Information on Air Pollution Control Technology For Woody Biomass Boilers
March 2009

DISCLAIMER: This document is a collection of readily available public information on woody biomass boiler design and air pollution control technology. It should not be considered as formal or informal guidance nor does it represent Federal or State or local agency policy. Consultation is necessary with the appropriate air pollution control agencies for compliance with all local, state and federal standards to ensure the health and safety of local neighborhoods. The information in this document is current as of March, 2009 and may be revised if new information becomes available.

OVERVIEW

Numerous health studies have linked exposure to fine particle pollution to a wide range of heart and lung health effects affecting older people, children, and those with pre-existing heart or lung disease. This document provides information on potential ways to reduce emissions of fine particles and toxic pollutants from woody biomass boilers at schools, hospitals, or other buildings.

This document describes the types of control technology available and their effectiveness, and various aspects of designing and operating woody biomass boilers. The following questions and answers are included in this document:

1) What are some examples of woody biomass boilers?
2) What steps should be taken prior to installing a boiler?
3) What source test methods can be used to measure emissions?
4) What are the different fuel types?
5) What factors should be considered for selecting a woody biomass boiler?
6) What are some technical issues associated with air pollution control technologies?
7) Are there new or emerging technologies to consider?
8) What dispersion modeling tools are available?
9) How effective is a tall stack for controlling air pollution?
10) What kind of operator training is needed?

QUESTIONS and ANSWERS

1) What are some examples of woody biomass boilers?

Most small wood boilers operating in the United States have a heat-input capacity less than 20 million British thermal units (mmBtu/hr) and share common design and operational features. All inject fuel into a combustion chamber in the presence of air. The following are some of the key design factors that can impact wood boiler efficiency and emissions:

- System sizing

- Combustion controls
- Instrumentation to monitor combustion performance
- Fuel moisture
- Boiler and pipe insulation
- Multiple boilers

Below are the two primary boiler designs typically used in the United States: 1) direct-burn and 2) two-chamber boilers.

Direct-Burn Boiler

A direct-burn boiler has a single combustion chamber that is usually located directly under the boiler on a specially designed base (Figure 1). Air is injected into this chamber both below and above the grates where the wood is burned.

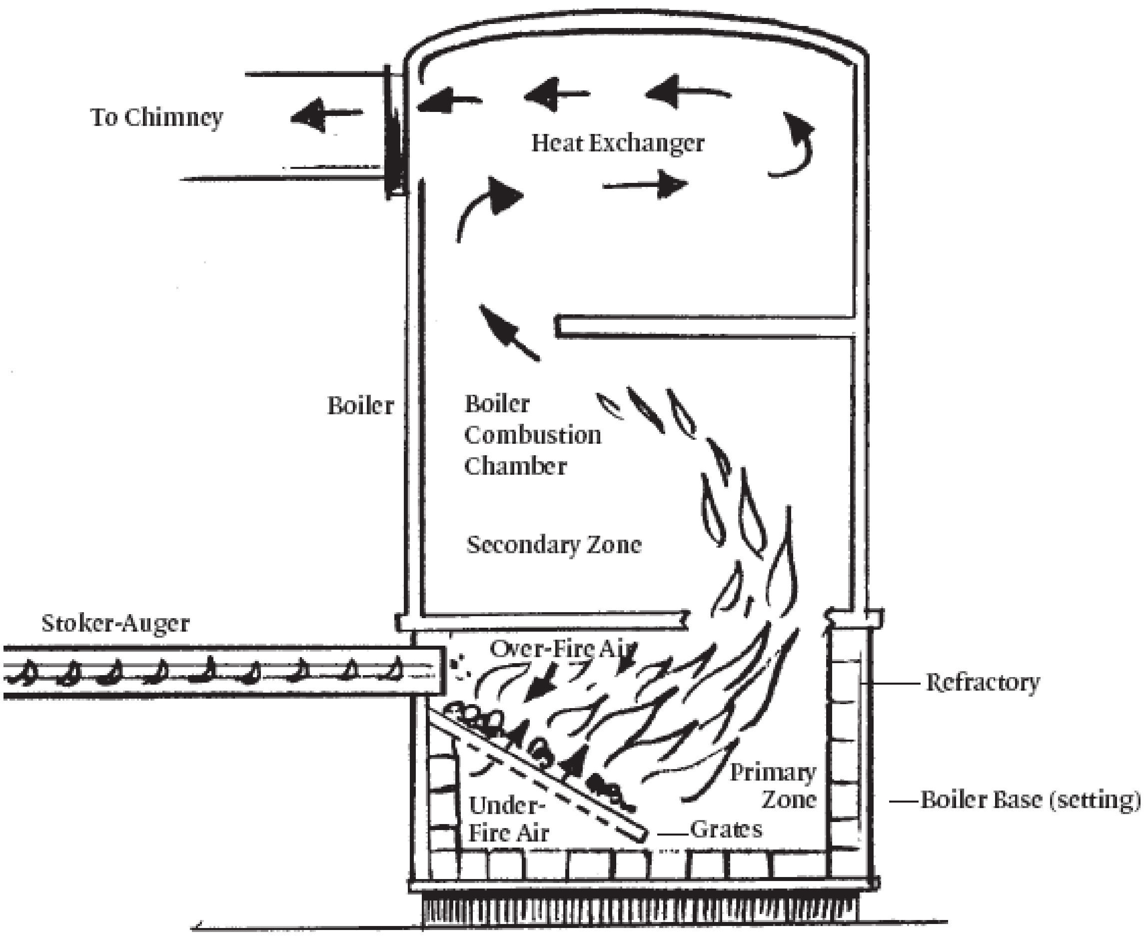


Figure 1. Direct-Burn Wood Boiler System

In some designs, the boiler is open to the combustion chamber, which sits above it. The hot gases rise up from the grate area into the combustion chamber, where combustion of the hot gases and solid combustible particles is completed. The hot exhaust gases then pass into the heat exchanger. When such systems are used to burn high moisture content wood, they can be prone to incomplete combustion which increases emissions of fine particles and toxic pollutants.

In other direct burn designs, there is a refractory baffle separating the primary and secondary combustion zones. The baffle is used to enclose the primary combustion area above the grates, thus increasing primary zone temperature and lengthening the flame path to give more time for the carbon in the hot gases to oxidize completely. This also burns better in low fuel load conditions. In general, these design changes can improve the likelihood of more complete combustion and, thus, lower emissions of fine particles and toxic pollutants.

In a mechanical forced-draft direct-burn system, however, unless the base and access doors of the boiler are effectively sealed, it can be difficult to limit the introduction of unintentional air to the combustion chamber. This can result in high excess air levels, decreased efficiency, and increased emissions of fine particles and toxic pollutants.

Direct-burn systems have a simpler design and may cost less than two-chamber boilers. If direct-burn systems are properly designed with effective combustion controls, they are capable of highly efficient combustion and reduced emission levels.

Two-Chamber Boiler

In two-chamber systems, a separate refractory lined combustion chamber sits next to the boiler, connected by a short horizontal passage or blast pipe that is also refractory-lined (Figure 2 and Photo 1). Hot gases from the combustor pass through the blast tube or directly into the combustion chamber of the boiler itself so that the boiler's combustion chamber becomes the secondary chamber of the combustion system.

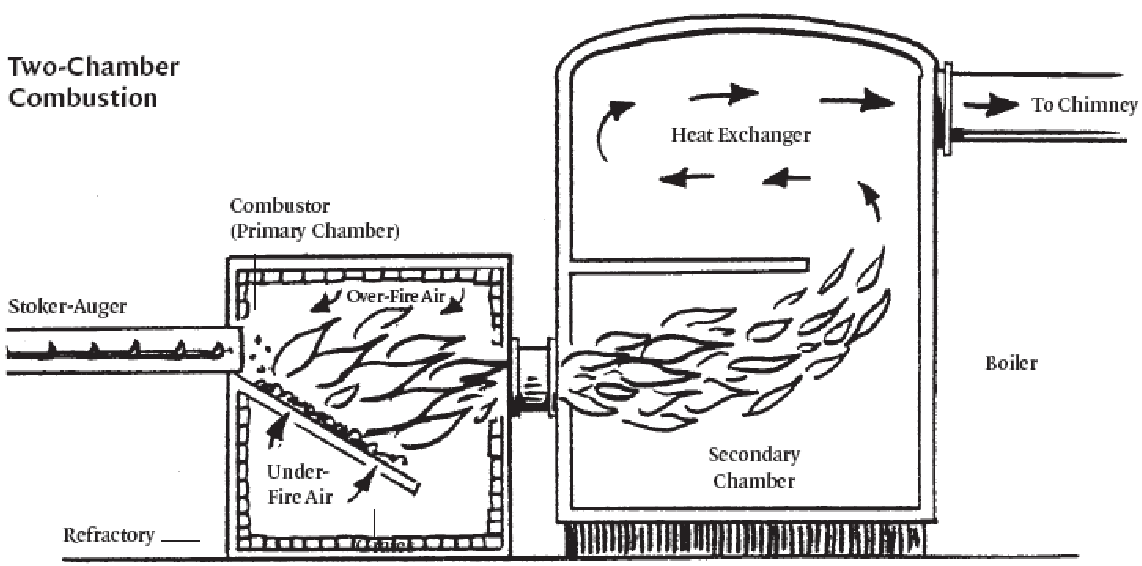


Figure 2. Two-chamber wood boiler system

Below is a photo of a 2.1 mmBtu/hour wood boiler with a two-chamber design. The small combustion chamber (box on left) is connected to the boiler (larger unit on the right) by a blast tube pipe.

Two-chamber systems have been used to burn both high-moisture and low-moisture biomass fuels and are frequently used with high-moisture fuels like green softwood. Because the boiler is typically more insulated and sized smaller in relation to the heat load, these systems may achieve and maintain high temperatures in the primary combustion zone even when the fuel has a moisture content of greater than 50 %.

The combustor of a two-chamber system is generally airtight to limit the amount of oxygen available for combustion. Excess air can cool the fire and reduce efficiency. Two-chamber systems are designed to prevent unintentional air or "tramp air" from entering the combustor with the fuel. The control of primary and secondary air and the elimination of tramp air allows control of combustion in the primary chamber.

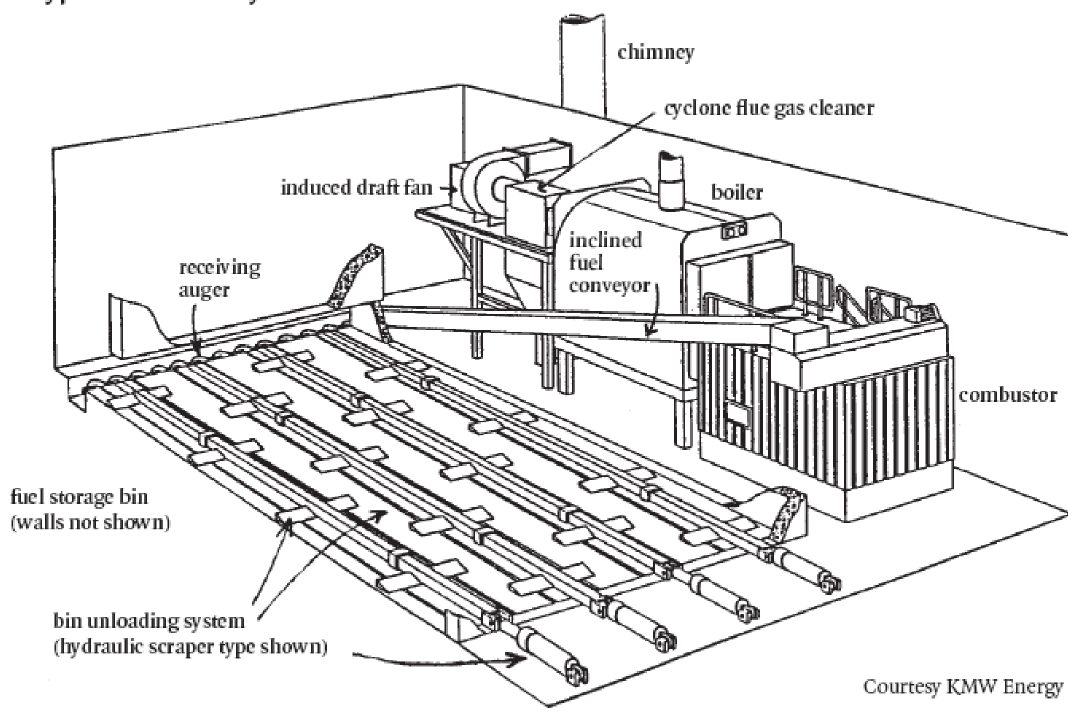
Regulation of boiler temperature is critical because sustained high gas temperatures are needed to achieve complete combustion. A potential advantage of two-chamber systems is that they can have longer flame paths, more turbulence (for mixing oxygen with combustible gases) and longer retention times of high-temperature gases. The longer the flame path and retention time, the more complete the combustion of the gasified fuel. This more efficient combustion reduces fine particle emissions and increases energy production.

Two-chamber systems that produce high gas temperatures in the secondary chamber need carefully matched heat exchangers to extract enough energy from the hot flue gases. If the heat exchanger is undersized, the stack temperature will be too high and excessive heat energy will go up the stack. This will reduce the system's efficiency and indirectly result in increased emissions due to the increased fuel use from the lower system efficiency.

A close-coupled gasifier is a type of two-chamber system where the combustion air in the primary chamber is restricted so that the wood gases produced are prevented from burning completely in the combustor. Final combustion air is added to the blast tube or the first chamber to increase turbulence and produce high gas temperatures entering the secondary chamber. Close-coupled gasifiers are characterized by lower primary combustion temperatures, a relative absence of visible flame in the primary chamber, and higher temperatures in the secondary chamber. A potential advantage of this technology over conventional boiler combustion is that by separating the gasification and combustion zones and using air injection to increase turbulence, fuel may dry more completely and burn more efficiently at higher temperatures resulting in lower levels of fine particles and toxic pollutants.

Below is an example of a typical biomass system.

A Typical Biomass System



Courtesy KMW Energy Systems

The Biomass Energy Resource Center (http://www.biomasscenter.org/) provided the majority of the technical information, including the diagrams and photos.

2) What steps should be taken prior to installing a boiler?

The first step is to contact the appropriate State or local air quality office to identify any regulations that apply. Depending on these regulations, the next steps are to identify the general design and operating features as outlined in Question #5 and to consult with candidate boiler vendors. For instance, it is important to maintain fuel quality by considering storage and handling early in the planning process. If an engineering firm is being used to construct the biomass facility, this firm may be able to coordinate purchasing, installation, operating, and maintenance activities.

3) What source test methods can be used to measure emissions?

Source tests may be performed to determine emission rates of pollutants from the boiler. Results of the source test may be used to meet air quality compliance or permit requirements, assess the boiler's wood combustion performance or determine control technology efficiency.

Selection of a test method depends on the pollutant of concern and compliance requirements. Table 1 presents EPA Reference Methods that may be used to determine emission rates for select pollutants. The Reference Methods are used to meet compliance with standards and maintenance requirements for permitted facilities. Other test methods are available to determine emission rates, but may not meet regulatory needs. It is important to consult with air quality regulatory agencies before installing a wood boiler because agencies may prescribe other specific source tests to obtain an operating permit or to meet other state or federal requirements. For more information on EPA test methods and full copies of the methods, see http://www.epa.gov/ttn/emc.

Table 1 EPA Methods for Determining Pollutant Emission Rates

Pollutant	EPA Method
Gas flow & properties, CO_2	1, 2, 3A, 4
PM2.5 / 10	OTM 27 / 28 [the future revised 201A / 202]
Total PM	5
NOx	7E
CO	10
Organic gases (e.g. VOCs)	25A
SOx	6C
Opacity/ Visible Emissions	9 / 22
Benzene	18
Speciated Hydrocarbons	23 low resolution or CARB 429 or EPA 0100 with SW-846 analysis
Chlorine & HCL	26 / 26A
Total speciated metals (silver, barium, beryllium, cadmium, chromium, copper, manganese, zinc, arsenic, nickel, lead,	29

selenium, potassium)	
Acrolein & Formaldehyde	CARB 430 or NCASI ISS/WP-A105.01

4) What are the different fuel types?

Although woody biomass fuel types can vary widely, there are two major categories of wood fuel used in small wood boilers. One is chipped, ground wood or wood residue, typically referred to as “wood chip fuel.” Terms like “clean chips” refer to wood without bark; “hogfuel” is a common term for ground wood that has bark and may also include needles. The other is a refined product “wood pellets”, which are made from sawdust, shavings or other wood residues. The pellets are dried to consistent moisture content whereas wood chips can vary from 15% to 50+% moisture content. Pellets also come in various grades which is a reflection of ash content. Woody biomass fuel types and the qualities of each can vary widely. The type of fuel can make a significant difference in the operation of your system which can influence the amount of emissions.

Wood chip fuel can be categorized by how it is produced. Mill residue can include sawdust, shavings, chips, and bark that are produced at mills while debarking logs and cutting them into boards. Post and pole peelings are the bark and outer layer of wood that are removed to make straight posts and poles for fencing. House log peelings are similar materials.

The tops and limbs and other unmarketable wood (such as dead, decaying or defective logs) that are removed during forest management activities of all types are generally referred to as “slash.” This material can be processed into wood fuel for boilers by chipping or grinding, but generally contains bark and some proportion of needles.

Wood pellets are made by reducing wood to sawdust or to very small, dry pieces of wood. This wood is then dried and extruded through a pellet machine, which uses pressure and heat to bind the material together and reduces the moisture content to 6-8%. Wood pellets come in four grades: 1) super premium, which contains less than 0.5% ash and less than 6% moisture content; 2) premium with less than 1.0% ash and less than 8% moisture content; 3) standard, which contains up to 2% ash; and 4) utility, which is commonly referred to as “all-tree” pellets with higher ash content, up to 6% and 10% moisture content.

Boiler controls are tuned for the type of wood fuel that is available for the facility. Air pollution levels are influenced by any changes in the type and quality of wood fuel, such as moisture, wood density, species, and size, unless adjustments are made in the boiler controls. Additionally, material with a higher content of forest slash (bark, needles, inorganic-crustal material) or a high moisture content (ranging from 40% to 55%, depending on the type of wood and how recently the wood was cut, stored and processed) may also influence air pollution levels.

5) What factors should be considered for selecting a woody biomass boiler?

An optimum wood boiler system is one that achieves high combustion and boiler efficiency, generates low levels of air pollution, requires minimal operator attention, and operates reliably. Selection of a direct-burn versus a two-chamber system depends on many factors, including the size of the unit, the type of wood fuel that will be used, the amount of monitoring and maintenance required, air quality considerations, and cost. The following factors should be considered depending on specific facility needs and requirements:

a) Wood boilers are most efficient when operating close to the design capacity of the facility. If the boiler operates significantly below its design capacity, then the wood may combust less efficiently, resulting in higher emissions. Another consideration is whether to use multiple boilers instead of a single boiler. Multiple boilers offer flexibility for routine maintenance shut-downs and repairs. For example, a parallel set of boilers may be practical in a facility with alternating periods of high and low demand and occasional periods of peak demand. Supplemental heating sources such as natural gas may also be used during periods of varying boiler demands.

To optimize pollutant control efficiency, the following are some of the boiler design characteristics to consider:

- Gasification and staged combustion (secondary and tertiary burn chambers) use separate burn chambers and paths for primary and secondary combustion. The boiler should be able to maintain about 1200° F in gasification chamber. Lower temperature gasification helps to reduce soot formation by reducing fuel rich, high temperature zones in flame. This also reduces ash-based particle formation.
- Pre-heating all combustion air.
- Insulated secondary combustion chamber.
- Ensure adequate residence time in secondary combustion chamber.
- Oxygen sensor or thermo-couples that automatically optimize air/fuel ratio.
- Forced combustion air supply to control firing rate.
- Integrated multicyclones in combination with a baghouse to reduce fire hazard.
- Ash drop-out systems in primary combustion chamber and automatic ash removal.

b) A computer-based combustion control system is critical to ensuring proper combustion. The control system receives its basic information from a data acquisition system which consists of computer hardware and related software. The system reads signals from various process monitors (temperature thermocouples, O_2 sensors, pressure gauges, and flow meters) and then adjusts the various process controls to maintain optimum operating conditions throughout the operating range.

c) Startup and shutdown emissions are a normal part of boiler operations. For most boilers, the period of emissions is relatively short during startup or shutdown compared to normal operations. However, emissions during this time may be considerably higher than during normal operations. To minimize pollutant emissions consideration should be given to effective startup and shutdown procedures. This is very important on peaking boiler units, as the number of startup and shutdown events may be more frequent.

d) Boiler cleaning and maintenance play key roles in boiler performance and a regular schedule should be considered. This includes periodic ash removal and disposal.

6) What are some technical issues associated with air pollution control technologies?

Technical issues vary depending on the kind of control device that is used with the boiler. Typically, these issues range from boiler heat input, exhaust flow rate, exhaust temperature, particle size and concentration. Table 2 summarizes, for each control device, annual maintenance and operating costs, availability, type of pollutants controlled, percent pollutant reduction, cost, and the level of technical and engineering expertise needed by an operator.

Table 2 Summary of Potential Particulate Matter Control Devices
(Reference NESCAUM **http://www.nescaum.org/**
http://www.nescaum.org/topics/commercial-wood-boilers)

Control	*Removal Effectiveness*	*Cost ($)**	*Comments*
Cyclone	PM_{10} - 50% $PM_{2.5}$ – 0 to10%	Installation* $7K-10K Lower maintenance*	• Easy to use & maintain; little space required • Inexpensive • Ineffective at removing fine PM and condensable PM • Performance level: 0.20-0.25 lb/mmBtu (depends on fuel) • Sensitivity to particle loading and flow rates • Creosote may condense on cyclone
Multicyclone	PM_{10} - 75% $PM_{2.5}$ – 0 to10%	Installation $10K-16K Lower maintenance	• Easy to use & maintain; little space required • Inexpensive, but higher cost than single cyclones • Create greater pressure drop than cyclones so need more fan energy to use • Ineffective at removing fine PM and condensable PM • Performance level: 0.20-0.25 lb/mmBtu (depends on fuel) • Sensitivity to particle loading and flow rates • Creosote may condense on cyclone
Core Separator (CS)	PM_{10} – >90% $PM_{2.5}$ – 40-60%	Installation $83K for 24inch CS $130K for 12inch CS Maintenance - Unknown	• Easy to use • Ineffective at removing condensable PM • Better capture efficiency than traditional cyclone tech • Range of performance on different boilers - 12-in CS manufacturer data: 0.07 lb/mmBtu 24-in CS manufacturer data: 0.11lb/mmBtu • Limited deployment; questions about availability • Lack of independent performance testing
Baghouse/ Fabric Filter/ Cyclone	PM_{10} – 99% $PM_{2.5}$ – 95-99%	Installation $85K-105K (10-15 mmBtu/hr unit	• Higher cost than ESP • Highly effective at removing fine PM & condensable PM • Collection performance can be monitored

		(including multicyclone and smaller boilers) Medium maintenance $10K	• Critical to combine baghouses with cyclones to reduce fire risk • High flue gas temperatures must be cooled • Anticipated performance: 0.025 lb/mmBtu per hr • Requires additional operator training and maintenance • Condensation of exhaust gases on bags may cause plugging • Need to replace bags regularly (e.g., every 2-3 years)
Electrostatic Precipitator (ESP)	PM_{10} – 90-99% $PM_{2.5}$ – 90-95%	Installation $90K-100K (1-5 mmBtu/hr units); $100K-175K (10 mmBtu/hr units) Lower maintenance $1K-2K	• Easy to use • Higher cost • Highly effective at removing fine PM • Ineffective at removing condensable PM • Exhaust moisture content is not an issue • Can be operated at high temperatures • Anticipated performance: 0.03 lb/mmBtu per hr • Power requirements & pressure drops lowest compared with othe high efficiency collectors • Units w/higher loading need more frequent maintenance • Requires operator training due to high voltage

* Notes:
1. Installed means the control device is operational. There may be additional costs based on specific state requirements. This does not include compliance monitoring.
2. Maintenance costs are annual.
3. All costs are based on vendor quotes for 2008.

7) Are there new or emerging technologies to consider?

Wood gasification has existed for well over 100 years but more refined techniques are being developed and show promise of being somewhat cleaner than traditional wood boiler systems. A true gasification system can convert woody biomass into a combustible gas, which is commonly referred to as a "producer gas" made from ambient air or "syngas" made with pure oxygen. Either wood-derived gas can then be used as a fuel in engines, gas turbines, boilers, generators, and many other applications. To run the gas through an engine requires further cleaning and thus filtration systems are also being developed that result in an even cleaner burning gas.

Many companies and developers are working in this area resulting in a rapidly changing market for these technologies. Currently, woody biomass gasifiers smaller than 10 mmBtu/hr are not yet commonly available in the United States; however, at least one 7 mmBtu/hr system was recently installed in Vancouver, British Columbia. Some smaller combined heat and power systems have been installed as demonstrations and information on the operation and maintenance costs and the fuel requirements are still being refined. They aren't commercially "off the shelf" available yet.

Some technologies with other control efficiencies may be available or used in various parts of the world. These include technologies such as high efficiency cyclones or European designs for scrubbers, panel bed filters, rotating particle separators, and flue gas condensation. As of March 2009, reliable information on these technologies was not available nor is it known when they will be commercially available in the United States.

8) What dispersion modeling tools are available?

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations. These air quality models are used to determine compliance with National Ambient Air Quality Standards (NAAQS), and other requirements such as New Source Review (NSR) and Prevention of Significant Deterioration (PSD) permitting programs. These models are addressed in Appendix A of EPA's **Guideline on Air Quality Models** (also published as Appendix W (PDF) of 40 CFR Part 51), which was originally published in April 1978 to provide consistency and equity in the use of modeling within the U.S. air quality management system. These guidelines are periodically revised to ensure that new model developments or expanded regulatory requirements are incorporated. For additional information on preferred/ recommended models, see **http://www.epa.gov/scram001/dispersionindex.htm**

9) How effective is a "tall stack" for controlling air pollution and avoiding plume downwash?

"Tall stacks" do not reduce air pollution. They are typically designed to disperse air emissions over a larger area downwind, with the goal of reducing the maximum ground-level concentrations. However, this reduction in maximum local concentrations may be at the cost of exposing more people over a larger area. In addition, during thermal inversions and other meteorological conditions, dispersion of the pollutants may not adequately reduce the peak concentrations.

Also, tall stacks do not always prevent “downwash” of pollutants (the tendency of emission plumes to bend towards the ground as the wind passes over or around nearby buildings). Good engineering practice (GEP) for tall stacks means that the stack height should be no taller than 2.5 times the height of nearby structures. Typically this height aids dispersion and reduces “downwash”. However, stacks that conform to GEP may not be high enough to overcome the low buoyancy of plumes or building downwash effects. The influence of aerodynamic downwash can result in very high ground-level impacts in the building cavity recirculation region immediately downwind of the building. This area of elevated concentrations could lead to exposure of nearby sensitive populations in some cases, and also raises concerns regarding indoor air pollution. The pollutants captured in the cavity may enter the building through doors, windows, and other building vents. Another issue of concern is the location of the facility and the potential for high concentrations on nearby terrain features such as depressions and valleys. Stagnation conditions may also be a concern in sheltered valley settings.

10) What kind of operator training is needed?

Boiler operators are responsible for ensuring that a boiler is continuously operated and maintained in a manner which complies with the applicable local, state and federal regulations. Thus, training should be provided that is appropriate for the type of boiler and air pollution control equipment. It should emphasize the operating parameters provided by the vendor that directly influence air emissions. Boiler operators need to have a good understanding of the effects of their actions on the air pollution emitted from the boiler. Periodic training on the operation of fuel, ash, and other auxiliary systems will ensure the health and safety of the both the operator and the users of the woody biomass system.

This document was prepared in collaboration with the following entities: USDA Forest Service; U.S. Environmental Protection Agency (OAQPS, Regions 1 and 8); Montana Department of Natural Resources; Washington Department of Ecology; North East States for Coordinated Air Use Management (NESCAUM).