased wood moisture generally results in substantially increased PM emissions.[37] The 2015 NSPS fueling protocol test methods require a moisture content range beginning from a low of between 15 and 19 percent and extending to a maximum of 25 percent. In addition, the 2015 NSPS prohibits consumers from using wood fuel with a moisture content of greater than 20 percent.

Moisture content varies not only according to variations in consumer behavior regarding the degree to which the wood is seasoned (dried), but also according to wood species. Seasoned hardwoods (such as oak) have a higher moisture content than seasoned softwoods (such as pine). Because of the closed cell nature of hardwoods compared to softwoods, hardwoods take longer to season than do softwoods – and in fact, may never dry out as much as softwoods do. Consequently, hardwood is often burned wetter than softwood.[38]

Furthermore, some states have concerns that the current methods used to measure moisture content are not robust enough to be accurate for especially hardwood fuels such as oak, given the difficulty in obtaining uniform moisture content throughout the fuel piece.[39] Obtaining an accurate measure of moisture content is important because moisture content affects the variability of measured PM emissions in the test methods. How to better reflect the range of actual (in-home use) moisture content in the certification test methods, while at the same time reducing unnecessary variability, needs to be discussed further.

3.6 Capturing Variability in Burn Rates, Firebox Load and Start-up

Burn rate. Burn rate means the rate at which wood fuel is consumed in a wood stove, as expressed in units such as kg/hr or lb/hr. Lower burn rates cause more PM emissions for a given amount of fuel (a higher emission factor). It is has long been known and is widely accepted that increased burn rates result in lower PM emission factors (g/kg PM on probe and filter catch) and lower CO emissions as well.[40] PM emissions measured by using the EPA Method 28 protocol are calculated by a prescribed weighting of the probabilities of national burn rates. Houck has noted that "As a consequence of this weighting scheme, emissions at low burn rates represent only a fraction of the calculated weighted certification emission values yet they can be expected to represent a larger fraction of the wood heater use in [climates requiring relatively fewer high/hot burns]…"[41] NESCAUM has stated that "It is vital that all residential wood heating devices be tested at their lowest burn setting and that they be manufactured to permanently prevent alteration of this low burn setting."[42] On the other hand, while emission factors (PM for a given amount of fuel) are lower at higher burn rates, the emission rate (PM over a given time period) can be higher at the high burn rate for some devices, due to the emission factor decreasing proportionally less than the fuel consumption increase.

Arguably, improved certification test methods need to focus more on emissions at low and high burn rates to better reflect the range of wood heater burning and emissions around the country, and to focus more on burn rates during which emissions are highest. NESCAUM points to EPA's 2009 Stack Testing Policy (at **http://www3.epa.gov/ttnemc01/guidlnd/gd-050.pdf**) and asserts that the policy requires a test method that captures the highest emission rate under normal (in-home use) operating conditions and allows for determination of whether compliance with the emission limit is continuous, not intermittent based on averaging.[43] Stakeholders such as NESCAUM commented on the 2014 NSPS proposal that they favored certification emission values based on the low (Method 28 Category 1) burn rate and high (Method 28 Category 4) burn rate, with two more runs repeated at the burn rate with the highest PM emissions.[44] This would capture emissions at the most polluting (worst case) burn rate and would improve precision at this burn rate. Whether future certified emission value(s) for wood stoves should be based on worst case emissions at either the low or high burn rates, or be based on a weighted average, requires further discussion.

For hydronic heaters, the categories in EPA Method 28 WHH are based on a heat load demand (in Btu/hr) rather than a burn rate. Some stakeholders, such as NESCAUM, maintain that the heat load categories in Method 28 WHH do not reflect typical heat load patterns and that certification emission levels based on these categories in the test method lead to an underestimation of emission levels compared to actual (in-home use) emissions.[45] For the in-depth hydronic heater study prepared for NYSERDA, experts used a duty cycle or "call for heat" load pattern based on a simulation program for heat demand typical of homes in Syracuse, NY – also known as the "Syracuse load profile".[46] NESCAUM has suggested that using an emission profile such as the Syracuse load profile used in EPA Office of Research and Development's analysis of hydronic heater emissions instead of Method 28 WHH's heat load categories would be more reflective of in-home device use and thereby more protective of people exposed to hydronic heater emissions, such as neighbors.[47] In addition, research has shown that oversizing of hydronic heaters causes the devices to spend more time idling, with dampers closed, which decreases efficiency and increases PM emissions.[48] (Thermal storage capability in hydronic heaters improves these performance problems of oversized units.) Continued discussion is needed regarding using load patterns more typical of in-home device use than is currently prescribed in Method 28 WHH's fueling and operating protocol.

Wood load amount in firebox. Completely filling the firebox of a wood heater is considered overloading it, compared to ideal operation, and causes lower combustion efficiency with higher PM emissions.[49] It was established by the 1980s that PM emissions increase significantly with greater fuel loading density – that is, with greater mass of wood per unit firebox volume.[50] In general, smaller more frequent loads emit less PM than large loads – that is, smaller loads generate lower emissions in the same stove at the same burn rate.[51]

Some studies suggest that the wood load amount may have a more significant effect on PM emission rates (not necessarily emission factors) than burn rate. This is because the higher stack flow rates at higher burn rates (which have lower g/kg PM emission factors) and the lower stack flow rates at lower burn rates (which have higher g/kg PM emission factors) tend to counterbalance each other with respect to (g/hr) PM emission rates.[52]

With respect to consumer behavior, it is known that consumers often load up their wood heaters with as much fuel as feasible, in order to maximize burning times between reloading and thereby minimize stove-tending labor. This is especially true of overnight burns, in which wood heaters are loaded to the max and air flow is temporarily increased to create a high burn before closing down dampers to create a very low, smoldering burn with a full wood load overnight and ensure hot embers in the morning. This low burn rate coupled with the large fuel load amount results in significantly increased emissions.

Improved fueling protocols need to better reflect the range of consumer behavior regarding wood loading amounts. The currently prescribed test fuel loading densities in the fueling protocols may not represent the range of wood loading amounts typical of consumers, especially with regard to overloading of fireboxes.

Start-up and refueling emissions. Start-up ("cold-start") of wood heaters result in a disproportionate and large amount of PM emissions from all stoves, including notably some that are relatively clean burning at higher temperatures, like catalytic stoves (*e.g.*, if the catalyst is bypassed because it hasn't yet heated up to operating temperature).[53] Start-up emissions vary from region-to-region and consumer-to-consumer, but some of the highest emission rates typically occur during start-up. More cold starts can be expected in mild climates compared to colder climates because in cold climates wood stoves may be burning around the clock, with at least hot embers ever-present in the fire box to avoid cold starts. On the other hand, many consumers even in cold climates use their wood heaters as a supplemental heat source rather than a primary heat source – in which case cold-starts are more frequent. NESCAUM has argued that, based on actual monitoring of stack temperatures, there are typically two cold starts per day for wood stoves; therefore peak emissions rates for wood stoves are occurring 2 to 4 times per day.[54]

Similar to start-up emissions, emissions during refueling are problematic especially for hydronic heaters. NESCAUM notes that high-level, short-term PM emissions are not sufficiently captured by current test methods:

> *The current test method does not capture these spikes because it averages emissions over a full fuel charge. These can last from 2 to 40+ hours and include in the average what is referred to as the "charcoal tail" (a long period where the unit operates at very low emissions). As a result, the current test procedure does not adequately capture high emissions that can occur immediately after refueling a unit.*[55]

This problem is also seen in wood stove testing, where it is estimated that ~30% of the testing time is needed to burn the last 10% of the fuel charge. Regarding the test methods, a "hot to hot" test means that emissions are measured starting when fuel is placed on a hot coal bed and the test is ended while the coal bed is still hot. Incorporating start-up conditions could use two methods: a "cold to hot" test or a separate start up test protocol. A "cold to hot" test means that emissions are measured starting when no coal bed exists and ends when the second steady state fuel charge has been completely combusted. Alternatively, a separate emissions test could be conducted to measure emissions from the starting of the fire until the unit is ready to be reloaded for a steady state test.

It is important that the certification test method takes into account start-up and refueling emissions, in order to recognize wood heaters that perform well under these conditions from those that do not. By measuring emissions throughout a device's duty cycle, EPA can ensure cleaner operation during in-home use and also recognize those devices that have invested in new technology and design. How exactly the fueling protocol and emissions calculations should be revised in order to better capture start-up and refueling emissions is a matter for further discussion.

4.0 EPA's Process for Approving Alternative Test Methods Allowed Under the Current NSPS

This section discusses the EPA's process for reviewing and approving case-by-case alternative test method requests, how the EPA receives input on alternative test method approvals, and EPA's approval of broadly applicable alternative test methods.

4.1 Case-by-Case Alternative Test Method Approval

EPA's process for approval of alternatives and modifications to test methods and testing procedures is outlined in Guideline Document GD-022, available on the internet at: **http://www3.epa.gov/ttnemc01/guidlnd/gd22.pdf**.

The General Provisions to 40 CFR Parts 60, 61 and 63 (NSPS and NESHAP, Sections 60.8(b)(2), 61.13 (h)(1)(ii), and 63.7(e)(2)(ii)) provide the EPA Administrator with the authority to approve alternatives or changes to test methods, specified in the subparts to these CFR parts, for determining compliance of stationary sources with these Federal emission limitations or standards. The authority for approval of major alternatives to methods can be delegated only within the Office of Air and Radiation (OAR). Within OAR, the authority for approval of major changes to test methods has been delegated down through the Office of Air Quality Planning and Analysis (OAQPS) to the Leader of the Measurement Technology Group in the Air Quality Analysis Division. In addition, the 2015 NSPS states in sections 60.539(a) and 60.5482 that EPA will not delegate the authority of the establishment or revision of test methods.

The Measurement Technology Group undertakes a rigorous review of each alternative test method request, with a focus on making a technical determination that the requested alternative test method will provide results adequate for the EPA Administrator's determination of compliance and that the proposed change in the test method will not negatively affect the stringency of the applicable regulation.

A party wishing to comply with a rule in Part 60, 61, or 63 using an alternative test method approach must provide sufficient evidence demonstrating that the alternative test method is needed in their instance. Examples of such supporting reasons may be: 1) that there are concerns regarding interferences or biases to the rule-prescribed testing approach and/or 2) that allowing for new technology or testing approaches allows for improved accuracy and/or lower costs and/or 3) that allowing alternative measurement locations for hybrid processes or processes subject to multiple regulations might be measured more appropriately with alternate means.

Approval of an alternative test method application is based on substantive review of technical supporting information and/or data. Examples of such information include: 1) direct comparisons with existing reference or compliance test methods (*e.g*. Method 301 comparison data), 2) precision and bias determinations of the proposed approach and detailed test procedures and 3) data quality objectives of the proposed approach.

An alternative test method application may be rejected, or approved with modifications, or approved as submitted, depending on the findings of the technical review. Rejected applications may be re-worked and re-submitted if appropriate. Tests conducted with an approved alternative test method must be conducted according to the procedures listed in the approval letter.

Requests of these types are typically approved on an individual basis (in this case, for use by a specific wood heater), though on occasion where it is deemed appropriate by review, the request may be approved for use on a broader basis (*e.g.* source category-wide or, in this case, for more than just the specific heater referred to in the application), as explained further in Section 4.3.

4.2 Process for EPA to Receive Input on Alternative Test Methods

Like rulemaking, the review of an alternative test method request by the EPA Administrator's delegated authority and his/her technical staff is an inherently governmental process. Once a site-specific (heater-specific) or broadly applicable alternative test method approval is made available for use, members of industry or the general public may send the EPA comments at any time, providing information and opinion about the details and measurement appropriateness of a specific test approach. (See 72 FR 4257, 1/30/2007, regarding the EPA's decision and plan to issue broadly applicable alternative test method approvals, available at: **http://www3.epa.gov/ttn/emc/approalt/FRNotc.pdf**.) Where substantial data driven examples are made available, the EPA may undertake an additional technical review of an existing alternative test method and modify or withdraw that test method if the technical justification to do so is sufficient.

It must be noted that any time the EPA reviews an alternative test method request, the same principles listed above would apply. The alternative test method must continue to provide results adequate for the EPA Administrator's determination of compliance and the proposed change in the test method must not negatively affect the stringency of the applicable regulation.

4.3 Broadly Applicable Alternative Test Method Approval

Where the EPA's Measurement Technology Group finds that it is appropriate to allow an alternative test method for compliance determinations on a broader basis, a public posting of the Broadly Applicable Alternate is made available here: **http://www3.epa.gov/ttn/emc/approalt.html**. Additionally, an annual notice that summarizes all such broadly applicable alternative test methods approved during the previous calendar year is published in the *Federal Register* each spring.

Note that when an alternative test method has been found to be appropriate for use as a Broadly Applicable Alternative Test Method, the EPA may include modifications in the approval notice that must be followed each time the alternative test method is used.

Alternative test method approvals are also subject to withdrawal. The EPA may list a "sunset date" in the original approval, or the Agency may withdraw an approval, for cause, at any date in the future. Such instances may be when rule compliance requirements change rendering the alternative test method obsolete for the purposes of compliance determination, or when other technologies appropriate for determining compliance become cost effective and continue to provide equal or superior data quality.

Device manufacturers or testing laboratories may voluntarily choose to use these broadly applicable alternative test methods. Use of these alternatives does not change the applicable emission standards.

5.0 EPA Reference Test Method Development

This section discusses the meaning of an EPA reference method in general, the currently available reference test methods for residential wood heaters specifically, and the process for adopting a new EPA reference test method.

5.1 What is an EPA Reference Test Method?

The term ‘‘reference method’’ is used in 40 CFR parts 60 and 61 instead of the term ‘‘test method’’ which is used in 40 CFR part 63. In 40 CFR part 60, reference method means “any method of sampling and analyzing for an air pollutant as specified in the applicable subpart.” The definition in 40 CFR part 61 is similar. For simplicity, we use the term ‘‘test method’’ in this paper to refer to both ‘‘test methods’’ under 40 CFR part 63 and ‘‘reference methods’’ under 40 CFR parts 60 and 61. Citations and definitions in all three of these parts refer to the use of alternatives to test (or reference) methods. The EPA maintains a list of promulgated reference test methods applicable to stationary source emissions that is available at: **http://www3.epa.gov/ttnemc01/promgate.html**.

The EPA’s rules and regulations may also refer to test methods not promulgated by the EPA but rather established by a voluntary consensus standard, such as ASTM test methods.

5.2 What are the EPA Reference Test Methods for Wood Heaters?

40 CFR 60, Subpart AAA lists the following test methods for particulate emissions compliance demonstration (for adjustable and single burn rate wood stoves and pellet stoves):

Crib wood:

Method 28R of 40 CFR 60, Appendix A-8, or
ASTM E2779-10,
Both of these fueling protocols use ASTM E2515-11 for PM determination

Cordwood:

An EPA approved alternative test method based on Draft ASTM Cordwood Test Method WK47329 (fueling protocol), using ASTME2515-11 for PM determination.

40 CFR 60, Subpart QQQQ lists the following test methods for particulate emissions compliance demonstration (for hydronic heaters and forced-air furnaces):

Crib wood:

Method 28WHH of 40 CFR 60, Appendix A-8 (for hydronic heaters), or
ASTM E2618-13 (for hydronic heaters)
Both of these fueling protocols use ASTM E2515-11 for PM determination

Cordwood:

Method 28WHH-PTS of 40 CFR 60, Appendix A-8 (for hydronic heaters), or
CSA B415.1-10 (for forced-air furnaces),
Both of these fueling protocols use ASTM E2515-11 for PM determination, or
EN 303-5 (for hydronic heaters at 2015 Step 1 only), or

An EPA approved alternative test method using ASTM E2515-11 for PM determination.

5.3 Process for Adopting a New EPA Reference Test Method

The EPA's process for development of new test methodology involves several steps. Initially a review of existing test methodology is conducted and target criteria are identified to provide Data Quality Objectives for the test method once completed. The EPA then engages stakeholders in open discussion regarding potential testing approaches, including a request for outside information and data, and feedback on draft methods prior to proposal (likely two or three iterations).

The EPA then assembles the method for proposal based on feedback from the most recent draft and any recently collected data. This begins the formal "Notice and Comment" review of the test method where the EPA publishes the proposed method in the *Federal Register* and opens a public docket to collect public information, comment, and additional data if made available. At the end of the comment period, the EPA reviews all comments submitted and drafts a response to substantive comments along with a final version of the test method. The final test method is then promulgated through publication in the *Federal Register* and the test method is available for use. For more information about EPA's Data Quality Objectives process see: **http://www3.epa.gov/epawaste/hazard/correctiveaction/resources/guidance/qa/epaqag4.pdf**.

Once established as a promulgated test method, a new EPA test method can be requested as an alternative to an existing test method for use in meeting the requirements of a regulation, provided that it meets the alternative test method technical review requirements previously discussed in Section 4. Additionally, it may be incorporated into other EPA regulations, such as Subpart AAA through notice and comment rulemaking (as just described).

Fueling protocol. Creation and adaptation of a revised or new fueling protocol for crib wood or cordwood will follow a similar process to development of a new sampling/analytical test method, as described above.

6.0 Process for Improving Cordwood Test Methods

As mentioned earlier, it is a common goal of stakeholders that test methods transition from a crib-based certification test to a cordwood test. This section summarizes the goals, structures and process for identifying robust cordwood test method(s). The goal of this process is the development of an EPA reference test method for residential wood heaters that uses cordwood rather than dimensional ("crib wood") lumber as the test fuel, more accurately representing in-home use emissions and improving testing reliability. The process must meet regulatory needs, as well as understand industry concerns. The EPA believes that this is a reasonable approach to further the science and to develop cordwood methods that reflect in-home use, improve the precision of wood stove testing, and be protective of human health and the environment as the cornerstone of the NSPS certification program.

To achieve this goal, a multi-tier process is envisioned by state regulators that consists of a Steering Committee and two Technical Workgroups. The Technical Workgroups will identify data needs, obtain and review data, and develop recommendations. The Steering Committee will provide oversight, develop guidelines, and review and adopt recommendations from the Technical Workgroups. The state MJO's will take a lead role in this process, with the EPA participating in an advisory role to communicate the types of information required to revise EPA reference test methods.

6.1 Steering Committee Process

The primary role of the Steering Committee is to develop test method evaluation guidelines and prepare a paper that presents recommendations, and, if applicable, incorporates dissenting opinions. The Steering Committee will develop a framework to guide the work of Technical Workgroups, provide feedback/prioritization on Technical Workgroup recommendations, determine preferred methods, and compile the findings of this effort. Ideally, the Technical Workgroups will report quarterly to the Steering Committee on their efforts, and more frequently when necessary. The Steering Committee will be responsible for presenting recommendations for consideration by the EPA.

Membership in the Steering Committee is comprised of staff with legal and regulatory expertise, representing the needs of state and local regulatory authorities. The Steering Committee is led by the multi-jurisdiction organizations (MJOs) participating in this effort. The MJOs are responsible for convening the Committee, developing agendas, facilitating meetings, and documenting outcomes. Core membership in the Steering Committee has been identified and additional members will be considered upon request.

The core membership of the Steering Committee consists of NESCAUM, WESTAR, and state regulators from Washington state, Massachusetts, Vermont and Alaska. One of the first efforts of the Steering Committee was to develop a timeline and to begin drafting a framework for the Technical Workgroup process. Draft elements are identified below.

6.1.1 Timeline

The core Steering Committee established a proposed timeline for the cordwood test method development process. The goal is to have the first Steering Committee meeting in the summer of 2016. The major milestones are:

- Spring 2016 - Discussion Paper: The paper (this document) outlines major themes and their key criteria. The major themes are fueling and appliance operation protocol and measurement method improvements. The key criteria were developed by the Steering Committee, as outlined in Section 6.1.3. This Discussion Paper will also serve to further open these topics for input from any party.

- Spring of 2016 – Form Technical Workgroups: The Steering Committee plans to form Technical Workgroups by the spring of 2016. The two groups will be a PM Measurement Method Workgroup and a Fueling/Operational Protocol Workgroup.

- Summer/Fall 2016 – Develop Process and Data Needs: The Technical Workgroups will develop and present recommendations on their respective processes, the technical questions that they will address, and their data needs. Outreach to stakeholders will be a joint effort of the Technical Workgroups and Steering Committee.

- 2017-2018 – Technical Workgroups' Review of Methods: As data become available and analyses are conducted, the Technical Workgroups will review and draft comments on their respective technical questions. This information will be presented to the Steering Committee at quarterly meetings. The Technical Workgroups may request that the EPA conduct research on specific questions for which the data are limited.

- Summer 2018 – Wrap-up: The Steering Committee will compile the conclusions of the Technical Workgroups. Alternative options and opinions will be provided.

The EPA will review the information provided by the Steering Committee and the Technical Workgroups and will determine whether it has sufficient basis to propose an EPA reference test method based on cordwood. There is no timeline for any future regulations.

6.1.2 Steering Committee's Charge to the Technical Workgroups

The core Steering Committee identified five areas of focus for the Technical Workgroups including:

- Identify criteria to guide test method recommendations;
- Determine which processes and associated data are needed to ensure that emissions measurements are based on an equivalent or more stringent method;
- Select and prioritize devices for cordwood test method acceptance;
- Develop a formal timeline for submitting test methods for consideration; and
- Define documentation requirements for review.

Key Criteria. An initial list of parameters and variables that will need to be considered by the Technical Workgroups is provided in Table 3. This list is meant to create a starting point for a discussion with the Technical Workgroups.

The Workgroups and the Steering Committee will refine the preliminary list of key criteria and finalize in the summer of 2016. Additionally, Steering Committee members will attempt to identify potential funding sources to allow independent research to be conducted to inform this process. If successful in obtaining funds, the Steering Committee will direct the Technical Workgroups to draft priority items to be researched with the available funds. The research priorities will be reviewed and modified or approved by the Steering Committee. The Technical Workgroups will also assist in designing research recommendations and other similar technical guidance as needed. The Technical Workgroups are discussed in more detail in the next section.

Table 3. Preliminary List of Key Criteria to be Considered for Cordwood Test Method

Criteria	Description, Metric and Other Considerations
Device Type	Identify units to test that demonstrate minimal variability due to design. Assure that variability is due to the method rather than the device.
Fueling	Cordwood species or density (to capture regional variabilities)
	Cordwood piece sizing
	Cordwood piece moisture
	Loading configuration – standardized versus “chaotic”/in-home use
	Loading amount – Owner Manual’s instructions versus more in-home use
Burn Periods	Start-up (SU) – cold start?
	Steady State (SS) – refined further
	Idling condition
	Shut-down (SH)
	Other Periods such as reload? Are the burn periods device-specific? (Note: Most methods include nominal or category 4 burns, which may be an important linkage to past data even if not a strong component of future testing.)
Operation during Burn Periods	Steady State versus Emission Profile (*i.e.*, controls not touched under steady state versus allowing for and perhaps dictating controls to capture an emission profile); Scripted operation to represent common homeowner fueling practices (*e.g.*, should equipment settings be scripted to capture going quickly from a very high burn rate to a very low burn rate to simulate an overnight burn)? If scripted, how many runs at each setting (*e.g.*, 4 scripts with 3 runs per script, for a total of 12 runs)?
Representative Length of Burn Periods	Capture entire burn period or just portion of each key period? For scripted runs, how long at each setting (*e.g.*, 2 to 3 hours of measurements for an “abbreviated batch run” to capture overnight smoldering emissions versus measuring during an entire overnight run) and what is the cost benefit analysis?
Adjustments during Burn Periods	Is raking of coal bed allowed?
	Is poking of fuel allowed?
	Is the door open or closed? When and how long?
	Should owner’s manual dictate operation or not – should it instruct conditions on the test method?
	Note: Cordwood burns in non-uniform patterns, sometimes forming arches that can collapse at odd intervals; accommodation is needed for this practical reality
Duration of Burn Period / Test Run	Should test runs have consistent definition of end and what should that definition be (*e.g.*, when 90% of fuel is consumed in order to eliminate charcoal tail and minimize duration)?

Table 3. Preliminary List of Key Criteria to be Considered for Cordwood Test Method

Criteria	Description, Metric and Other Considerations
Stack height	What stack height should be specified or allowed during testing? (Note: Manufacturers stipulate stack heights for many devices to optimize performance. Testing heights should not be less than these heights unless there is evidence of lower stack heights in common field practice. This may have higher relevance to central heaters than room heaters.)
PM Emission Measurement	Burn period's emission measurement: individual emission measurements for each burn cycle/category or a single (simple or weighted) average?
	What PM should be measured (*e.g.*, Total PM, Filterable PM, Condensable PM, 7-day versus immediate measurement, ambient or 40 degree PM)
	What metric (*e.g.*, average, typical, peak/maximum, sub-daily, daily, annual)
	What units should be used for testing (*e.g.*, g/hr, g/kg, g/MJ, lb/mmBtu)? Would the same metric apply across devices, including room heaters and central heaters? What is most helpful to consumers?
Precision / Repeatability*	Need to improve the precision and repeatability of the cordwood fueling protocol and PM emission measurements to improve confidence in the certification process and reduce cost and time to determine certification*
PM Measurement Method	Dilution tunnel issues including dilution ratio and residence time, semi-volatile loss, filter material (glass versus Teflon filters), filter temperature, relative humidity issues, alternative PM methods, characterizing method precision*
Pollutants	What pollutants beyond PM should be measured (*e.g.*, CO, NOx, VOC, PAH)
Efficiency Measurement	How to provide usable efficiency for consumers (*i.e.*, importance of level playing field). Note for example that currently hydronic heaters use thermal output to measure efficiency, while stack loss method is used to measure efficiency of forced-air furnaces.
Flexibility	The fueling protocol of the test method needs to be flexible enough to capture software settings, and to encourage smart devices without running risk of allowing evasive software settings during a test
Cost	Importance of cost of conducting the test
Ease	Importance of ease of conducting the test (*e.g.*, KISS principle)
Verification	Importance of opportunities for outside verification of method
Transparency	Importance of test method transparency

* Note: Regarding capturing variability, running the test method on a pellet stove and pellet boiler as the basis for a Method 301 comparison was suggested. This would minimize fueling variability and get at measurement variability in isolation. Then the comparison process could move up to a cordwood stove and boiler to start characterizing fueling variability.

6.2 Technical Workgroup Process

MJOs and state regulators plan to form two Technical Workgroups: (A) PM Measurement Workgroup and (B) Fueling/Operational Protocol Workgroup. The role of these workgroups is to develop recommendations to the Steering Committee based on the most recent science, and conduct an independent review of the data to develop recommendations for a preferred cordwood method pathway based on these findings. The workgroups will help refine criteria and review processes, identify data needs, conduct an independent review and develop recommendations that will be presented to the Steering Committee for consideration. Another important component of the Technical Workgroups' charge will be to assist the Steering Committee in prioritizing testing with any funds that are available, helping with experimental design, etc., as outlined in Section 6.1.3. If needed, additional more-narrowly-focused technical workgroups might be formed to address specific topics. New workgroups may be created dependent on the availability of staff and/or resources to support these groups. The Technical Workgroups will be formed by invitation from the Steering Committee.

6.2.1 PM Measurement Method Workgroup

The PM Measurement Method Workgroup will address issues specifically related to PM measurement methods included in 5G, 5H and other alternative measurement methods referenced in the NSPS such as ASTM, CSA and EN measurement protocols, or other new methods. This workgroup may also provide feedback to the alternative test method process for sun-setting outdated measurement and fueling protocols. The Steering Committee will develop a list of potential participants in this workgroup. This workgroup will update the Steering Committee at least once per quarter. The Steering Committee will oversee all workgroup efforts. The following is a draft timeline for this process:

- Spring 2016 – Form PM Measurement Method Workgroup: The Committee will invite nominees to participate.

- Summer 2016 - Refine Research Topic Areas: Compile and review a list of PM measurement topics and further refine and modify this list. The group might also conduct literature reviews and reach out to industry, labs and researchers worldwide to determine if data exists to inform the review effort. Upon completion of this effort, the group will identify a prioritized list of research needs. The information completed under this effort will be presented to the Steering Committee as items are finalized.

- Fall 2016 - Develop Method Recommendations: The group will review existing data and literature and prepare recommendations for the Steering Committee to improve the capacity of PM measurement methods.

- Early 2017 – Wrap-up: The Technical Workgroups and Steering Committee will prepare materials for the EPA's review and consideration, including elements for an EPA proposal for method improvements.

6.2.2 Fueling/Operational Protocol Workgroup

The role of this workgroup is to review candidate cordwood methods, focusing primarily on the fueling and operational protocols. This workgroup will review individual methods and complete an assessment of each method submitted for review. Reviews will be based on the key criteria listed in Table 3. This workgroup will also provide technical guidance on test method fueling and operation issues as they are identified. This will involve a review of the preliminary criteria developed by this workgroup, as well as an assessment of available data and future data needs.

This workgroup will update the Steering Committee at least once per quarter. The Steering Committee will oversee all workgroup efforts. The workgroup will prepare a recommendations paper for the Steering Committee that outlines the strengths and weaknesses of various methods and presents, if possible, a single recommended or preferred method for use in U.S. regulatory programs. If consensus is not reached on all or some items, these issues should be detailed in the recommendations report.

This workgroup will be comprised of a small group of technical experts that may be chosen from a variety of entities including regulatory agencies, laboratories, industry, MJOs, or academia. Members should have expertise in test methods, unit operations, and PM measurement. The Steering Committee will develop a list of potential participants in this workgroup.

The following is a draft timeline and outline for this workgroup:

- <u>Spring 2016 - Form Fueling Protocol Workgroup</u>: The Steering Committee will draft invitations and invite nominees to participate in the effort.

- <u>Summer 2016 - Review and discuss framework</u>: Convene the workgroup to further refine and define the Steering Committee's framework. Meet with Steering Committee to discuss and adopt refinements.

- <u>Summer/Fall 2016 - Draft recommendations on data needs for comparative analysis</u>: The workgroup should:

    - Discuss and summarize data needs that are critical for completing a comparative review of test methods and present these findings to the Steering Committee;
    - Identify research that must be completed prior to recommending a preferred method;
    - Identify existing test methods that should be included in the review process; and
    - Outline outreach efforts necessary to raise broad awareness of this effort.

- <u>May 2017 to May 2018 - Review and comment on methods</u>: After the test method review criteria have been finalized and approved by the Steering Committee, the workgroup will review data and conduct a comparative analysis of various test methods as they are submitted for review by the Steering Committee.

- <u>June 2018 - Draft recommendation and brief Steering Committee on cordwood fueling/appliance operation technical recommendations document</u>: The workgroup will draft a report that details findings of the review, a recommended path forward, and areas where a lack of consensus or data gaps prevented the development of recommendations. This report will be presented to the Steering Committee. A joint meeting of the workgroups and Steering Committee will be held to brief the EPA.

6.3 EPA's Approval Process for Alternative Methods

While the cordwood test method review and analysis is underway, EPA's Measurement Technology Group has responsibility for the approval of alternative test methods.

For now, EPA's Measurement Technology Group will make case-by-case approvals of alternative cordwood test methods. Regarding wood stoves, these case-by-case approvals will likely be based on the draft ASTM cordwood test method. During this time, the EPA will collect data from the approved alternative cordwood test methods to inform a more broadly applicable cordwood test method. Results of these tests will also be provided to the technical workgroups for their use in developing recommendations for the Steering Committee.

If sufficient data are collected via case-by-case reviews of alternative test methods, the EPA's Measurement Technology Group may approve a broadly-applicable alternative cordwood test method. This broadly-applicable method could become the "default" alternative cordwood method until an EPA reference method is promulgated. The EPA will collect data using this default cordwood method in order to inform an EPA reference method.

7.0 Topics for Further Consideration

The EPA has established a non-rulemaking docket for any comments submitted on this Discussion Paper under Docket ID No. EPA-HQ-OAR-2016-0130. All documents in the docket are listed in the www.regulations.gov index. If you want your input to be considered in the process, please send by June 30, 2016. Please submit your input, questions or suggestions relevant to this Discussion Paper to Docket ID No. EPA-HQ-OAR-2016-0130, by one of the following methods:

- www.regulations.gov: Follow the on-line instructions for submitting comments.
- Email: a-and-r-docket@epa.gov, Attention Docket ID No. EPA-HQ-OAR-2016-0130.
- Mail: U.S. Postal Service to EPA Docket Center, EPA West (Air Docket), Attention Docket ID Number EPA-HQ-OAR-2016-0130, U.S. Environmental Protection Agency, Mailcode: 28221T, 1200 Pennsylvania Ave., NW, Washington, DC 20004.

The EPA will post all submitted non-CBI information to this publicly available website. If you need to submit CBI material, please contact Amanda Aldridge, EPA, Office of Air Quality Planning and Standards (OAQPS) for instructions at telephone number (919) 541-5268, or aldridge.amanda@epa.gov.

We suggest you provide comment on the following topics and provide data if applicable:

1. Table 3 *Preliminary List of Key Criteria to be Considered for Cordwood Test Method* - provide feedback regarding the listed criteria and questions/notes in the *Description, Metric and Other Considerations* column. In addition, list and describe any important criteria that are missing from this table.

2. The most important aspects of in-home device fueling and operation by responding to some or all of the following questions:

   - What are the most common fueling and operating practices by catalytic wood stove users that lead to high emissions?
   - What are the most common fueling and operating practices by non-catalytic wood stove users that lead to high emissions?
   - What are the most common fueling and operating practices by hydronic heater (wood boiler) users that lead to high emissions?
   - What are the most common fueling and operating practices by forced-air furnace (warm-air furnaces) that lead to high emissions?

3. The importance of the test method (fueling and operating protocol) capturing the variability in emissions based on fuel species, fuel density, and moisture content. Specify which types of devices you are referring to, such as catalytic wood stoves, non-catalytic wood stoves, hydronic heaters, or forced-air furnaces.

4. The importance of the test method (fueling and operating protocol) capturing emissions at the lowest and highest possible burn rates used by consumers. Be sure to specify which device(s) you are referring to in your comment.

5. The importance of the test method (fueling and operating protocol) capturing emissions when the firebox is loaded to full capacity. Be sure to specify which device(s) you are referring to in your comment.

6. The importance of the test method (fueling and operating protocol) capturing start-up and refueling emissions. Be sure to specify which device(s) you are referring to in your comment.

7. Updates that should be made to the PM measurement method to improve the sampling and analytical protocol.

8.0 Endnotes for All Sections

[1] Consensus Positions of WESTAR, NESCAUM, and HPBA re "Proposed Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced Air Furnaces, and New Residential Masonry Heaters". Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1712**. August 18, 2014.

[2] U.S. EPA. *Wood Stove Emissions, Particle Size and Chemical Composition*, EPA-600/B-0050. Prepared by National Risk Management for the Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. June 2000.

[3] Seljeskog, Morten, et al. *Particle emission factors from wood stove firing in Norway*, Report by SINTEF Energy Research to the Norwegian Climate and Pollution Agency, 2013-04-11 V7, Report No. TR A7306, ISBN 978-82-594-3607-8. April 11, 2013.

[4] U.S. EPA. 2011 *National Emissions Inventory (NEI) Data*, Version 2. Available at **http://www3.epa.gov/ttnchie1/net/2011inventory.html**. (2011 NEI Data also available at **https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data**; 2011 NEI Documentation available at **https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-documentation**.) Released March 4, 2015.

[5] U.S. EPA. *National Air Toxics Assessment*, 2011 NATA: Assessment Results. Available at **http://www.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#nationwide**. The NATA Technical Support Document is available at **http://www.epa.gov/sites/production/files/2015-12/documents/2011-nata-tsd.pdf**. Released December 17, 2015.

[6] U.S. EPA. *Strategies for Reducing Residential Wood Smoke*. EPA–456/B–13–001. Prepared by the Outreach and Information Division, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC 27711. pp. 4–5. Available at **http://www.epa.gov/burnwise/burn-wise-strategies-reducing-residential-wood-smoke**. March 2013.

[7] U.S. EPA. *Estimated Contribution of Fine Particle Emissions from Wood Combustion in Four U.S. Cities*. Memorandum from David Cole, Office of Air Quality Planning and Standards, U.S. EPA to Docket ID No. EPA-HQ-OAR-2009-0734. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0144**. April 4, 2013.

[8] Schrieber, Judith and Robert Chinery. *Smoke Gets in Your Lungs: Outdoor Wood Boilers in New York State*, prepared for the Office of the Attorney General of New York. Revised March 2008. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0079**. See also *Preliminary Results of a Study to Assess Air Quality Impacts Associated with Outdoor Wood Boiler Use*, prepared by Judy Abbot of the Bureau of Toxic Substance Assessment for the NYS Department of Health, overview available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0080**. December 11, 2009.

[9] Marin, Arthur, Executive Director of NESCAUM. Letter to Gina McCarthy of the U.S. EPA. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0070**. January 14, 2011.

[10] See the Docket for the Residential Wood Heater New Source Performace Standards at **http://www.regulations.gov/#!docketDetail;D=EPA-HQ-OAR-2009-0734**.

[11] Marin, Arthur Marin, Executive Director of NESCAUM and Dan Johnson, Executive Director of WESTAR. Letter to Steve Page of U.S. EPA. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0244**. April 29, 2008.

[12] Collier, David, President of WESTAR. Letter to Steve Page of the U.S. EPA. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-0071**. July 18, 2011.

[13] Department of Ecology, State of Washington. *How Wood Smoke Harms Your Health*. Pub. No. #09-02-021. Available at **http://www.ecy.wa.gov/pubs/91br023.pdf**. Revised June 2012.

[14] Liu LJ, et al. "Exposure assessment of particulate matter for susceptible populations in Seattle". *Environ Health Perspect* 111(7): 909-918. 2003.

[15] Barn P, Larson T, et al. "Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness". *Journal of Exposure Science and Environmental Epidemiology* 18: 503–511. 2008.

[16] Brown, David, et al. "Outdoor Wood Furnaces Create Significant Indoor Particulate Pollution In Neighboring Homes". *Inhalation Toxicology* 26.10: 628–635. DOI: 10.3109/08958378.2014.946633. 2014.

[17] U.S. EPA. *National Air Toxics Assessment*, 2011 NATA: Assessment Results. Available at **http://www.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#nationwide**. The NATA Technical Support Document is available at **http://www.epa.gov/sites/production/files/2015-12/documents/2011-nata-tsd.pdf**. Released December 17, 2015.

[18] Department of Ecology, State of Washington. *How Wood Smoke Harms Your Health*. Pub. No. #09-02-021. Available at **http://www.ecy.wa.gov/pubs/91br023.pdf**. Revised June 2012.

[19] Liuhua Shi, et al. "Low-Concentration $PM_{2.5}$ and Mortality: Estimating Acute and Chronic Effects in a Population-Based Study". *Environ*. *Health Perspectives*, 124:46-52. **http://dx.doi.org/10.1289/ehp.1409111**. January 2016.

[20] Department of Ecology, State of Washington. *How Wood Smoke Harms Your Health*. Pub. No. #09-02-021. Available at **http://www.ecy.wa.gov/pubs/91br023.pdf**. Revised June 2012.

[21] U.S. EPA. "Wood Smoke and Your Health". EPA's Burn Wise website, available at **http://www.epa.gov/burnwise/wood-smoke-and-your-health**. See also EPA's website regarding the Health Effects of PM at **http://www3.epa.gov/airquality/particlepollution/health.html**. February 2016.

[22] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[23] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[24] Canadian Standards Association, *B415.1-10 Performance Testing of Sold-Fuel-Burning Heating Appliances*, (CSA, 5060 Spectrum Way, Suite 100, Mississauga, Ontario, Canada, 2010), Annex C, p. 71. March 2010.

[25] Houck, James E. *Review of the Puget Sound Clean Air Agency December 5, 2012 letter to Mr. Stephan D. Page of the Office of Air Quality Planning and Standards U.S. Environmental Protection Agency,* page 1. April 3, 2013. Attachment 10 of HPBA's comments on the Proposed NSPS for Residential Wood Heaters, available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1643**.

[26] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[27] Consensus Positions of WESTAR, NESCAUM, and HPBA re "Proposed Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced Air Furnaces, and New Residential Masonry Heaters". Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1712**. August 18, 2014.

[28] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 13. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[29] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 19. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[30] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[31] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 13. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[32] Allen, G. *Contribution of Wood Smoke to Particle Matter Levels in Connecticut - Source Characterization of Outdoor Wood Furnaces*. NESCAUM, p. 4-1. Available at **http://www.vtwoodsmoke.org/pdf/CT-NESCAUM_OWB_Test_Rpt.pdf.** September 9, 2008.

[33] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 19. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[34] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[35] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[36] Burnet, Paul G., Edmisten, Norman G., Tiegs, Paul E., Houck, James E. and Rachel A. Yoder. *Particulate, Carbon Monoxide, and Acid Emission Factors for Residential Wood Burning Stoves*, Journal of the Air Pollution Control Association, 36:9, 1012-1018, DOI: 10.1080/00022470.1986.10466139. 1986.

[37] Preto, F. *Emissions from Residential Wood Combustion*. Presentation at IEA Task 32 Workshop, Paris, France. Available at: **http://www.ieabcc.nl/workshops/task32_Paris_ssc/Preto.pdf**. October 21, 2005.

[38] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[39] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 19. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[40] Leese, K.E. and Harkins, S.M. *Effects of Burn Rate, Wood Species, Moisture Content and Weight of Wood Loaded on Woodstove Emissions,* Prepared for the U.S. Environmental Protection Agency by Research Triangle Institute, Research Triangle Park, NC, EPA-600/2-89-025. 1989.

[41] Houck, James E. *Review of the Puget Sound Clean Air Agency December 5, 2012 letter to Mr. Stephan D. Page of the Office of Air Quality Planning and Standards U.S. Environmental Protection Agency*. April 3, 2013, Attachment 10 of HPBA's comments on the Proposed NSPS for Residential Wood Heaters, available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1643**.

[42] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 17. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[43] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 14. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[44] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

[45] Rector, Lisa of NESCAUM. Conversation with U.S. EPA. February 2016.

[46] New York State Energy Research and Development Authority (NYSERDA), *Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater Technologies, Executive Summary*, Prepared for NYSERDA by the USEPA, ARCADIS, Post-Doctoral Fellows to the USEPA and the University of Dayton Research Institute, NYSERDA Report 12-15. Pages.S-5, S-6. **https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Wood-Fired-Hydronic-Heater-Tech-Summary.pdf.** June 2012.

[47] Rector, Lisa of NESCAUM. Conversation with U.S. EPA. February 2016.

[48] New York State Energy Research and Development Authority (NYSERDA), *Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater Technologies, Executive Summary*, Prepared for NYSERDA by the USEPA, ARCADIS, Post-Doctoral Fellows to the USEPA and the University of Dayton Research Institute, NYSERDA Report 12-15, page S-9. **https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Wood-Fired-Hydronic-Heater-Tech-Summary.pdf.** June 2012.

[49] Gras, J., Meyer C., Weeks, I., Gillett, R., Galbally, I., Todd, J., Carnovale, F., Joynt, R., Hinwood, A., Berko, H. and S. Brown. *Emissions from domestic solid fuel burning appliances (wood-heaters, open fireplaces)*. Environment Australia, March 2002.

[50] Burnet, Paul G., Edmisten, Norman G., Tiegs, Paul E., Houck, James E. and Rachel A. Yoder. *Particulate, Carbon Monoxide, and Acid Emission Factors for Residential Wood Burning Stoves*, Journal of the Air Pollution Control Association, 36:9, 1012-1018, DOI: 10.1080/00022470.1986.10466139. 1986.

[51] OMNI Environmental Services, *Effects of Design Factors on Emissions from Non-Catalytic Residential Wood Combustion Appliances*, p.15, Prepared for the U.S. EPA. May 1986.

[52] Leese, K.E. and Harkins, S.M. *Effects of Burn Rate, Wood Species, Moisture Content and Weight of Wood Loaded on Woodstove Emissions,* Prepared for the U.S. Environmental Protection Agency by Research Triangle Institute, Research Triangle Park, NC. EPA-600/2-89-025. 1989.

[53] Houck, James E., Pitzman, Lyrik Y., and Tiegs, Paul. *Emission Factors for New Certified Residential Wood Heaters*. Presented at the 17th Annual Internation Emission Inventory Conference (**http://www3.epa.gov/ttnchie1/conference/ei17/**) by OMNI Environmental Services and Test Laboratories. **http://www3.epa.gov/ttn/chief/conference/ei17/session4/houck.pdf.** June 2-5, 2008.

[54] Allen, George, et al of NESCAUM.*Contribution of Wood Smoke to Particle Matter Levels in Connecticut – Source Characterization of Outdoor Wood Furnaces*. **http://www.nescaum.org/documents/source-characterization-of-outdoor-wood-furnaces/**. September 9, 2008.

[55] NESCAUM's comments to the U.S. EPA regarding the Proposed NSPS for Residential Wood Heaters, page 13. Available at **http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0734-1551**. May 5, 2014.

9.0 Appendix

- Table A-1: Summary Table of Wood Stove Cordwood Test Methods
- Table A-2: Summary Table of Hydronic Heater Cordwood Test Methods
- Table A-3: Summary Table of Forced-Air Furnace Cordwood Test Method

Table A-1. Summary Table of Wood Stove Cordwood Test Methods

Parameter	Draft ASTM "Standard Test Method for Determining PM Emission from Wood heaters using Cordwood Test Fuel"	AS/NZS 4012 & 4013:2014 "Domestic solid fuel burning appliances" methods for determination of power output & efficiency and determination of flue gas emission	EN 13240 "Roomheaters fired by solid fuel. Requirements and test methods"	
			Full load	Partial load
Feed	Manual - Cordwood	Manual (batch) - Cordwood	Manual - Cordwood	
Test Type	Cold to Hot (high burn) Hot to Hot (medium and low burns)	Hot to Hot	Hot to Hot	
Measurement Method	Dilution tunnel	Dilution tunnel	Direct flue gas	
Fuel requirements	Cordwood Multiple species allowed within a set specific gravity range (0.48-0.73), free of decay, fungus & loose bark	Cordwood Hardwood and softwoods with specified density range, moisture content and ash content	Cordwood Multiple species including birch and beech	
Fuel moisture (dry, unless specified)	19-25% (load average)	16-20% (softwood, wet basis) 12-16% (hardwood, wet basis)	13.4-20%	
Method of Efficiency Determination	Stack Loss (Indirect) Method	Direct Method (calorimeter room used to measure energy output vs input)	Stack Loss (Indirect) Method	
Number of categories	3	3 (with 3 runs/"cycles" per burn rate)	2	
Burn Rates	100% Lowest setting ≤ 1.15 kg/h Between lowest and highest air settings	High (controls fully open) Low (controls open minimally) Medium (following high & low rates)	100%	30%
Test Duration	Returns to weight prior to loading or 90% consumed and no weight loss for at least 30 minutes (for high burn)	Mass of test fuel load is consumed to within ±0.5% of mass of test fuel load	Entire fuel charge has been burnt & only ash remains	Returns to weight prior to loading the fuel charge
Pollutants	Total PM CO	Total PM	Filterable PM, CO, Nitrogen Oxide, VOCs	
Metric	Grams per hour	Grams per kilogram (dry fuel burned)	Gram per megajoule	
Emission rate calculation	Weighted average = 40% low burn average + 40% medium burn average + 20% high burn average	Arithmetic mean of the average PM emissions at each burn rate	Reported by load, no averaging	
Startup emissions	Captured in high burn run, cold to hot	No	No	
Steady state emissions	Low and medium burn rates	Yes	Yes	
Shutdown emissions	No	No	No	
CO measurement	CSA B415.1, Clauses 6.2.2, 10.4.3	No	Yes	

Table A-2. Summary Table of Hydronic Heater Cordwood Test Methods

Parameter	ASTM E2618-13	BNL Partial Storage Method	EN 303-5	CSA B415.1
Manual Loaded Fuel	Cordwood	Cordwood	Cordwood	Both cordwood and crib wood
Feed: Manual/Automatic/Both	Both	Manual	Both - wide range including coal	Both - wide range but not including coal
Wood Fuel Species	Any within specified density range	white or red oak	5 species optional	Any within specified density range
Moisture range (dry basis)	19-25%	19-25%	13.4-20%	18-28%
Method of Efficiency Determination	Thermal Output	Thermal Output	Thermal Output	Stack Loss Method
Number of Categories	4[5]	4 with 2 as optional	2	4
Lowest Output Tested - Manual Feed	15%	15%	50%[4]	35%
PM Emission Metric	Annual average lb/MMBtu output	Annual average lb/MMBtu output	Average over two periods at full load - mg/m3	Simple average of test runs - lb/MMBtu output
PM Emission Rate (g/hr)	YES - RUN AVERAGE	YES - by phase of burn cycle	NO[3]	NO
Startup	NO	YES	NO	NO
Steady State	NO	YES	NO	NO
End	NO	YES	NO	NO
Dilution Tunnel or In-Stack	Dilution Tunnel	Dilution Tunnel	In-Stack	Dilution Tunnel
Thermal Storage?	No, partial, or full	PARTIAL	NO	NO
Cold Start?	YES- with storage[6]	YES- Cat I and II	NO	NO
CO Required to be measured?	YES	YES	YES	YES
CO emission metric?	NO	YES	YES	YES
CO emission limit	NO	NO	YES	NO
Emissions measured for phases of burn cycle?	NO	YES	Measurement during 2 segments only	NO
Upper size limit	NO	350,000 Btu/hr[2]	500 kW (1.7 MMBtu/hr)	500,000 Btu/hr
Fuel Loading	10 lb/ft3	10 lb/ft3	Manu Specifications	10 lb/ft3

Notes

1. By reference to the EPA Partnership Agreement
2. By reference to EPA M28 WHH
3. Not reported but could be estimated from measured data
4. PM only tested during full load (nominal) output test
5. Tests are run in four categories with no storage or partial storage. With full storage there is only one run condition but this is repeated 3 times.
6. With partial thermal storage the Category I (15%) and II (25%) runs are done with cold start. The Category III and IV runs are done with a hot start. With full storage, only a cold start is used.

Table A-3. Summary Table of Forced-Air Furnace Cordwood Test Method

Parameter	CSA B415.1
Manual Loaded Fuel: Crib, Cord, or Both Addressed	Both - wide range but not including coal
Feed: Manual/Automatic/Both	Both - wide range but not including coal
Wood Fuel Species	Any within specified density range
Moisture range (dry basis)	18-28%
Method of Efficiency Determination	Stack Loss Method
Number of Categories	4
Lowest Output Tested - Manual Feed	35%
PM Emission Metric	Simple average of test runs - lb/MMBtu output
PM Emission Rate (g/hr)	NO
• Startup	NO
• Steady State	NO
• End	NO
Dilution Tunnel or In-Stack	Dilution Tunnel
Thermal Storage?	NO
Cold Start?	NO
CO Required to be measured?	YES
CO emission metric?	YES
CO Emission Rate (g/hr)	NO
CO emission limit	NO
Emissions measured for phases of burn cycle?	NO
CO Emission Rate vs Time Required	NO
Upper size limit	500,000 Btu/hr
Fuel Loading for hand-fed units (minimum)	10 lb/ft3