STAGED COMBUSTION BIOMASS BOILERS:
LINKING HIGH-EFFICIENCY COMBUSTION TECHNOLOGY TO REGULATORY TEST METHODS

FINAL REPORT 10-19
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NEW YORK STATE
ENERGY RESEARCH AND
DEVELOPMENT AUTHORITY

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Final Report

Prepared for the

NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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PREFACE

This report is the result of a workshop with manufacturers and importers of two-stage combustion wood boilers. It was held to discuss operational details of two-stage wood boiler and modern pellet- and chip-fired boilers with respect to energy efficiency and the duty cycles in the European-based EN 303-5 and US EPA Method 28-OWHH for Voluntary OWB certification tests. NYSERDA's Biomass Heating Program is a joint effort of the Environmental R&D and Building R&D Programs to develop a high-efficiency biomass heating market of technologies with acceptable emissions performance in New York State.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The story of direct use of thermal energy from combustion of biomass presents a long history, increased future potential, and well-known problems. The historical absence of emission and efficiency requirements based on rigorous regulatory test methods for wood-fired hydronic heaters is rapidly changing. Forthcoming U.S. Environmental Protection Agency (EPA) rules for all biomass combustion appliances are anticipated to result in technologies with greatly improved emissions performance. EPA's previous efforts on wood stoves in 1988 resulted in a 70% reduction in emissions. The current regulatory effort will have broad impacts on the industry and create new opportunities. A critical aspect of these changes hinges on the test methods for certification, and understanding how the test method links to the combustion technologies and integrated heating-system concepts such as thermal storage. Europe instituted tight efficiency and emission standards along with test method EN 303-5 over a twenty-five year span which provided impetus for the growth of new technology firms manufacturing biomass combustion technologies with thermal efficiencies similar to modern oil heating systems with substantial decreases in fine particulate emissions. European test methods provide a valuable experience base to the EPA, which for some years past has relied on a voluntary program to qualify model lines using Test Method 28-OWHH seeking to clean up emissions from Outdoor Wood Boilers (OWBs). This voluntary program has been successful in motivating some manufacturers of OWBs to improve emissions performance as evidenced by the number of OWBs obtaining “Orange Tag” and now “White Tag” qualification, in what will necessarily be an iterative process of technology forcing limits via the voluntary program and New Source Performance Standard (NSPS). However, another class of combustion design, staged combustion, is not well-suited for the evaluation methodology in Method 28-OWHH.

Two-stage combustion systems that are both lower in fine particle emissions and demonstrate high thermal efficiency are sufficiently distinct from typical OWBs to require examination of test methods applied to this technology class. Upgrading the underlying test methods will be a critical aspect of EPA rulemaking in setting the stage for technology evolution in the marketplace applied more broadly than to just conventional OWBs. The New York State Energy Research and Development Authority (NYSERDA) convened a one-day workshop among manufacturers and importers of two-stage wood combustion equipment to review test method impacts on their products and make recommendations for improvements in Method 28-OWHH.

The major finding from the workshop is that Method 28-OWHH, developed by EPA with input from the conventional OWB manufacturers and the Northeast States to serve the needs of a voluntary OWB program and State regulations, needs relatively minor, yet significant modifications for application to the broader array of two-stage combustion technologies which are distinct in fundamental design and operation as compared to typical OWBs. Among these are:

1. A revised Method 28-OWHH should be in the public domain and published in the Code of Federal Regulations (CFR).

2. Revisions to Method 28-OWHH should be on a 5-year periodic basis in recognition of changes in: measurement instrumentation, health-based emission standards, combustion technology innovation, and the need for short-tests to parallel full certification data.

3. EPA should place specific attention on the burn-rate modes of the certification test (Categories I-II-III-IV). A wide range of combustion technologies for which Method 28-OWHH must now apply under the new NSPS includes conventional OWBs, two-stage combustion technologies, automated pellet burners, and systems with and without thermal storage. This variety of combustion and thermal storage concepts should lead EPA to review the appropriateness of the very low burn rate called for in testing Category I. The recommendation is that EPA follows the European test method standard and/or allows exact testing according to manufacturer specifications for how the device is to be used by consumers.

4. EPA should consider a review of crib wood moisture testing, and provide a data review of how much moisture can be found in air-dried crib wood.

5. EPA should consider modifying Method 28-OWHH to conduct the test with crib or cord wood loaded into the firebox according to the written specifications of the manufacturer as in the European EN 303 test. This is especially important for determining nominal load as fireboxes can hold more fuel than currently prescribed in Method 28-OWHH

6. Method 28-OWHH should be modified to add requirements for the temperature of the cold water and hot water supply as there are none presently and these temperatures impact firebox water jacket temperatures which in turn impact emissions and efficiency measurements. European specifications for inlet and outlet water temperature in EN 303-5 are suggested.

7. Piping and control systems for cold water return and hot water supply lines external to the boiler under test must follow manufacturer specification with respect to pipe sizes, circulator capacities, tempering and mixing valves as these have great effect on reported efficiencies and measured emissions.

8. It is recommended that EPA and industry establish an inter-lab "round robin" testing protocol that would serve as the benchmark for certification test variability as is currently required in the NSPS for wood stoves.

9. It is highly recommended that EPA add a simulation of thermal storage to upgrade Method 28-OWHH for the needs of the new NSPS.

10. EPA should consider allowing the use of the indirect method for documenting thermal efficiencies by requiring CO and CO_2 measurements as part of certification testing, especially for pellet-fired boilers, which can operate with steady firing conditions.

1 INTRODUCTION

Significant differences exist in the performance of residential biomass boiler technologies in the U.S. and Europe. These are primarily due to the evolution of staged combustion designs in European heating equipment over the past 30 years (NYSERDA, 2008; 2010). Figure 1 illustrates the **minimum** thermal efficiency required in Europe. Note that Classes 1 and 2 will soon be retired as allowed efficiency standards effectively establishing Class 3 as the performance floor. Classes 4 and 5 are the proposed new requirements. Even in advance of the Class 5 efficiency standards, 25% of the new European residential boiler technologies on the market average 87% thermal efficiency (based on the high-heating value of wood) and thus exceed proposed Class 5 requirements. Some of these achieve even higher thermal efficiencies called for in the "Blue Angel" and "Nordic Swan" eco-label targets set by individual European countries [analogous to the "Energy Star" labels in the US]. Several brands of European residential wood boilers have been imported to the U.S. in the past and more recently companies are entering the U.S. market and forming manufacturing partnerships with U.S. boiler makers.

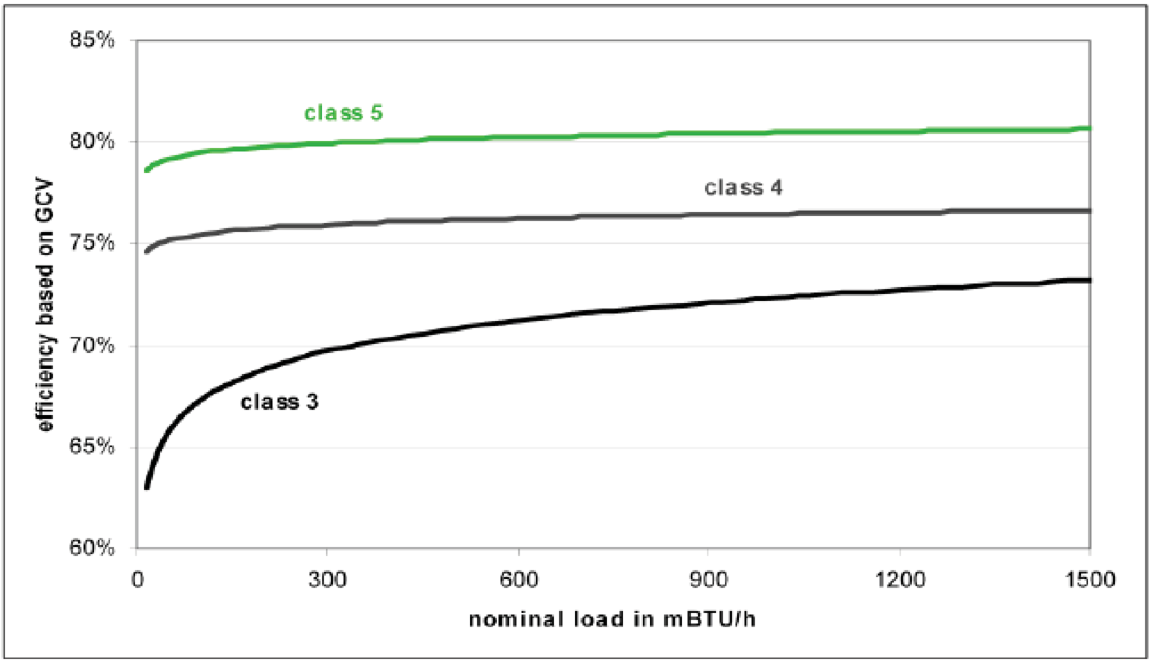


Figure 1. European efficiency requirements based on higher heating value

In addition to very tight thermal efficiency standards, the Europeans also have adopted a parallel supporting set of regulations on the emissions for all biomass combustion devices. There is a strong inverse relationship between energy efficiency and emissions. That is, as efficiency increases, emissions decrease, often in a nonlinear fashion. Higher-efficiency units are typically capable of meeting tight emissions requirements without any post-combustion control technologies. To maximize efficiency and minimize emissions, boilers should be operated at a relatively high output, also known as the "Nominal" or "Rated" output. To facilitate this type of operation, European regulations often require a matched, thermal storage heat reservoir for cord-wood boilers that is external to the boiler itself (as opposed to the large water jacket surrounding the combustion chamber on conventional OWBs). This storage vessel, which is also called an "accumulator tank" allows the entire charge of wood in the firebox to be burned cleanly at high efficiency without periods of oxygen starvation and smoldering or idle operation as a means to modulate heat output. Oxygen starvation, used as a control parameter in conventional OWBs to modulate heat output, leads to the smolder combustion and extremely high emissions. Thermal storage is highly recommended even for pellet-fired boilers with automated combustion control. Figure 2 is a schematic of a pellet boiler, pellet-storage bin, accumulator (thermal storage) tank and solar-thermal hot water system.

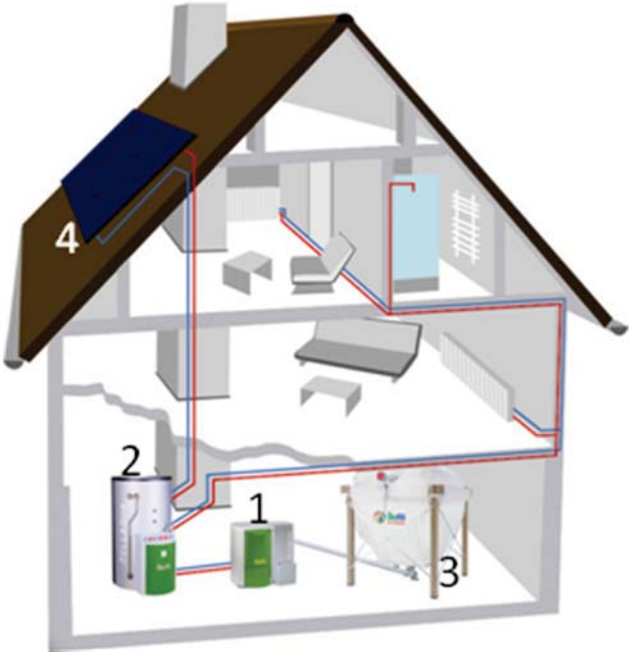


Figure 2. Schematic of a residential installation: (1) pellet boiler, (2) accumulator tank, (3) pellet storage bin, and (4) solar-thermal panels (Courtesy of Maine Energy Systems).

European success in the area of high efficiency, low emissions, and growth of high-tech manufacturing jobs in wood combustion technology, can be thought of as a "three-legged stool" that rests on 1) high performance requirements for thermal efficiency, 2) tight standards for emissions, and 3) repeatable and easily-conducted test methods for (1) and (2) that guide and encourage the best technologies.

1.1 DESIGN AND OPERATIONAL DIFFERENCES: TWO-STAGE COMBUSTION BOILERS AND OWBs

All combustion processes require a vaporized, or "gas" fuel source in order for combustion to proceed. This is true of a dinner candle as well as a jet aircraft engine: vaporized fuel is what burns. The word "gasification" as it relates to fuel preparation prior to combustion is used by virtually any and all manufacturers of any biomass burning device. First a combustible vapor must be produced, and then the evolved fuel vapor is fed to the chemical reaction process identified as "flame". The distinguishing characteristics of two-stage combustors is that the generation of combustible fuel vapors are physically and process separated from the dominant heat-release of the vapor combustion step. In conventional combustion (i.e. fireplaces, OWBs, traditional wood stoves, campfires, etc.), the fuel vaporization generation process is not separated spatially from the dominate heat-release flame front. In two-stage combustor systems, there is a small flame that is needed to force the evolution of combustible vapor from the solid fuel charge, followed by a separate fuel-vapor combustion process step. This separation of fuel vapor preparation from combustion heat release is the basis for the term "Two-Stage Combustion". Compared to open combustion where fuel (cordwood) is vaporized and burned in one continual step, two-stage combustion principles provide the combustion engineer designer the opportunity to control flame properties leading to clean emissions and high thermal efficiency.

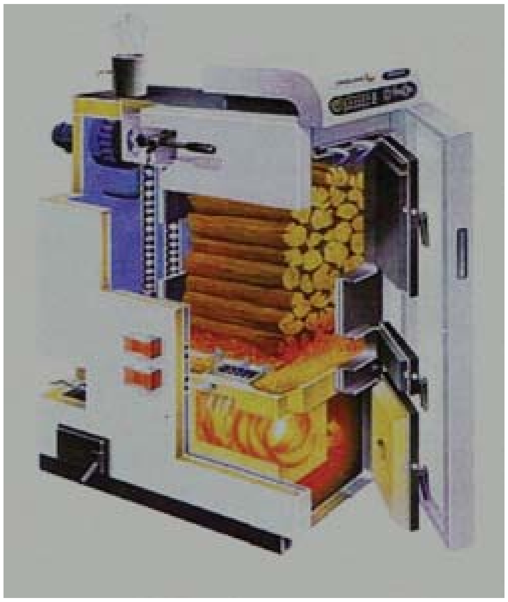


Figure 3. Two-stage, split-wood, down-draft gasification boiler (Froeling, 2005).

Figure 3 is an example of a typical down-draft, two-stage wood boiler. The top chamber contains the charge of cord wood with a small flame bed at the base which serves to force the generation of combustible vapor fuel. This fuel jet is then pre-mixed with secondary pre-heated air and burns in a separated chamber at the bottom. Heat transfer then follows at the back. Sophisticated controls regulate the flow of air to both the upper chamber to generate combustible vapors from the supply of fuel wood, and also to the vapor combustion step (producing the main heat release) in the lower combustion chamber lined with refractory. A process schematic of two-stage combustion is shown below:

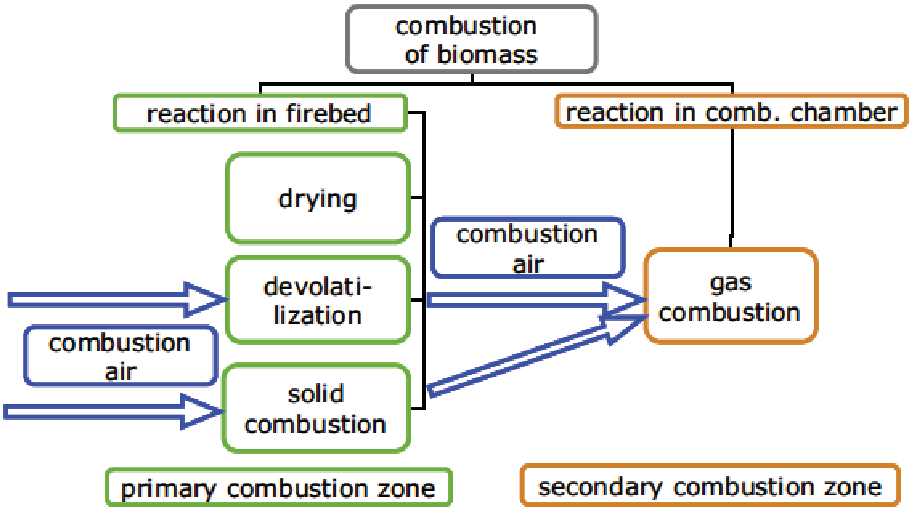


Figure 4. Process schematic of two stage combustion (NYSERDA, 2010).

In contrast to two-stage wood combustion, OWBs characteristically have the fuel vapor generation and combustion of these vapors taking place up through the stack of fuel wood charged to the boiler. This is called “through combustion”.

Control of the ratio of air (oxygen) for combustion to the fuel vapor available for mixing and burning (Air/Fuel ratio) is critical to emissions control. The A/F control in modern automobiles is accomplished by an oxygen sensor located in the exhaust providing feedback many times per second, allowing computer controls to modulate air and fuel to the engine for the wide range of operation conditions which keeps CO and CO_2 combustion emissions in very narrow limits, regardless of load or vehicle operation mode. Like the automobile, two-stage wood appliances are moving in the direction of ever tighter control and modulation of A/F and some are using oxygen sensors (lambda control) in the downstream to provide even tighter real-time continuous control. The left-hand side of Figure 5 shows the CO_2 (left Y axis) and CO (right Y axis) emissions for typical through combustion process where uncontrolled combustion leads to large swings in both emissions products as the fuel charge is depleted during a test burn. The upper right-hand side of Figure 5 is from a comparable two-stage combustion device where the relative constant levels of both CO and CO_2 are seen between times when the unit is re-charged with wood. **NOTE**: the scale range markings for CO emissions for the OWB graph are twice as large as for the two-stage data.

The lower right-hand figure in Figure 5 is the same data from a modern tightly controlled pellet boiler, demonstrating even tighter windows of CO_2 and CO control. The combination of CO_2 and CO emissions at any given moment in the burn cycle is a key indicator of low emission [low CO], high efficiency and complete combustion.

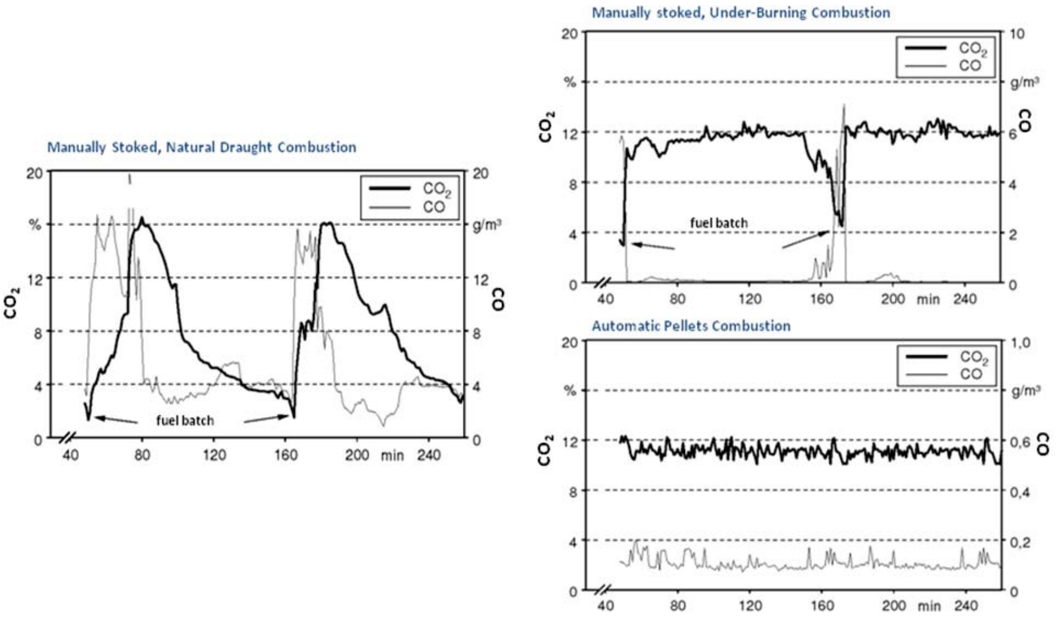
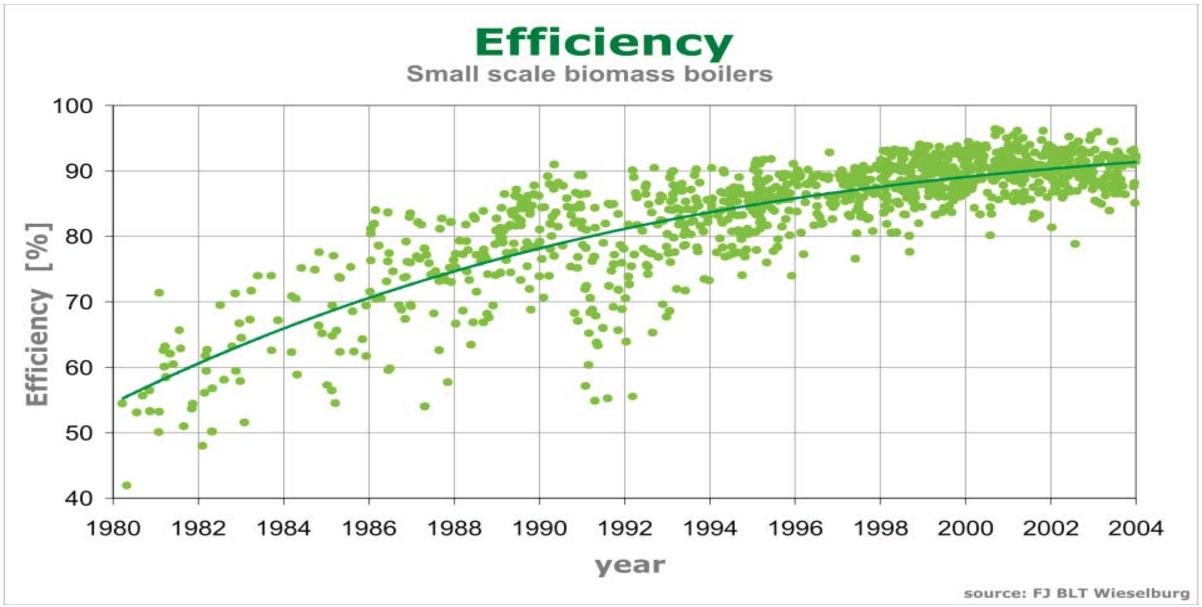


Figure 5. Comparisons of real-time CO/CO2 emissions for through combustion, two-stage split wood, and 2-stage pellet boiler combustion performance (Hartmann, 2003).

The track record of huge gains in both efficiency and low emissions in Europe is shown in Figures 6 and 7 below where many test data points are shown from a wide range of devices. Over a 25-year period, thermal efficiency has improved from about 55% to over 90% based on the lower heating value. CO emissions have in the same time frame reduced from nearly 15,000 mg/m^3 to 50 mg/m^3.



source: FJ BLT Wieselburg

Figure 6. Efficiency improved from 55% to > 90% (based on LHV) over 25 years (Voglaur, 2005).

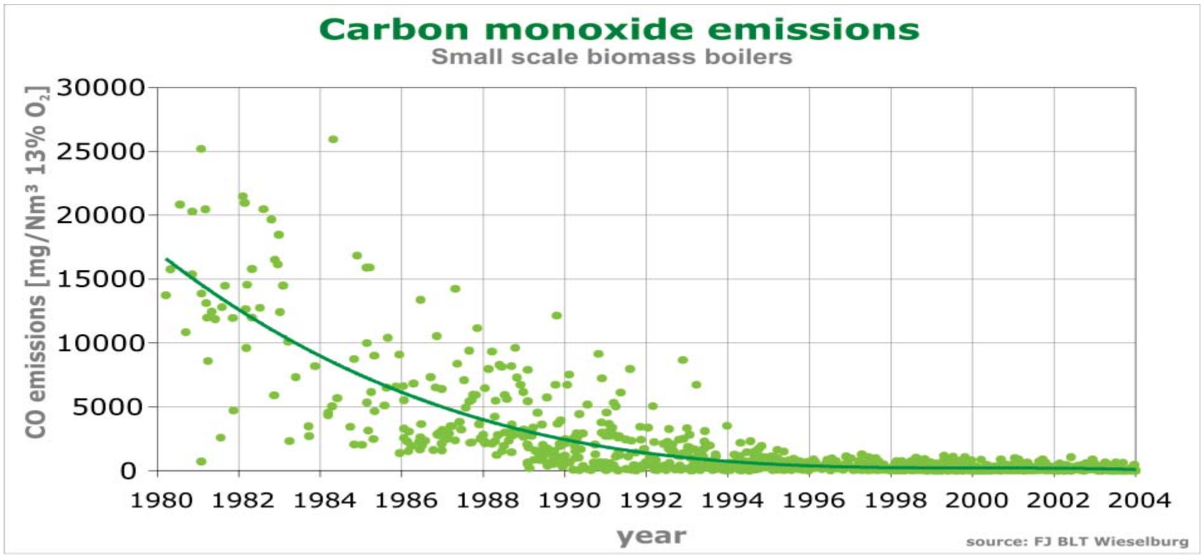


Figure 7. Carbon monoxide emissions drop from 15,000 to < 50 mg/m3 over 25 years (Voglaur, 2005).

1.2 U.S. EPA Technology Forcing Activities

In an effort to encourage improved emission performance of new OWBs sold in the U.S. the EPA in 2007 implemented a voluntary program for Outdoor Wood-fired Hydronic Heaters "OWHH". This EPA program utilizes a test method known as "**Method 28 OWHH**" adapted from the historic Wood Stove Method 28 of 1988 for application to OWBs with operation test modes selected to capture the range of OWB operations. A schematic of how the OWB is set up for operation in Method 28-OWHH is below:

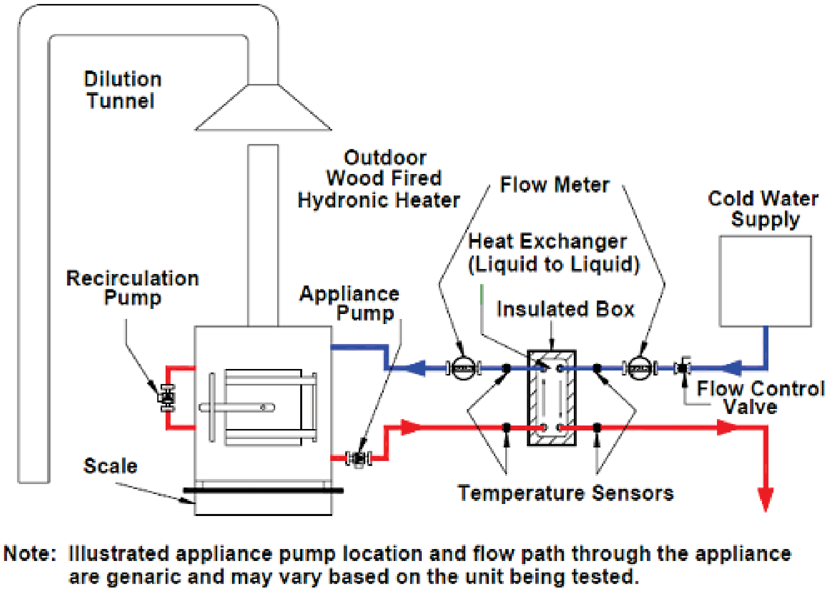


Figure 8. Schematic of experimental set up for boiler evaluation according to Method 28 OWHH (U.S. EPA, 2008).

This first step by EPA to reduce emissions from OWBs included a voluntary partnership agreement, testing by EPA-accredited laboratories, reporting of test results, and EPA issuance of labels and hangtags denoting qualification of Phase 1 (Orange Tag) and Phase 2 (White Tag) models. In conjunction with EPA's effort, the Northeast States for Coordinated Air Use Management (NESCAUM) developed a model rule for OWB emissions to leverage implementation of the test reviews completed under EPA's voluntary program (NESCAUM, 2007). In the absence of federal regulations, eleven states have adopted or proposed OWB regulations (not voluntary) based on the NESCAUM Model Rule. In March 2010, the EPA Voluntary Program Phase 1 "Orange Tag" (0.6 lb/MMBTU <u>input</u>) was retired and only the Phase 2 "White Tag" level (0.32 lb/MMBtu <u>output</u>) is now recognized in the program. This change in the emissions performance requirement, in conjunction with linking the emissions standard to thermal output, rewards higher efficiency systems and is a positive supporting link between efficiency and low emissions.

EPA is currently in the process of updating the emissions performance requirements (regulations, not voluntary) of all residential wood heating technologies including wood stoves, pellet stoves, wood boilers and others. These New Source Performance Standards (NSPS) revisions will require that all newly manufactured wood-fired heating systems meet emission levels that represent the current best demonstrated technology; i.e., all new units sold in the United States will have to meet the level of performance of today's best designs. The EPA must complete an evaluation of "best demonstrated technology (BDT)" that will include emissions data gathered under the voluntary program as the basis of the certification test for NSPS for wood boilers. EPA is examining emissions and cost data from wood-fired heating technologies from both within and outside of the United States to determine appropriate BDT emission standards as applicable to the forthcoming NSPS EPA rule.

Two-stage wood-fired units do not operate in the same fashion as conventional OWBs that Method 28-OWHH was designed to evaluate. The two-stage combustion boilers have a primary combustion chamber where volatile components of the wood fuel are gasified under oxygen-starved conditions at relatively low temperatures. In the secondary chamber the volatiles are combusted with preheated air under oxygen-rich conditions. Such a two-stage setup promotes complete combustion and high efficiencies. These units also tend to have a higher level of sophistication including operational controls that utilize a microprocessor, temperature and gas sensors, and variable speed blowers that lead the boiler to operate at high-loads and avoid idling modes. It is because of the staged combustion and controls that resulting thermal efficiencies and emissions performance is so improved relative to single combustion chamber appliances.

Conventional OWBs typically have a large water volume surrounding a large volume firebox, and are operated in alternating burn-smolder modes as the call for heat varies as seen in Figure 5. In order to capture this high emission mode in testing for approval, EPA required that the Method 28-OWHH include a certain amount of operation be conducted in a very low output mode identified as "Category I", defined in Method 28-OWHH as less than 15% of the full output capacity (measured rated output) for the unit.

Two-stage wood appliances operating at high-efficiency were not designed to operate in a smolder or idle mode. Neither do these commonly have a large water volume in the combustion vessel itself like most conventional OWBs (typically several hundred gallons). They are more commonly operated with small water jacket volumes (typically about 40 gallons) and run in high output modes, and/or with thermal storage systems. Most two stage boilers can cycle on and off to meet low load situations, although most were designed for heat storage that is separated from the combustion unit.

1.3 PURPOSE OF WORKSHOP

The New York State Energy Research and Development Authority (NYSERDA) convened a workshop on April 6, 2010, with firms manufacturing or importing high-efficiency wood-fired boilers in the Northeast. The purpose of the workshop was to discuss operational details of two-stage wood boilers and modern pellet- or chip-fired boilers with respect to energy efficiency and the duty-cycles in the European-based EN 303-5 and Method 28-OWHH for Voluntary OWB certification tests.

Participants were given a summary of the workshop purpose and a link to Method 28-OWHH. On the day of the workshop, after an introductory session and charge to the participants, the attendees were split into two groups; one to address cordwood-fired boilers and the other to address pellet- and chip-fired boilers. Questions given to the groups to address were:

1) Are the test burn cycle modes in Method 28-OWHH (Cat I-II-III-and IV) representative of how a two-stage combustion boiler operates?
2) Are there fundamental differences in the way your boiler operates that prevents it from functioning properly in the Method 28-OWHH test modes?
3) For each procedure in the test, is your boiler able/ready to operate for the duration of the mode?
4) What design elements, tools, or techniques does your boiler employ to avoid idling or smoldering?
5) What sizing parameters would you recommend for the use of hot water storage or accumulator tanks in the test and for installation in a residence?
6) In the context of the existing Method 28-OWHH procedure, what would you recommend to improve the duty cycle (modes) in the test to more appropriately reflect recommended boiler operation?
7) In the context of an Energy Star or Annual Fuel Utilization Efficiency, what would you recommend the duty cycles (modes) in the test be to more appropriately reflect application of the technology for a central New York State climate?
8) What boiler sizing recommendations do you have? Is this compatible with sizing of oil-fired systems using Manual J, Residential Load Calculations, published by the Air Conditioner Contractors of America?

2 CORDWOOD BREAKOUT GROUP DISCUSSION AND FINDINGS

Note there were several boiler manufacturers and combustion experts participating in the discussion group, and a diversity of views were expressed. The following summary attempts to capture as much of these as possible, but may not reflect all specific individual discussion points. The points are by individuals unless denoted otherwise. NYSERDA arranged for the facilitation of the discussion and may or may not agree with each individual point.

As a historic reference, manufacturers and representatives of most two-stage and automatically fired biomass boilers did not participate in industry meetings starting early in the previous decade as Method 28-OWHH was created as a tool to measure emissions from OWBs under the voluntary EPA program.

Workshop participants expressed some concern that EPA includes their high-performing products with conventional OWBs and they believe that the two-stage products, those that burn cleanest, are at a distinct disadvantage when evaluated by Method 28-OWHH. The participants believe that Method 28-OWHH can be adapted to include two-stage combustion technologies, and the technologies themselves can also evolve. Method 28-OWHH was applicable to a certain need, but the new NSPS test method should now include a much wider range of combustion systems, especially as the introduction of high thermal-efficiency types of systems should be one of the goals the regulation seeks to advance.

Test cycles from all types of combustion systems must strike a balance between the need for repeatable tests with reproducible results, and cover a wide range of operation modes that fairly reflect expected real-world operation. No single test cycle or test protocol is ever perfect in both regards. The duty cycle that is presently in Method 28-OWHH was built around a conventional OWB technology concept and the need to control emissions from these, but as the new NSPS regulation is advanced, a wider range of combustion concepts that more realistically capture the duty cycles found with in-use operation of high-output, shorter burn, high-efficiency systems needs to be considered.

2.1 DUTY CYCLE OUTPUT LOAD CATEGORIES

The Method 28-OWHH test protocol calls for four distinct burn-rate test stages that are each a percentage output of the maximum measured rated output for the unit (Table 1). Note the “Rated” or “Nominal” output upon which each category level is based is also determined by Method 28-OWHH. Manufacturers of two-stage appliances felt that the “Rated” output level measured by Method 28-OWHH significantly underestimates Nominal load (discussed in a later section), and this underestimation then propagates to all other burn-rate tasks.

To capture the emissions during the smolder or idle mode, Method 28-OWHH requires testing in “Category I” which is defined in Method 28-OWHH as being a heat output rate of 15% or less of the manufacturers Rated Heat Output Capacity. While this is understandable and important for systems that must operate in this smolder mode by design, this test requirement lays down a serious obstacle for systems that operate at high efficiency for short burn periods (typically less than 4 hours) at relatively high and constant output. Conventional OWBs can operate over many more hours on a single charge of wood and thus will encounter modes more typical of Category I.

The participants felt the sequence and timing of test mode Category I was unrealistic for the operation of a two-stage boiler. It is unrealistic to load a full charge into these units with only 30-45 gallons of water in the boiler jacket, operate the unit at high output and then turn down the heat output to less than 15% or even 25% of full load. This is a bit like running a vehicle engine at high load and suddenly pushing in the clutch. There is no place for the energy to go. For one product that is subjected to such a large turndown command, the boiler will overheat, an alarm will be triggered and the boiler will shut down because there is not enough mass to absorb the energy from a full charge of wood. In contrast, a conventional OWB still has hundreds of gallons of water in its jacket to absorb heat when the unit is dampened down in high-emitting smolder operation. This Category I type of operation is a normal part of the alternating “On/Off” control fits the design of a conventional OWB and allows the unit to hold a huge charge of cord wood and run for many hours in an on-off sequence in response to calls for heat.

Participants suggested that the low load test modes for two-stage appliances should be conducted after the fuel charge had largely been consumed since this char-burning phase is more amenable to large changes in output and is more representative of how an operator would use the equipment. Note that the Canadian Standards Association is revising the method for Performance Testing of Solid-Fuel Burning Heating Appliances and requires testing loads at <35, 35<53, 53<76, and full load, not the low loads used in Category I and II of Method 28 OWHH. The European test method for similar advanced two-stage cord wood boilers calls for testing to an output level of 50% of rated output, or other output level as given in manufacturer specifications. The simple change of operating any unit subject to testing according to the written instruction provided by the manufacturer could be made part of modifications to Method 28-OWHH and allow for testing conventional OWBs and two-stage combustion systems under the same test method, as is done in Europe. It is essential that any duty cycle proposed by the manufacturer characterizes actual operation expected in the field.

Concerns were raised regarding assisted starts with regards to the cycling. Some boilers utilize a fossil fuel or electric ignition device to aid with both starting and ramping up output of the boiler. Such energy is not tracked and may inflate the performance with regards to both energy and emissions. It was suggested that all energy inputs are documented in order to ensure an accurate evaluation of performance is achieved.

Table 1. Test Output Mode Levels (% of Rated or Nominal Output)

Boiler Certification Test	Load
Method 28 OWHH	IV 100%, nominal load III 25-50% II 16-24% I <15%
Canada-Wide Standards	100% 53<75% 35<53% <35%
European: EN 303-5 Cord Wood Thermal storage required	100% 50%
European: EN 303-5 Pellets	100% 30%

2.2 CALL FOR HEAT

The performance of two-stage wood boilers is best illustrated not by Method 28 OWHH duty cycle but in how they respond to a call for heat from a home. This is the approach taken by EPA-ORD in a recent technology evaluation supported by NYSERDA. Four technologies, a standard OWB (CL5036) by Central Boiler, a two-stage OWB E-Classic (E2300) by Central Boiler, the Econoburn EBW-150 with simulated hot water storage, and a fully automated pellet boiler (CATFIRE 40 kW imported from Austria by ACT) were evaluated for energy efficiency and emission (PM2.5, speciated organic PM, CO, CO2, and others) performance in response to the call for heat modeled for a 2500 square foot home in Syracuse, New York during the first two weeks of January. EPA has not yet finalized results and is in the process of finishing the study. Preliminary findings were presented at the 2010 Heating the Northeast with Renewable Energy Conference and some appear in a NYSERDA project factsheet.

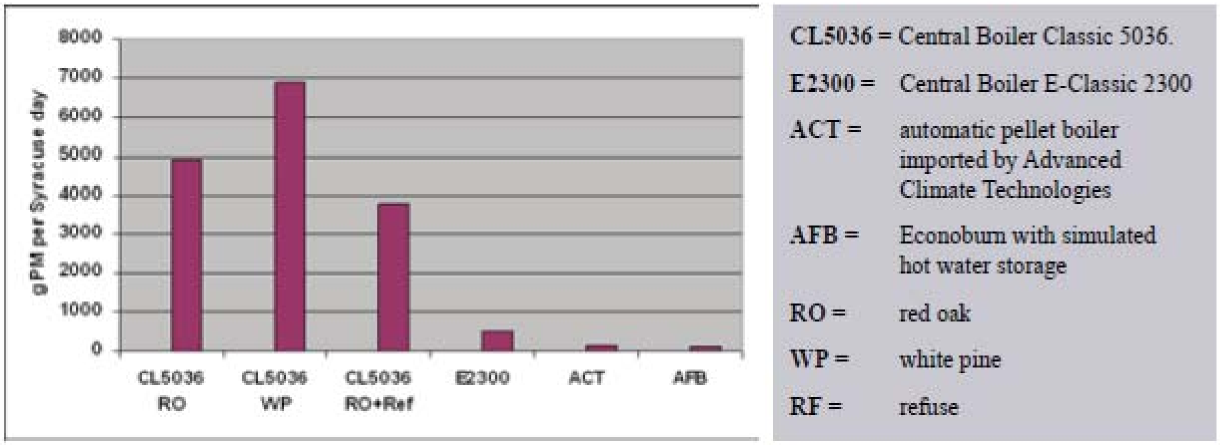


Figure 9. Grams of PM emitted per model Syracuse day (NYSERDA, 2010).

A large difference in PM emissions was observed among technologies in EPA's study. The output-based emissions of the E-Classic were approximately an order of magnitude lower than the most common conventional OWB, demonstrating the success of the voluntary program in encouraging manufacturers to offer lower-emitting OWBs. The pellet boiler emissions were 1/3 that of the E-Classic and less than 5% of the conventional OWB emissions. The Econoburn with simulated hot water storage would have operated at full load for ¼ of the day under this cycle and then shut down, resulting in comparative daily emissions of 20-25% of those of the E-Classic and less than 5% of the conventional OWB. Another important observation was the relatively high uncertainty on the emissions rates presented, especially for lower emission rate appliances. It is worth noting that the pellet boiler was not installed to make use of hot water storage but instead operated at approximately 30% of full load to provide the heat called for. A final report is anticipated in Fall, 2010.

2.3 FUEL, FUEL LOADING, AND DETERMINATION OF NOMINAL LOAD

The ASTM Method 2618 and EN 303-5 both call for cordwood as a test fuel; however, the EPA Method 28 calls for crib wood. Workshop participants expressed opinions about the appropriateness of using crib wood versus cord wood as the test fuel, the representativeness of fuel moisture measurements, the method by which fuel is stacked in the combustion box, and the determination of nominal load.

2.3.1 Crib Wood Moisture Content

Method 28 calls for the use of air-dried crib test fuel wood cut into 4 inch by 4 inch cross sections tested to a moisture content of 19-25% as measured ¾ inch into the sides of the test fuel specimen (4"X4"). It is possible that this requirement leaves open the possibility of having test wood that meets the requirement of Method 28-OWHH but still contains unacceptable high moisture content in the center portion of the crib wood. Such conditions lead to increased emissions and lower efficiency that would not be found had the test crib wood been uniformly dry throughout. Most manufacturers of two-stage combustion systems call for an upper limit of 20% moisture in order to ensure clean and efficient combustion. This potential source of test variability due to unaccounted moisture in the center of the wood used in testing can be resolved by EPA through a simple procedural change to require moisture measurements at the center of the wood.

2.3.2 Crib Wood and Cord Wood for Testing

The use of split, dry cordwood is recommended by manufacturers, and should be fuel that determines the in-use emissions that impact the environment. For certification testing, and to reduce the inherent variability, the benefits of using kiln-dried crib wood of exact specifications for testing are understood as "fuel specifications" [dimensions, species, split vs round, moisture content, and loading protocol]. The current Method 28-OWHH calls for the artificial spacing of crib wood. EPA and industry might collaborate on alternative approaches that would modify the planer surface of the 4"X4" crib wood to have dado notches cut in cross patterns so that when it is time to charge a load of wood for testing there is no need for elaborate stacking of ¾" shim stock to be put in place between each layer of crib wood. Loading both crib wood and shim stock onto a bed of hot coals remaining from the pre-conditioning burn, all in a prescribed short window of time, appears to be a test protocol topic where improvements might be possible. A slightly different uniform crib wood which could be simply and quickly loaded might be found to satisfy the test variability needs while also allowing the test fuel to conform to manufacturers recommendations for how their device should be used in actual service.

2.3.3 Fuel Loading and Determination of Nominal Load

Crib wood is dimensional rough sawn oak placed in a carefully measured and stacked within the firebox under prescribed protocols given in Method 28-OWHH. The test crib load is 10 pounds per cubic foot of firebox. This can cause serious issues with sizing. For example, if a 140,000 BTU/hr two-stage boiler has a firebox of 5 cubic feet it will require 50 pounds of wood. Using 4" x 4" x 17" long oak cribbing this procedure leads to a charge of 5 lengths of wood, whereas in the field [manufacturers specifications] this fire box would typically be loaded with the equivalent of 12 lengths. Therefore the boiler's certified nominal output will be grossly lower than expected in the field. This lower output rating will then propagate to all other Category burn rates, negatively impacting the efficiency and emission results for this unit. Furthermore, as the rating becomes the authorized information for consumers and installers, this seemingly simple and unobtrusive process leads to substantial over sizing in consumers' homes.

As an example, the Econoburn 150 had its nominal load determined using engineering calculations by the manufacturer as having 150,000 Btu/h nominal load. It was subsequently tested at one EPA-accredited laboratory using Method 28-OWHH (crib wood) and nominal output was determined to be 163,000 Btu/hr, within 10% of anticipated value. A recent test of a different unit of the same model at a second EPA-accredited laboratory, also by Method 28-OWHH, found the nominal output to be 115,000 Btu/hr, 29% lower than the previous results. Additional nominal load measurements of the Econoburn 150 will also be made at Federal laboratories.

Workshop participants prefer that cord wood be the test fuel over crib wood and the method of loading fuel for determining nominal load should follow the manufacturers' written specifications.

Table 2. Lab-to-Lab Test Variability for Determining Rated Output (Cat IV) on the Econoburn

Econoburn Two-Stage 150,000 BTU/hr	**Weight of Wood (lbs)**	**Nominal load (Btu/hr)**	**Supply Temperature ^oF**	**Return temperature ^oF**	**Delta T ^oF**	**η%**
Manufacturer target		**150,000**	**175-200**	**160-185**	**20**	
Method 28 crib wood	51.9	162,000	130	64	66	71.8
Method 28 crib wood	53.5	115,000	126	93	33	68.4

2.4 DIRECT AND INDIRECT OUTPUT MEASUREMENT METHODS

Method 28-OWHH calls for the use of the direct method when determining thermal efficiency of the boiler. This method requires the entire combustion device and water jacket to be placed on a scale rendering the efficiency standard unnecessarily cumbersome and difficult for manufacturers to replicate in their facilities. In contrast, the indirect method employs flue gas measurements of CO/CO_2 and other heat loss measurements to document the process. Table 3 is a comparison of thermal efficiency measurements of cord wood and pellet boilers using both the direct and indirect methods as conducted by Bioenergy2020+ in Europe. It is seen in the last column of Table 3 that for over twenty manufacturer tests the two methods agree extremely well. On this basis, presuming proper protocols are followed, it is recommend that flue gas analysis be allowed, or the indirect method, for testing of efficiency rating. Allowance of the indirect method for efficiency determinations will save testing cost at EPA accredited laboratories. This change would also provide manufacturers with a low-cost method that could be conducted in-house for R&D purposes and prior to shipping the boiler to an accredited test laboratory, giving manufacturers greater certainty in how the boiler will perform.

Table 3. Comparison of Thermal Efficiency Measurements by the Direct and Indirect Methods

fuel	Manufacturer	Nominal load MBtu/h	direct	indirect								Difference direct-indirect method (%
			$\eta_{,GCV}$ %	T_{amb} °F	$T_{fluegas\text{-}exit}$ °F	$CO_{2,meas.}$ %	$CO_{meas.}$ ppm	$q_{radiation,\ NCV}$ %	$q_{un\text{-}burnt,NCV}$ %	$q_{Tfluegas\text{-}exit,\ NCV}$ %	$\eta_{,GCV}$ %	
solid wood	"A"	68	82.6	70.7	255.6	12.2	110.5	2.8	0.059	6.6	81.3	1.3
	"B"	92	83.3	74.1	281.7	15.5	314.3	0.7	0.132	6.1	83.7	0.4
	"C"	123	83.5	68.4	229.8	14.8	349.4	0.6	0.153	.9	84.9	1.6
	"D"	137	81.7	72.1	297.9	13.9	139.3	1.1	0.065	7.3	82.3	0.6
	"E"	123	81.7	82.2	234.7	13.5	192.7	1.6	0.093	5.0	83.9	1.2
	"F"	205	83.2	68.7	259.7	15.2	194.9	0.6	0.083	5.7	84.2	1.0
	"G"	171	82.4	70.7	305.8	14.6	143.2	1.1	0.064	7.3	82.3	0.1
	"H"	205	82.1	71.6	317.1	15.5	72.5	0.6	0.030	7.2	82.8	0.7
	"I"	208	81.4	71.4	305.6	14.6	64.1	1.5	0.029	7.2	82.0	0.6
pellets	"J"	48	87.8	71.6	157.1	13.7	59.6	0.8	0.028	2.7	89.3	0.5
	"K"	51	87.7	80.1	225.5	16.5	53.2	0.8	0.021	3.9	88.1	0.4
	"L"	32	87.2	73.9	220.3	13.4	90.3	1.7	0.043	.7	86.6	0.6
	"M"	41	86.6	82.2	241.9	13.7	97.1	1.5	0.046	5.1	86.4	0.2
	"N"	85	88.0	85.3	222.8	13.0	20.1	0.2	0.010	.5	88.1	0.1
	"O"	70	86.5	70.0	206.8	12.7	122.5	1.4	0.062	.6	86.9	0.4
	"P"	68	86.1	69.8	219.9	12.9	10.1	0.9	0.005	5.0	87.1	1.0
	"Q"	55	85.8	71.2	260.6	12.9	123.2	0.8	0.061	6.3	85.9	0.1
	"R"	169	89.0	77.9	202.5	14.4	27.3	0.3	0.012	3.8	88.8	0.2
	"S"	102	87.8	71.4	204.6	14.4	6.1	1.5	0.003	.0	87.4	0.4
	"T"	219	86.6	68.7	263.7	14.4	76.6	0.5	0.034	5.9	86.6	0.0
	"U"	350	86.6	79.5	286.3	15.3	26.6	0.7	0.011	6.0	86.4	0.2
	"V"	478	85.3	68.9	308.3	13.3	18.8	0.3	0.009	7.8	85.1	0.2

2.5 RECOMMENDED WATER TEMPERATURE

Method 28-OWHH does not specify a range for boiler output and input water temperature as is the case with EN 303-5. EN 303-5 requires output flow to have a temperature between 158 and 194 degrees ^{o}F. The return temperature must be 18 to 45 ^{o}F lower than the output flow temperature. Also the relation $\frac{Ts-Tr}{2} - Ta \geq 72$ must hold where Ts (^{o}F) is boiler supply temperature, Tr (^{o}F) is boiler return temperature, and Ta (^{o}F) is ambient air temperature. Instead Method 28-OWHH is to follow the manufacturer's operating recommendations. However, this was not achieved at either of the EPA-certified tests of the Econoburn which specifies output water temperature should be between 175 and 200 ^{o}F. The evaluations were conducted at an average output water temperature of only 130 degrees ^{o}F and 126 ^{o}F for the two laboratories respectively (average return temperatures were 64 and 93 ^{o}F respectively). One federal laboratory indicated the test was conducted according to manufacturer's requirements.

2.6 TEST CONFIGURATION FOR THERMAL TEMPERING VALVES AND RE-CIRCULATION LOOPS

Thermal tempering valves and recirculation loops are common requirements in both oil and two-stage wood combustion systems in order to improve performance. Test-to-test variability and lab-to-lab variability can be impacted if manufacturer requirements in the areas of tempering and re-circulation pumps are not carefully followed. Method 28-OWHH, states that "*…a recirculation pump shall be installed between the connection at the top and bottom of the appliance to minimize thermal stratification…*" and is illustrated in Figure 8. Some manufacturer experiences with test labs have found these manufacturer requirements to be ignored in testing. EPA should emphasize that in order for test lab data to be repeatable, it is important that manufacturer requirements and specifications be followed. Most two-stage combustion units require an on-appliance circulator loop that runs during ramp-up of jacket temperature, starting from a cold-start burn. This system serves to keep fire box and heat transfer surfaces at a relatively constant temperature. Doing so avoids combustion moisture condensation on the walls of the combustion chamber, which would otherwise lead to corrosion of firebox metal and increased variability of measurements. Moisture condensation and steps to manage this are common to all types of burners-oil, gas, and wood. If not used, the resulting un-even temperatures on surfaces in the boiler heat transfer surfaces can result in greatly increased emissions as semi-volatiles and cause these to condense on cold spots which are baked off during periods of high burn. The return water to the boiler should be tempered as part of proper operation to avoid cold spot and condensation areas. This is well-known and a normal requirement for oil boiler operation, but this piping is external to the boiler itself and is usually a field-installed component. Due to this it is critical that all involved in testing (manufacturers, labs, oversight personnel, etc.) must become fully aware of the proper recommended set-up for any boiler to achieve certified and repeatable results.

Manufacturer experience with testing labs indicates that details such as the proper sizing of piping have been at times overlooked. For example, using 1" pipe instead of the manufacturer specified 1 1/4" pipe results in a 36% decrease in flow area which can detrimentally affect boiler performance. In some lab testing, sufficient heat could not be extracted from the unit and the test was aborted, leaving the appearance that the combustion device was in some way at fault. These seemingly simple differences can have huge impacts of measured efficiencies, emissions, operations and interpretations of test results. All stakeholders involved must be on the same page with testing requirements and possibly a checklist of requirements should be provided by the manufacturer and witnessed during the test.

2.7 TEST-TO-TEST AND LAB-TO-LAB MEASUREMENT VARIABILITY

In any type of testing method there will be some inherent variability in results. Manufacturers, regulatory agencies, and the environment in general all benefit to the extent that inherent test variability is minimized. The goal for certification testing should be that the test method fully describes what will be the emissions from an in-use combustion device in actual service. All stakeholders benefit by efforts to reduce any test-to-test and lab-to-lab variability that is attributable to uncontrolled variations in test wood moisture, for instance. The importance of un-accounted sources of test variability increases as regulatory standards become more stringent. From a manufacturer's perspective, if the inherent test method variability is "X", then to be safe in certification testing, they are wise to make sure their product is designed to meet the required standard with a margin of safety greater than "X". The testing method itself needs to be under continual improvement over a several-year timeframe. In the forthcoming NSPS rule it is recommend that EPA establish a five-year review cycle for revisions to Method 28-OWHH to account for changes in testing systems, new combustion technology, and new regulatory standards.

Note that even the experimental determination of "Rated Output" as shown in Table 2 reveals significant variability among test labs. Uncertainty in one aspect of the test propagates to all other measurements further increasing what one might consider the acceptable test-to-test variability. It is recommended that EPA, manufacturers, and test laboratory contractors undertake periodic "round robin" test programs where candidate combustion devices are tested and then shipped to participating test facilities and re-tested, with all results made public. This type of program has been in effect for many years for vehicles and heavy-duty diesel engines, and has served to be an essential part of the testing paradigm that supports all stakeholders. Much can be learned about testing method procedural improvements. This is expensive and time consuming but an essential element of a comprehensive program.

2.8 THERMAL STORAGE FOR IMPROVED BOILER PERFORMANCE AND OVERALL EFFICIENCY

External thermal storage is a technique that can greatly improve the performance of batch loading wood boilers by providing a mechanism by which combustion continues at high load after the space's call for heat has been satisfied. Thermal storage also provides a buffer and serves to minimize the performance deficiencies associated with over sizing and the slight output variations associated with split wood systems. The lower cost of initial purchase for a boiler and increased efficiency with which it operates when right-sized to the load demand are important and, in the end, have links to how these devices should be tested and certified. When a properly sized boiler is coupled with thermal storage the overall combustion efficiency and emission performance are improved, boiler cycling is reduced, and a later call for heat is responded to more promptly by exchanging heat from the thermal storage device into the hydronic loop faster than can be achieved by reloading a wood fuel charge.

Conventional OWBs characteristically operate with significant on/off cycling during real-world use. The large fireboxes of conventional OWBs hold large charges of wood, and the fire is modulated between "on" and "smolder" conditions over long periods of the burn to meet varying load demands of the residence. The large volume of water in the jacket of the unit acts as self-contained thermal storage and can deliver heat after the fire dies down or goes out.

Table 4. Comparison of OWB and Two-Stage Specifications

Manufacturer Model #	Rated Output Btu/hr	Firebox Volume ft^3	Jacket Water gal	Burn Time
Central Boiler E-Classic 2300	150,000/ 8 hr 50,000/24 hr	25.6	450	8-hour burn
Econoburn EBW-200	200,000	8	44	4-6 hr @ full output
Econoburn 150	150,000	6.2	37	3.5-5 h @ full output

Note: For 2-stage units, the total (primary plus secondary) combustion chamber is larger than the firebox.

Efficient two-stage gasification boilers have smaller firebox volumes, much less water in the jacket of the boiler unit, and tend to operate at a constant output over a shorter burn time (Table 4). It is common, although not universally required, that two-stage combustion systems will employ an external thermal storage receiver and are designed to extract combustion heat and send thermal energy to the separate storage system during a relatively constant burn rate for the entire charge of wood.

It will be incumbent on EPA in revision of the Method 28-OWHH test method to include testing provisions that can be related to clean, high thermal-efficiency wood boilers with auxiliary heat storage. This need not imply that heat storage needs to be part of the test, but simply that it should be recognized as an enabling technology to advance clean emissions and high-efficiency combustion and the certifying test should be altered to allow and encourage these advanced technologies for high thermal efficiency.

The quantity of 4X4 crib wood that is used in Method 28-OWHH is based on the volume of the firebox, and is much less than the actual amount of wood that can normally be loaded into a hot-coal bed appliance of either an OWB or two-stage gasification appliance. In the case of two-stage systems with smaller fireboxes, the small charge of wood during certification testing skews results to the disadvantage of the technologies. The root of the problem arise with the testing in that Cat I-III are dependent on Cat IV loads, so if Cat IV is understated then all other loads are understated which makes it even more difficult for the two-stage systems to perform. In other words, a Cat II load in the field may actually represent a Cat III load in the lab. It is recommended that EPA consider how the formulas for setting the mass of test wood impact different types of combustion systems. Real-world operation of conventional OWBs typically uses larger charges of wood than in Method 28-OWHH testing. Two-stage combustion units are designed to accommodate full loads of cordwood and burn at a relatively constant high rate at high efficiency and low emissions. It is recommended that certification testing follow manufacturer recommended specifications as to type of wood (cord vs crib), and the mass of wood to be charged as this approach has worked well in Europe, and serves to test all units in ways that are more reflective of real-world conditions.

There is an ASTM test method for thermal storage which calls for testing of thermal storage combustion systems to use a "cold-start burn-to cold-end dead fire" test method. It is not clear that this test method will have any connection to what EPA will contemplate for revisions to Method 28-OWHH as a means to include thermal storage. Since the entire regulatory test process explicitly leaves the cold-start emissions performance out of the process, it is inconsistent for any test, especially for thermal storage testing, to have cold start be part of the test.

Method 28-OWHH makes no allowance for testing combustion devices that are normally run with external thermal storage to remove heat from the combustion device and store this in an auxiliary thermal reservoir. In the case of conventional OWBs with a large water storage jacket surrounding the firebox, a degree of "thermal storage" is built into the appliance itself. However for modern two-stage combustion systems the heat is generated at a typically high-load burn rate and then "parked" away from the combustion system. European systems recognize the emission reduction benefits of thermal storage and have minimum storage volume requirements. Figure 10 shows data from European testing documenting the large emissions reduction in both CO and organic gases when a thermal storage system is employed to allow the combustion unit to burn in a high efficiency and low emissions mode throughout the test burn.

$$V_{AT} = 4.5 \cdot T_B \cdot Q_N \cdot \left(1 - 0.3\,\frac{Q_H}{Q_{\min}}\right)$$

V_{AT}	*Accumulator tank capacity*	*l*
Q_N	*Nominal heat output*	*MBtu/h*
T_B	*Burning period*	*h*
Q_H	*Heating load of the premises*	*MBtu/h*
Q_{min}	*Minimum heat output*	*MBtu/h*

Figure 10. Storage tank sizing guidelines prescribed by EN 303.5.

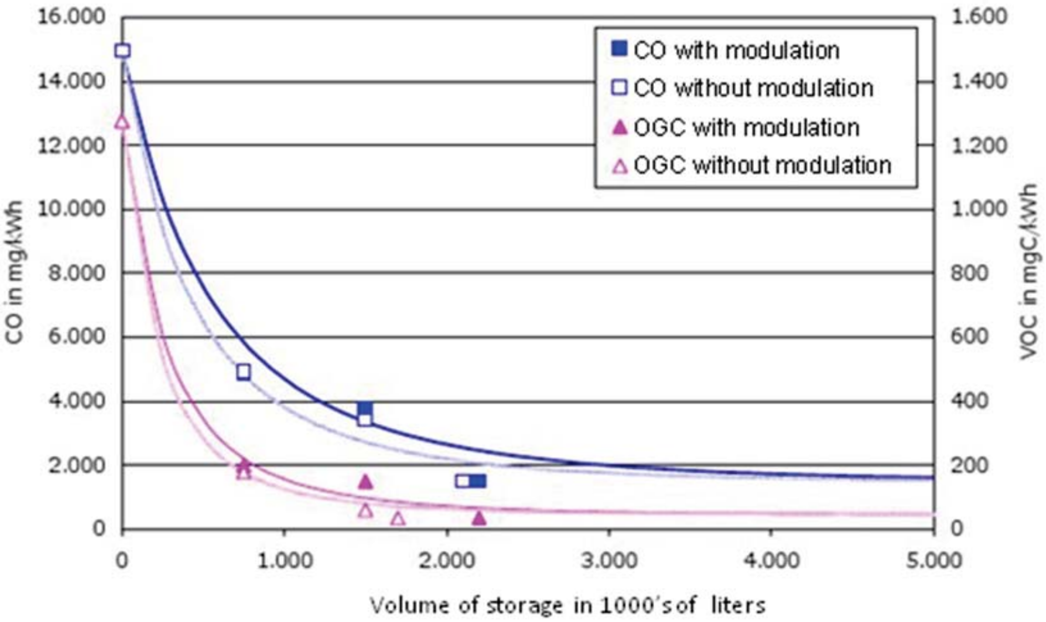


Figure 11. Emission reductions in CO and organic gases with thermal storage (Struschka et al., 2004).

There are several design and implementation issues associated with thermal storage, including whether storage is in a pressure-rated and certified vessel or in an open system at atmospheric pressure using heat exchangers. The well-known benefits of buffering heat generation and heat demand by an intermediate storage medium has a direct parallel in the case of hybrid cars. Greater fuel efficiency and ease by which low emissions are achieved are both apt parallels for a thermal energy storage system linked to wood combustion. Bioheat USA recommends a minimum of 40 gallons per 10,000 Btu for wood boilers and a minimum of 14 gallons per 10,000 Btu for pellet boilers. Econoburn recommends approximately 50 gallons storage/10,000 Btu/hr boiler.

In the case of conventional OWB, the thermal storage is built into the unit itself due to the large water volume in the boiler jacket. However, conventional OWBs operate in smolder or idle modes that lead to high emissions. The testing method and burn cycles that EPA prescribes for the NSPS revisions to method 28-OWHH must carefully account for the realities of likely installations and operation. It is recommended that EPA examine the Method 28-OWHH testing protocol so that thermal storage is simulated in the way heat is extracted from the combustion device during certification testing. This may involve slightly more sophisticated monitoring and control of return water temperature during testing. Controls would be necessary to simulate the rise in temperature of initially cool storage reservoirs that, during the course of the burn, return water of higher temperature which forces the boiler control system to enter the idle or smolder mode discussed above. Note that any such test would be different than simply running the full test burn of a load of wood at the 15% of max output as presently called for in Method 28-OWHH. An idle mode test that happened automatically near the end of a full burn cycle could be expected to give different emission and efficiency results as the drying and volatile combustion phase of burning the charge would have been completed and the char-burning phase would be more typical of normal operation.

Method 28-OWHH requires an idle-mode (Category I) test that can result in boiler over temperature when a two-stage boiler is running at high output and then is suddenly turned down to the Category I mode. This operation is not a manufacturer's recommended procedure or consumer practice. In some cases this has resulted in voided and stopped tests due to excessive heat being generated. Two-Stage boiler manufacturers prescribe that a "heat-dump" be installed for times of emergency as in the case of electrical power outage when the unit is running at full output and the circulators stop running. This is analogous to having a runaway ramp as the bottom of a long hill on the highway. It is suggested that if the turn-down test to Category I from a full load starting position is to be retained in Method 28-OWHH then the test set-up should also be established with the prescribed heat dump piping and heat dissipation systems in place to augment the dissipation of excess heat during the ramp-down to avoid over temperature voided tests.

3 PELLET AND CHIP WOOD BREAKOUT GROUP DISCUSSION AND FINDINGS

Many of the very general comments summarized in the preceding section also apply to pellet and chip wood systems. Here the discussion is focused on unique factors related to pellet and wood chip boilers and how these affect test methods.

3.1 OPERATING CHARACTERISTICS

Unlike cordwood systems which are fed in batches, separated by hours, pellet and chip boilers are fed nearly continuously at a rate which can be modulated depending upon the load. In typical systems pellets are fed with an auger system in which the auger operates for a brief time perhaps once a minute. So in contrast to a cordwood system which goes through phases – including volatiles combustion, mixed combustion, char burnout – a pellet system has essentially one mode. This is reflected in rather steady flue gas CO_2 concentration and temperature in Figure 4.

Typical pellet boilers can operate in a modulating mode between 30 and 100% of full rated output. Systems differ, however, in the way that they operate when the load is less than 30%. Some systems go completely off during extended idle periods and then automatically relight when a load is imposed. Other systems do not go out but rather into a long “pilot” or “keep alive” mode in which there is a very low but continuous combustion rate. Under low load periods such as might be found during spring or fall there would be lower emissions and higher efficiency with a system which goes out totally.

It is very common for these systems to have a near-boiler recirculation pump and mixing valve to hold the minimum return water temperature in the 140 F range. This is important to avoid cold walls exposed to combustion products in the boilers. These cold walls or “cold spots” can lead to local condensation of water and organics which can yield increased VOC emissions. These circulation systems are an important part of the boiler system and need to be included and properly functioning in emissions and efficiency testing.

Some pellet and chip-fired boilers are designed and installed to meet only space heating loads but most are intended for use with both space heat and domestic hot water. In this case the system would have a separate water storage tank which would be treated like any heating zone by the boiler. In this case the operation during periods when no space heating is required would be very much intermittent and the efficiency and emissions would need to be evaluated separately from those during a heating season mode.

3.2 STORAGE

All of the participants in this working group voiced the opinion that storage is a very good if not essential part of a proper system installation. However, there was also uniform agreement that storage should not be mandatory. The benefits of adding storage to a pellet system are not as significant as with a cordwood fired boiler. The cost and space requirements for storage are seen as prohibitive to those making system purchasing decisions. By having storage as a highly recommended but not mandatory part of the system building owners can purchase just the boiler initially and then upgrade to add the storage later. The presence of a storage system also enhances the potential to add solar thermal in the future. Sharing the installed storage between the wood and the solar system reduces the solar system installation cost.

Clearly, however, manufacturers recognize the benefits of storage. Adding storage to a system allows the use of a smaller boiler to meet peak load demands. The capital cost savings associated with this can help to offset the additional capital cost required for the storage.

The addition of storage to a system can dramatically reduce cycling rates and this is likely most significant during periods when the heating load is light. During the workshop discussion, one manufacturer described an internal field study in which it was shown that the addition of storage can result in much lower maintenance costs. This results from reduced stress on the system as it undergoes reduced thermal cycling. Another manufacturer participating in the group reported that they have customers sign a waiver if they choose not to add storage.

In addition to storage there was considerable discussion about system oversizing which also affects cycling patterns. It is a general observation in the heating and cooling industry that consistent oversizing reduces efficiency, increases capital cost, and increases maintenance requirements.

3.3 TEST PROCEDURE

The operating characteristics of pellet and chip boilers are clearly very different from those of cord wood boilers and the procedures for efficiency and emissions testing should be considered completely separately. Since pellet boilers can operate in true steady state at any input rate from 30 to 100% they should be tested over time periods which are much shorter – on the order of 1 hour per data point is seen as adequate. Two such steady state tests are seen as adequate – one at full nominal load and the other at somewhere between 30 and 50% of full load. This low load point should be based on the manufacturer's specifications for the minimum input.

Manufacturers are concerned about the high cost of tests like the Method 28. For discussion at the workshop this was taken as $25,000. This high cost is a barrier to iterative design cycles in which product improvements are continuously implemented based on test protocol results. Having a simpler, lower cost test procedure would enable manufacturers to more rapidly improve their products. Considering this, and the very steady operation of pellet and chip boilers, the use of a flue-gas loss combustion efficiency rather than an input-output efficiency test should be seriously considered. The flue gas loss procedure is well established and is used, for example, as the standard to determine the efficiency of large industrial and utility boilers (ASME/ASTM PTC 4.1) operating in steady state. Use of this procedure would dramatically reduce testing cost and complexity and enable manufacturers to rapidly estimate efficiency with simple field and in-plant tests. Key measurements include flue gas temperature and composition (oxygen or carbon dioxide and CO). Additional measurements needed for a very accurate test include ash carbon content and outside wall temperatures. Fuel composition (moisture, ash, carbon, hydrogen) is also needed and this can be estimated for an approximate test or measured at a commercial fuel analysis lab for a more accurate test.

In addition to the steady state tests consideration might be given to an “idling test”. This would be done under conditions where the load on the unit is extremely low (or possibly zero), forcing the unit to shut off or to go into a “pilot” or “keep alive” mode. An example of the load for this would be a draw of approximately 6,000 Btu, over a 3 minute period, once each hour. Particulates would be measured over a repeat number of these cycles. The primary purpose of this test is to enable accurate credit to be given to those manufacturers who avoid high cycling particulates by integration of storage or more advanced technical management of the on/off cycling process.

An annual average number for particulate emissions and averaged efficiency could be developed from results measured during each of the two steady state runs and the idling test. The weighting factors for each of these three tests would depend on the case. If the boiler is matched with a hot water storage unit a much lower weighting factor would be given to the cycling test results. Similarly, a lower weighting factor would apply to units which are heat only appliances and do not meet domestic hot water loads.

4 RECOMMENDATIONS

The major finding from the workshop is that Method 28-OWHH, developed by EPA with input from the conventional OWB manufacturers and the Northeast States to serve the needs of a voluntary OWB program and State regulations, needs relatively minor, yet significant modifications for application to the broader array of two-stage combustion technologies which are distinct in fundamental design and operation as compared to typical OWBs. The recommendations from the scoping session are:

1. Whatever test method changes EPA adopts, the full method should be in the public domain literature and issued as part of the Code of Federal Regulations (CFR) and not developed in such a manner as to result in any organization claiming proprietary rights to the test method or documentation.

2. Cognizant that several relevant areas such as combustion appliance design, health effects of wood combustion on the public, analytical equipment for testing, among others are evolving in parallel with the forthcoming EPA-NSPS rule, EPA should adopt a periodic schedule for revisions and examination of the test method, standards, analytic system for testing, methods of measuring in-field compliance, and methods of certifying efficiency ratings. The recommendation is that once adopted for the new NSPS, the Method 28-OWHH be on a 5-year review schedule.

3. It is recommended that EPA revise the Method 28-OWHH with specific attention to making sure the method is applicable to the full diversity of combustion appliances in the marketplace, especially for two-stage cord-wood combustion technologies, pellet-combustion systems, as well as conventional OWBs. EPA should pay specific attention to the burn-rate modes of the certification test (Categories I-II-III-IV). The wide range of combustion technologies for which Method 28-OWHH must now apply including systems with and without thermal storage should lead EPA to review the appropriateness of the very low burn rates called for in testing Category I. The recommendation is that EPA follow the European test method standard (EN 303) and/or allow exact testing according manufacturer specification for how the device is to be used by consumers.

4. EPA should consider a review of crib wood moisture testing, and provide a data review of how much moisture can be found in air-dried crib wood that meets the current requirements when these specimens are re-sawn to fully document moisture content in the heart of the 4-inch by 4-inch crib wood specimens. Quantitative measurement of the total water content remaining in crib wood that meets current moisture specification should be performed. This could be done immediately and be useful in the NSPS rule with attached test method modifications.

5. EPA should consider modifying Method 28-OWHH to conduct the test with crib or cord wood loaded into the firebox according to the written specifications of the manufacturer as in the EN 303 test. This is especially important for determining nominal load as fireboxes can hold more fuel than currently prescribed.

6. EPA should consider modifying Method 28-OWHH to add requirements for the temperature of the cold water and hot water supply as there are none presently and these temperatures impact firebox water jacket temperatures which in turn impact emissions and efficiency measurements. European specifications for inlet and outlet water temperature in EN 303-5 are suggested.

7. Piping and control systems for cold water return and hot water supply lines external to the boiler under test must follow manufacturer specification with respect to pipe sizes, circulator capacities, tempering and mixing valves as these have great effect on reported efficiencies, and measured emissions.

8. It is recommended that EPA and industry establish an inter-lab "round robin" testing protocol that would serve as the benchmark for certification test variability as is currently required in the NSPS for wood stoves. While this is expensive to carry out, it is critical to establishing a data-driven basis for development, certification, and more. The examples of round robin testing programs EPA and industry carry out routinely for cars, and especially for heavy-duty diesel engines can provide a template for how such testing metrology efforts can be established. All stakeholders benefit as the field of clean efficient wood combustion moves forward.

9. EPA should add simulated thermal storage to upgrade Method 28-OWHH in the NSPS to better characterize the in-use duty-cycle of 2-stage combustion systems. A programmable controller to set the return water temperature profile might be a useful addition. Given the wide range of combustion concepts to which the NSPS must apply (OWBs with self-contained thermal storage and two-stage gasification boilers, and boilers with external storage, pellet boilers, etc), the ability to routinely and accurately program the temperature of the return water to the boiler water jacket can aid in reducing test variability.

10. EPA should consider allowing the use of the indirect method for documenting thermal efficiency based on the ability to do this as demonstrated in European testing where both were done. This use of CO and CO_2 measurements for thermal efficiency testing saves cost. As noted above for the need for short-tests, the use of CO/CO_2 measurements for indirect efficiency testing could also then provide, at no additional cost, the data needed for short tests. A short-test for these gasses attached as a record of certification for each boiler would be a valuable record for long-term use, just as all service technicians for oil and gas boilers use testing of these levels for routine field work.

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APPENDIX A

New York State Energy Research and Development Authority

Staged Combustion Biomass Boiler Technology Scoping Session

April 6, 2010

Agenda

8:00 Coffee

8:30 Introduction – Ellen Burkhard, NYSERDA and Dick Gibbs, MIT

9:00 Method 28 and other considerations – Scott Nichols, Bioheat USA

9:30 EN 303-5 – Birgit Musil-Schlaeffer, Bioenergy 2020+

A. solid wood boilers
B. pellet boilers including discussion of how these units avoid idling (not in test method)
C. role of hot water storage tanks
D. proper sizing of boilers and hot water storage tanks

10:15 break

10:25 Experience with the EPA voluntary program test method – Mark O'Dell, Alternative Fuel Boiler

10:50 Call for heat in January for Syracuse, NY and the oil-heat perspective Tom Butcher, Brookhaven National Lab.

11:20 Charge to the group – Dick Gibbs

- practical considerations of duty cycle for testing staged combustion technologies burning cord wood, chips, and pellets;
- the role/requirements for using hot water storage
- tools and techniques to avoid idling

11:45 Lunch on site

12:15 Break-out Groups

A. Cordwood fired boilers – Dick Gibbs and Nathan Russell facilitate (same room)
B. Pellet and chip fired boilers – Tom Butcher and Ellen Burkhard facilitate (Plattsburg room)

3:00 Reconvene in Plattsburg room to present points (issues/recommendations) made by the break-out groups (30 min each group)

4:00 Next steps - Gibbs facilitate

APPENDIX B

Participating organizations

Advanced Climate Technologies
Alternative Fuel Boilers
Bioenergy 2020+
Bioheat USA
Bluestone Boiler
Brookhaven National Lab
Evotherm USA
Fulton Companies
MA DOER
Maine Energy Systems
MIT
NYSERDA
Propell Energy
Thermo Control
Viessmann

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STAGED COMBUSTION BIOMASS BOILERS: LINKING HIGH-EFFICIENCY COMBUSTION TECHNOLOGY TO REGULATORY TEST METHODS

FINAL REPORT 10-19

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