1. CONTROLLING EMISSIONS FROM WOOD BOILERS

Currently, the use of emission controls on wood boilers is limited and has seen incremental forward movement, as compared with the advances used in Europe. The use of advanced boiler designs, as well as, the use of emission control devices such as ESPs and baghouses are commonly deployed in Europe on small wood boilers (units 1 million Btus and larger). However, in the United States the use of advanced emission controls devices is rare, and has generally been limited to the use of fabric filters. The lack of progress and market penetration for the development of control strategies can, in part, be attributed to the small market for controls for these systems, and the fact that, on the basis of a unit's size and annual output most units do not trigger state permitting thresholds for evaluating and applying LAER (Lowest Achievable Emission Rate) or BACT (Best Available Control Technology, notwithstanding the potential air quality and public health impacts from these boilers. The following attributes can influence emissions unit performance:

- Boiler design
- Combustion controls
- Boiler sizing and fluctuations in boiler load
- Fuel parameters, including moisture content, fuel type (e.g., chips or pellets), fuel size/fines, bark content and wood species
- Boiler optimization
- Boiler maintenance
- Operator expertise and automation of operating controls
- Use of pollution control devices

This section provides a review of techniques to source reduction measures and emission controls measures suitable for use on small- and medium-sized wood-fired boilers. Source reduction measures generally require modifying a process to reduce emissions. Control measures are typically applied after the combustion process.

This analysis does not incorporate the method of increasing stack height as an emission control since it is <u>not</u> considered as a method to reduce emissions. Increasing the height of stack will not reduce a given unit's emissions to the atmosphere, increasing stack height only aides in the dispersion of the pollutants emitted from these units. However, once all avenues to reduce emissions are exhausted, it may be necessary to increase stack height in order to reduce local exposure impacts.

1.1. Source Reduction Measures

This section provides an overview of techniques and strategies that affect emissions from wood combustion.

1.1.1. Boiler Design

To minimize emissions and obtain optimal combustion in the boiler, key factors that must be addressed include availability of oxygen, time, temperature, and turbulence. There is an optimum ratio of temperature, air and turbulence in boiler operations that minimize organic PM, NOx, and VOCs emissions in the flue gas will be minimized. One of the key source reduction measures to reduce emissions is the use of boilers designed for staged combustion and gasification. Typically, staged combustion units employ separate burn chambers and paths for primary and secondary combustion air. When staged combustion is employed, excess air varies in different sections and chambers. Lower temperature gasification helps reduce soot formation by reducing fuel rich, high temperature zones in flame, and results in reduced ash-based particle formation. To maximize benefits of staged combustion, accurate automated process controls are required to ensure operation at the appropriate air-to-fuel ratios required in each of the different zones.

Advanced boiler designs available in Europe

In Europe, computational fluid dynamics (CFD) have been applied to calculate boiler flow distributions and maximize combustion efficiencies all types of wood combustion units, from residential to commercial applications[1]. Common attributes of units that use advanced combustion techniques include:

- Staged combustion (air staging and combustion chambers)
- Pre-heating all combustion air
- Appropriate residence time in secondary combustion chamber
- Insulated secondary combustion chamber to help maintain high combustion temperatures
- Oxygen sensor and/or thermocouples and electronic controllers that automatically modulate air/fuel ratio
- Maintaining appropriate temperatures in gasification chambers
- Forced combustion air supply to control firing rate
- Computer aided analysis to optimize firebox design
- Integrated multicyclones
- Ash drop-out systems in primary combustion chamber and automatic ash removal
- Moving grate systems

In Europe, there are boilers greater than 500KW (1.7mmBtu) that have deployed advanced combustion design have total PM emissions ranging from 0.03 to 0.1 lb/mmBtu heat output with only the use of multicyclone technology.

Table 1-1 provides a comparison of U.S. and European boiler performance in terms of thermal efficiency and particle emissions.

[1] Baillifard, M.; Casartelli, E.; Nussbaumer, T.: Experimental Investigation of the Fluid Dynamics in Wood Combustion Processes. 16th European Biomass Conference and Exhibition, 2–6 June 2008, Valencia, Spain

Table 1-1 Comparison of Performance Levels among Small Commercial/Institutional Wood Boilers

Commercial boilers	Thermal Efficiency(%)	Particle emissions (lb/mmBtu)
U.S. conventional wood chip uncontrolled	70-75	~0.3-0.6
U.S. conventional wood chip*	70-75	0.2-0.25
U.S. conventional wood chip with ESP or bag house	70-75	0.03
European high efficiency and low emission chip (heat output)	85-90	0.06-0.1
European high efficiency and low emission chip or pellet w/ESP or bag house	85-90	0.002-.01

*System incorporates use of cyclone

1.1.2. Boiler Sizing

In Europe, sizing is considered a critical design component when employing clean burning equipment and the general approach is to maintain boiler operations at above 50 percent of capacity. Two primary concepts have evolved – base load and "ganging" of units. Base load means using the wood boiler as base load operation to cover the majority of the heating need, and then using oil or natural gas boilers during peak operations. This ensures that the boiler will be used at high load for long periods of time. Ganging involves using several smaller boilers to meet heating demand, or installing one large and one small boiler to provide flexibility in operations.

1.1.3. Fuel Parameters

Variability in the wood chip fuel properties can have an impact on the boiler operation and emissions. Changes in the wood fuel (moisture, wood density, species, and size) without adjustments in the boiler controls can result in increased emissions.[2] In cases where there are automated controls fuel variability may be less of an issue, if the boiler can automatically adjust fuel feed rates, oxygen flows, etc, to match the fuel variability. For systems that have less automation, including only a few pre-set options, optimizing performance for lowest emissions performance will be easier to accomplish with a tightly controlled, homogenous fuel. It would therefore be effective to establish detailed and tightly controlled fuel specifications for the facility. Fuel properties that should be considered in a fuel specification include:

[2] Discussions with boiler operators at Vermont schools

- Feed stock: natural wood, waste wood, or municipal residue
- Bark content: chips from debarked logs versus chips from bole tree or whole tree chipping. Stack test data and EPA's AP-42 emission factors indicate that wood chips containing bark will have higher emissions (for PM and air toxics) than debarked chips.
- Fuel composition: while the primary issue may be softwood versus hardwood, the facility should also consider wood density. Studies have indicated that wood with higher densities may have lower emissions.
- Moisture content: develop an appropriate moisture range
- Wood chip size: identify an appropriate chip size
  - Grossly oversized chips may create problems in the fuel feed system. This may cause the boiler to go off-line and result in higher emissions associated with the shutdown/startup process.
  - Excess fines may be of greater concern, as fines have different burning characteristics compared to typical "match-book"-sized wood chips

While some boilers are specifically designed to compensate for fuel variability, fuel specifications could address several of the variability issues and should be developed. In 1998, Europe developed specifications for biomass fuels using the European Committee for Standardization (CEN) process. CEN/TC 335 is the technical committee developing draft standards to describe all forms of solid biofuels within Europe, including wood chips, wood pellets and briquettes, logs, sawdust, and straw bales. These standards have been employed to create a consistent market specification. Currently, the CEN specifications for wood fuels include:

- Specifications for wood chips, including classification requirements for origin, size, moisture content, and ash content
- Technical standards for specified parameters to ensure a standard measurement method

1.1.4. Boiler Optimization

To minimize emissions and optimize efficiency, process monitors, such as those that monitor temperature, oxygen and carbon monoxide levels, can be installed and used with pre-defined schemes to ensure optimum operating parameters. These systems types allow automatic adjustments of air-to-fuel ratios, redistribution of combustion air between the primary, secondary and (possibly) tertiary combustion zones, and fuel feed rates for stable combustion. These types of controls have been retrofitted on existing wood chip boilers as part of pilot projects.

Boiler Maintenance

A key to minimizing emissions is proper boiler maintenance. Some systems in place today have automated ash removal systems. Such systems automatically remove ash from the primary and secondary burn areas. In addition, some systems pneumatically clean the boiler tubes. The pneumatic tube cleaning helps to minimize the soot buildup on the heat exchange surfaces of the boiler and therefore helps to maintain the optimum boiler efficiency. Continual ash removal and routine maintenance can ensure optimum performance and reduce ash entrainment since this increases PM emissions. In addition, maintenance should not overlook the seal between the fly ash collection device and its ash hopper. On these smaller systems, the hopper is typically a metal drum that must be periodically emptied and/or replaced with an empty drum. After changing out the drum, system operator must make sure there are no leaks where the collection drum is connected to the exhaust system. There is negative pressure in the exhaust system at this location and any air leaks will tend to re-entrain the fine PM

Operator Expertise

Boiler operations can be significantly influenced by the boiler operator. While automated systems can minimize some issues, inadequate operator training will likely compromise boiler availability, emissions, and efficiency.

1.2. Control Technologies

Control devices are technologies that are applied to the flue gas after completion of the combustion process. This section includes a review of PM and NOx control technologies.

1.2.1. PM Control Technologies

The particulate matter control technologies reviewed are summarized in

Table 1-2. They include:

- Cyclones
- Multicyclones
- Core Separators
- Cartridge filters
- Electrostatic precipitator (ESP)
- Fabric filters

Other devices, such as scrubbers, panel bed filters, flue gas condensation and rotating particle separators, are technically feasible but are not available in the United States at this time. Given the lack of availability in the United States, they were not evaluated, however, they are deployed in Europe on small- and medium-sized wood boilers. Should they become available, future work should be incorporate these technologies into the analysis. In addition, a high efficiency multicyclone has been deployed but stack testing data was not available at the time of publication of this report to determine the efficacy of this device.

Table 1-2 Summary of Potentially Applicable PM Control Devices

Control	*Removal Effectiveness*	*Cost ($)*	*Comments*
Cyclone	PM_{10} - Moderate control efficiency ~50 percent $PM_{2.5}$ – 0 to 10%	Installation *7-10K* Maintenance *minimal*	• Inexpensive • Ineffective at removing fine PM • Ineffective at removing gas phase PM (condensable PM)
Multicyclone	PM_{10} - Moderate control efficiency ~75 percent $PM_{2.5}$ – 0 to 10%	Installation *10-16K* Maintenance *minimal*	• Inexpensive • Ineffective at removing fine PM • Ineffective at removing gas phase PM (condensable PM)
Core Separator	PM_{10} – 98 percent and higher $PM_{2.5}$ – 98 percent and higher	Installation *83-130K* Maintenance *Unknown*	• Questions about availability • Questions regarding effectiveness
Baghouse / fabric filter	PM_{10} – 98 percent and higher $PM_{2.5}$ – 98 percent and higher	Installation *100K* Maintenance *10K*	• Higher cost • Highly effective at removing fine PM • Able to capture condensable PM
Electrostatic Precipitator	PM_{10} – 90 percent and higher $PM_{2.5}$ – 90 percent and higher	Installation *90-175K* Maintenance *1-2K*	• Higher cost • Highly effective at removing fine PM • Ineffective at removing gas phase PM (condensable PM)

Cyclones and Multicyclones

Cyclones and multicyclones are the most commonly deployed control technology in the United States. A cyclone removes particles based the principle of gravity and centrifugal force. Flue gases can flow into these devices either tangentially or in an axial direction. A multicyclone uses the same concept as a cyclone but employs multiple, smaller diameter cyclones to improve its capturing capacity. The particle control efficiency of both devices decreases as the particle size decreases and therefore do not adequately control $PM_{2.5.}$ While they may provide moderate control efficiency in capturing PM_{10}, their efficiencies for $PM_{2.5}$ are not adequate.

Performance

- Moderate control efficiency (50 – 75 percent) for large particles only
- Very poor control of fine fraction of particulate matter, estimated effectiveness of is 0-10%
- Will not reduce condensable PM emissions
- Low energy costs, however, energy costs are higher with multicyclones than single cyclones
- Performance level 0.20 to 0.25 lb/mmBtu depending on fuel used.

Performance will vary with the volume of exhaust gas treated. For a given cyclone design, as the exhaust volume is reduced (such as during periods of reduced boiler load), the centrifugal forces in the cyclone decreases and this results in lower control efficiencies.

Installation Costs

Cyclone	\$7,000 - \$10,000
Multicyclone	\$10,000 - \$16,000

Advantages

- Simple to use and maintain
- Low cost
- Little space required

Disadvantages

- Ineffective at removing fine particles
- Unlikely to remove condensable particulate matter
- Sensitivity to particle loading and flow rates
- Creosote may condense on cyclone
- Multicyclones create a greater pressure drop than cyclones and hence require more fan energy to use
- Not a good stand-alone control technology

Core Separator

The Core Separator technology[3] is based on the same physical principles as cyclones (i.e., differential inertia or velocities as a function of particle size). However, separation and collection of particles are accomplished discretely by two pieces of equipment: a Core Separator and a cyclone collector. The collection efficiency for large particles (above 2.5 microns) is similar to baghouses and ESPs (i.e., above 90 percent). For small particles (less than 2.5 microns), the control efficiency for modern Core Separators is approximately 60 percent.[4]

Easom Corporation provided NESCAUM a spreadsheet [5] that includes a summary of emission test reports for two designs of Core Separators: a 24-inch diameter and an advanced 12-inch diameter design. The Allard Lumber test report shows an average collection efficiency of approximately 60 percent and an average outlet particulate concentration of 0.069 lb/mmBtu. Cascade impactor measurements at the Core Separator inlet indicated that roughly 95 percent of the particle mass was smaller than 2.5 microns in size. It is therefore reasonable to assume that the collection efficiency for fine particles also approximates 60 percent. There are, however, other test results that may not support this assumption.

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[3] The Core Separator is a registered trademark of United Technologies.

[4] Personal communication, Bruce Easom, Easom Corporation, Groton, Mass Spring 2008

[5] The tests for Allard Lumber, which uses a Chiptek boiler, are public. The other tests are considered confidential, so plant names and test dates have been removed from the spreadsheet.

Based on its design principles, it is expected that the 12-inch unit will have higher collection efficiency than the 24-inch unit. Capital costs for the smaller Core Separator are approximately 60 percent higher than the larger unit. Currently, there are no complete data sets that characterize performance of the 12-inch diameter Core Separators operating downstream of a boiler burning clean wood chips. Such data would be useful for designing and applying a smaller diameter Core Separator system.

Performance

- Control efficiency for finer fraction estimated at 60 percent
- Unlikely to reduce condensable PM emissions
- Data available indicates a range of performance on different boilers
- Energy costs: unknown
- Performance levels:

  12-inch Core Separator manufacturer data indicates 0.07 lb/mmBtu
  24-inch Core Separator manufacturer data indicates 0.11lb/mmBtu

Installation Costs

- $130,000 for 12-inch Core Separator
- $83,000 for 24-inch Core Separator

Advantages

- Easy to use
- Better capture efficiency than traditional cyclone technology

Disadvantages

- Questions regarding efficacy for fine particles
- Effectiveness can vary when not properly matched with particle size distribution
- Lack of independent testing has led to questions regarding performance
- Questions about availability
- Limited deployment

Cartridge Filters/Collectors

Cartridge collector systems (also known as mini-baghouses) are modular units that can be interconnected to the stack. These units operate with a variety of cartridge types. They use Teflon or ceramic bags to capture particles, and may have high collection efficiencies. This type of system has been used in conjunction with other control devices. According to discussions with the manufacturer, however, due to high temperatures this technology is unlikely to work with the wood boiler flue gases. We therefore consider this technology technically infeasible at this time.

Electrostatic Precipitators (ESP)

In an ESP, particles are electrically charged and then exposed to an electric field in which they are attracted to an electrode. Periodically, this electrode is cleaned through vibration and the freed particles are directed into a collection unit. While ESPs have not been used in the U.S. on small wood-fired boilers, they have been used on other solid fuel devices. In Europe, ESPs are widely used in biomass applications. ESPs are used in applications as small as woodstoves but are more commonly applied in commercial and institutional boilers larger than 1 million Btus/per hour.[6] In many Northern European countries, new units over 1.7 mmBtu will be required to meet emission limits that require the use of an ESP. By 2012, all existing units must have ESP or equivalent controls.

Performance

- Greater than 90 percent capture efficiency is feasible
- Highly effective at capturing fine particles
- Low energy costs
- Anticipated performance 0.03 lb/mmBtu per hour

Installation Costs

- Capital cost to install European ESP in US: $90,000 – $100,000 for smaller units (1-5 mmBtu/hr) and up to $175,000 for 10 mmBtu/hr units.

Advantages

- High capture efficiency
- Effective in removing fine particles
- Exhaust moisture content is not an issue
- Power requirements and pressure drops are lowest when compared with other high efficiency collectors
- Easy to use
- Maintenance is nominal
- Can be operated at high temperatures

Disadvantages

- Dirtier boilers may require more maintenance
- Requires operator training due to high voltage issues
- Collection efficiencies will deteriorate if not properly maintained
- Unlikely to reduce condensable PM emissions

Fabric Filters/Cyclone Combination

Fabric filters and ESPs (wet and dry) have been widely used for controlling PM emissions from large combustion sources burning coal, wood, and oil. Virtually all large coal-fired electrical generating units (EGUs) in the U.S. have either fabric filters or ESPs with control efficiencies that can reach 99 percent or greater. Many of the EGUs are able to meet PM emission limits as low as 0.01 to 0.03 lb/mmBtu. Large wood-fired boilers (150 to 500 mmBtu/hr) and large coal and oil-fired industrial, commercial, and

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[6] Nussbaumer, Thomas. *Biomass Combustion in Europe: Overview of Technologies and Regulations: Final Report.* Prepared for the New York State Energy Research and Development Authority. Albany, NY, April 2008. Available at http://www.nyserda.org/programs/Environment/EMEP/Report%2008-03%20-%20Biomass%20Combustion%20in%20Europe-complete-after%20corrections.pdf

institutional (ICI) boilers are equipped with these devices and have PM control efficiencies of 99 percent or higher.

The concept of a fabric filter, or baghouse, is fairly simple. The filter is made up of cloth or woven specialty fibers. The flue gases are directed through the filter. The separation efficiency of bag filters is quite high. Because of their design (large surface area of bags and longer residence times in transit), fabric filters may capture a higher fraction of ultra-fine particles than ESPs. Due to the fire risk associated with the use of fabric filters, additional measures are required to run these devices on wood-fired boilers. Such measures include using a cyclone or multicyclone and periodically injecting a drying agent/flame retardant into the fabric filter.

NESCAUM has identified some installations of fabric filters with small wood-fired boilers:

- Two furniture plants in Canada have installed a fabric filter on a 350HP (approximately 16mmBtu heat input) wood boiler
- The Cooley Dickenson Hospital in Northampton, MA has a 600 HP (approximately 28 mmBtu heat input) wood boiler with a fabric filter and found that 16 – 20 oz (fabric weight) bags were required
- The Crotched Mountain Rehabilitation Center has installed a fabric filter to control the combined exhaust from an 8 and 4 mmBtu boiler for an aggregate output of 12 mmBtu .
- Mount Wachusett Community College in Gardner, MA has two boilers (a 10 mmBtu/hr boiler and a 4 mmBtu/hr boiler) controlled with a baghouse.

Description

- High capture efficiency
- Critical to combine bag houses with cyclones to reduce fire risks
- May require more operator training and maintenance than other control devices
- Low energy costs
- Likely to have higher operational costs than an ESP
- Anticipated performance 0.025 lb/mmBtu per hour

Installation Costs

- $85,000 to $105,000 for a 10 – 15 mmBtu/hr boiler (including a multicyclone)

Advantages

- High capture efficiency
- Collection performance can be monitored to assure capture effectiveness

Disadvantages

- High flue gas temperatures must be cooled
- Requires oversight and maintenance and may require knowledgeable operator to run properly
- Concerns with condensation of the moisture in the exhaust gas on the bags, causing them to become plugged

- Uncertain about how frequently bags need to be replaced; estimated to be every two to three years

Cost for PM Control Devices

It has been commonly assumed that installing advanced control devices is cost prohibitive. NESCAUM reviewed the costs of recent boiler installations funded by the State of Vermont. The review showed that the costs for these projects ranged from one to 2.5 million dollars. NESCAUM then compared these costs estimates with costs developed for a recently proposed project for a school in Vermont and the 2001 Resource Systems Group's BACT report[7], as shown in Table 1-2. This comparison shows that the feasibility determinations and costs contained in the BACT report are outdated, and the costs obtained by NESCAUM are consistent with the recent school analysis. It also indicates that advanced controls represent approximately four to 10 percent of total project costs. Analyzing costs based on the total project is appropriate for assessing impacts of the incremental cost of controls on heating costs. An analysis comparing the cost of controls to the boiler alone inflates the impact of controls on heating costs.[8]

Table 1-2 Comparison of Control Device Costs

Control	*Recent school analysis (2007 dollars) 8 mmBtu/hr*	*NESCAUM data (2008 dollars) 1-10mmbtu/hr*
Cyclones *Multicyclones*	$8,500 $14,000	$7,000-10,000 $10,000-16,000
Core Separator	NA	$83,000 - 24 inch $130,000– 12 inch
Fabric filter w/multicyclones	$93,500	$85,000-105,000
ESP	$97,000	$90,000-100,000 for 1-5mmBtu $175,000 for > 10mmBtu

[7] Resource Systems Group, Inc. An Evaluation of Air Pollution Control Technologies for Small Wood-fired Boilers, September 2001. This report can be found at: http://www.rsginc.com/pdf/R_Wood_Bact_Sept_2001.PDF

[8] Nussbaumer, T. *Particle Removal in Automated Wood Combustion Plants from 100KW to 2MW*. 15th European Biomass Conference and Exhibition, Berlin, May 2007.

1.2.2. CO Controls

Carbon Monoxide (CO) can be regarded as a good indicator of combustion quality.[9] EPA AP-42 rates emissions from these units at 0.6 lb/mmBtu. However, stack testing data indicates a high degree of variability in CO performance levels with results ranging from 0.0011 lb/mmBtu to 2.267lb/mmbtu. CO emissions can be reduced by avoiding intermittent boiler operations and/or through improved combustion process controls.[10] For a given system, CO emissions will be lowest at a specific air to fuel ratio, higher excess air will result in decreased combustion temperatures, while lower excess air will result in inadequate mixing conditions. It is critical that the introduction of air to reduce CO emissions is done accurately. Poor direction of air or introducing too much excess air may reduce CO emissions but PM emissions due to re-entrainment of fly ash.

1.2.3. NOx Controls

NOx emissions from wood burning come from two sources. One source is based on the nitrogen content of the wood, this is referred to as fuel based NOx. The amount of nitrogen in wood is highly variable. The second source is thermal NOx and the amount of emissions from this source is contingent on combustion conditions (temperature, available oxygen, residence time and turbulence) as well as the moisture content of the fuel. NOx emissions from the stack tests reviewed ranged from 0.11 pounds per mmBtu to 0.43 pounds per mmBtu with an average result of 0.20 pounds per mmBtu. The AP-42 emission factor for these units is 0.165 pounds per mmBtu, which is less than the average results for the boilers tested.

As with particulate matter controls, there are measures available for NOx abatement. Source reduction measures for NOx control mirror those for PM control. For control technologies, however, the most relevant techniques are selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR). These technologies have been used in several medium-sized units in Europe, however, NESCAUM was unable to identify any units under 30mmBtu utilizing these technologies in the United States.

Combustion control can reduce the amount of thermal NO_X formed. This could be achieved through the use of low temperatures in the gasification zone along with staged over-fire combustion air to limit the available oxygen and reduce peak flame temperatures. These same conditions can make it difficult to achieve complete combustion of the organic compounds in the wood gas. At this time we are not aware of any boiler designs for small biomass boiler that rely upon this technique to limit NO_X emissions.

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[9] Van Loo, Sjaak , et al. *The Handbook of Biomass Combustion and Cofiring.* Earthscan, London, England, 2008.

[10] Van Loo, Sjaak , et al. *The Handbook of Biomass Combustion and Cofiring.* Earthscan, London, England, 2008.

Selective Catalytic Reduction (SCR)

SCR is a process whereby ammonia vapor is injected into the flue gas which then passes through a catalyst bed that converts nitric oxide to free nitrogen and water. The ammonia can be anhydrous (99.5%) or aqueous (19% to 30% in solution) in form. The latter is significantly safer to handle and store than the anhydrous form.[11] The use of SCR is limited to larger biomass installation in North America and on units larger than 10 mmBtu in Europe. SCR is typically applied in the flue gas in a temperature range around 250°C to 450°C and enables a NOx reduction of up to 95 percent. However, relevant concentrations of undesired side products such as HNCO, N_2O, NH_3, HCN and others can be formed under unfavorable conditions. Hence, at this time given the potential negative impacts and the device costs, use of source reduction measures are preferable, if they can achieve sufficient emission reduction.

Selective Non-Catalytic Reduction (SNCR)

SNCR is a process where ammonia or urea is injected into the high temperature zone of the stack. The ammonia or urea reacts with the exhaust NOx to form nitrogen, water and in the case of urea, carbon dioxide.[12] SNCR has not been widely applied on wood-fired boilers in North America, however, in Europe they are being placed on units larger than 5mmBtu. Discussions with a European manufacturer revealed that they had recently installed five units in the size range of this report. They estimate that use of SNCR increased total project costs by thirty percent.[13]

SNCR has to be applied in a narrow temperature window around 820°C to 940°C that enables a NOx reduction of up to 90 percent. If the temperature is too low then the reaction is incomplete and ammonia slip occurs. SNCR systems are generally 50% to 60% effective at removing NOx. However, SNCR needs to be closely controlled which can be difficult in small wood combustion applications. As with SCR, undesired side products such as isocyanic acid, nitrous oxide, ammonia, hydrogen cyanide and others can be formed in certain conditions. Hence, at this time given the potential negative impacts and the device costs, use of source reduction measures are preferable, if they can achieve sufficient emission reduction.

Regenerative Selective Catalytic Reduction (RSCR)

Regenerative selective catalytic reduction (RSCR) is a selective catalytic reduction system that uses the same reagents and reaction chemistry to convert NOx into N2 and H2O as SCR systems. Optimum temperature for the chemical reaction to occur is at approximately 550 degrees F, but can occur between 350 F and 650 F. To achieve a sufficient chemical reaction rate at the designed operating temperature of the catalyst bed,

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[11] Resource Systems Group, Inc. An Evaluation of Air Pollution Control Technologies for Small Wood-fired Boilers, September 2001.
[12] Resource Systems Group, Inc. An Evaluation of Air Pollution Control Technologies for Small Wood-fired Boilers, September 2001.
[13] Conversations with representatives from Schmid in May 2008.

specifically formulated catalysts have to be used. The overall concept of an RSCR is to combine the heat recovery, temperature control, and catalyst elements into a single unit and to provide the maximum heat recovery for the chemical reactions to take place. RSCR has been used on several large wood chip boilers in the Northeast to reduce NOx emissions by an estimated 70%to meet a NOx emission levels less than 0.065lb/mmBtu. As with SCR, undesired side products such as isocyanic acid, nitrous oxide, ammonia, hydrogen cyanide and others can be formed under certain unfavorable conditions. Hence, at this time given the potential negative impacts and the device costs, use of source reduction measures are preferable, if they can achieve sufficient emission reduction.

1.3. Conclusions on Emission Reduction Strategies

- PM controls: There are several technically feasible combustion control options available for existing small- and medium-sized boiler that will reduce emissions below 0.10 lb/mmBtu per hour. In order to reach these emission levels boiler operations must be optimized and advanced emission control devices, such as fabric filters and ESPs, will need to be installed Based upon discussions with air quality regulators, it is likely that the advanced combustion control devices would also be deemed economically feasible as well.
- CO controls: There are no post combustion technologies available for these units, therefore boiler optimization is the best approach to minimize CO emissions
- NOx: While there are several technically feasible options available that would reduce NOx emissions from wood-chip boilers, the costs associated with these units are likely to deem them as economically infeasible at this time.