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New York State Wood Heat Report:

An Energy, Environmental, and Market Assessment

Final Report

April 2016

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New York State Wood Heat Report:

An Energy, Environmental, and Market Assessment

Final Report

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Notice

Abstract

A clean, high-efficiency wood-heat industry has great potential for growth in New York State (NYS). That potential includes promoting business opportunities and jobs while reducing reliance on imported fossil fuels that drain dollars from the State's economy. A sustainably managed thermal biomass, specifically wood heat, industry can also help support NYS climate mitigation efforts. Dependence on fossil fuel and rising energy costs, combined with the projected impacts of climate change, underscore the importance of increasing sustainable energy systems based on locally derived fuels. Today, NYS is the nation's second largest consumer of wood for heating, and its use is increasing rapidly. Between 2005 and 2012, the number of NYS homes using wood as the primary heating source grew about 60%. Wood smoke, however, is already the largest source of carbonaceous fine particulate matter in rural NYS counties, which can have serious health impacts. Furthermore, excessive smoke from inefficient devices often generates smoke nuisance complaints that pit neighbor against neighbor even in these relatively less-populated areas.

The goal of this report is to provide NYS with an analytically based framework to guide development of a viable wood heating industry and advance energy and environmental goals. The report evaluates critical technical, environmental, public health, economic, and policy issues related to development of a sustainable industry in NYS. It assesses potential wood feedstocks, their availability, combustion technologies, and the implications of feedstock and technology choices. It identifies critical actions to create a pathway that: (1) stimulates the necessary research, investments, and policies to build appropriate capacity; (2) maintains feedstock supplies; and (3) ensures public health and environmental protection. Given that the market for wood heat is growing regionally and nationally, a key objective is to provide information to help inform the regulatory community, industry, and consumers about options for cleaner and more efficient wood-burning technologies. The report will provide information for future stages of the Renewable Heat NY program, NYS's wood heat initiative that was launched in 2014.

Keywords

Wood heating, residential wood heating, institutional wood heating, commercial wood heating, oil heating, oil boiler, particulate matter, air quality modeling, economic analysis of wood heating, wood fuel supply

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Acronyms, Abbreviations, and Glossary

Bag house	A type of particulate removal device that removes particulates out of air or gas. Baghouses typically have a particulate collection efficiency of 99% or better, even when particle size is very small.
BATs	Best available technologies available commercially today
BAU	Business as usual technologies, typical installed units installed
Bole chips	Woodchips produced from the main stems or trunks of trees and includes bark
Btu	British thermal unit
CHP	Combined heat and power
Close-coupled gasifier	A boiler that produces combustible gases under controlled conditions in the primary combustion chamber or combustor, and burns the gases to produce heat in an adjacent chamber.
CO	Carbon monoxide
Combustion Efficiency	Ability to burn fuel measured by unburned fuel and excess air in the exhaust
Cyclone	A type of particulate control device that creates a dual vortex to separate coarse from fine dust. Cyclones typically have a particulate efficiency of 50-70% with wood-fired devices
Delivered efficiency	Overall efficiency of the boiler inclusive thermal efficiency of the heat exchanger, radiation and convection losses - output divided by input
Energy services company (ESCO)	A company that provides energy services to a building owner, typically including the financing and installation of energy improvements
ESP	Electrostatic precipitator – a highly efficient (typically 90% efficiency for fine particles) filtration device that removes fine particles, like dust and smoke, from a flowing gas using the force of an induced electrostatic charge minimally impeding the flow of gases through the unit
Gasification	The pyrolysis reaction in which heated biomass is converted to combustible gases in the primary combustion zone
Grates	Slotted or pinhole grates that support the burning fuel and allow air to pass up through the fuel bed from below
HAPs	hazardous air pollutants
Heat load	The demand for heat of a building at any one time, typically expressed in Btu/hour or million Btu/hour.
HHV	Higher heating value or gross calorific value- often but not always used to calculate efficiency values in U.S. wood technologies
ICI	industrial, commercial, and institutional
LHV	Lower heating value – lower calorific value of wood, used to calculate efficiency values in European wood technologies

Life-cycle cost analysis	A method of economic analysis that includes all costs associated with ownership. Includes price, installation, operation and maintenance costs and accounts for inflation over time and time-value of money.
Mill chips	Woodchips produced in a sawmill. Typically produced from slabwood, and debarked green saw logs
MBtu	thousand British thermal units
MMBtu	million British thermal units
Modulating fuel feed	A fuel feed system that adjusts fuel feeding rate up or down in response to heat load
Multi-cyclone	A particulate removal device that includes a number of cyclone separators
nBATs	best technology that is technically available but not commercially available, anticipated to be available by 2020
NOx	nitrogen oxides
On/off fuel feed	A fuel feed system that delivers fuel to the grates on an intermittent basis
Over-fire air	Combustion air supplied above the grates and fuel bed
Payback	A method of economic analysis in which cost effectiveness is based on installed cost and ownership savings. Also refers to the number of years it takes an improvement to pay back the investment
PM	particulate matter
Pyrolysis	The oxidation process by which solid wood is converted to intermediate combustible gases and combustible solids through a variety of thermochemical reactions
Seasonal efficiency	Efficiency of a heating system averaged over an entire heating season
Sensitivity analysis	Part of economic analysis used to determine how sensitive the results of the analysis are to changes in the input variables
Sizing	Process of specifying the size (measured in MMBtu/hour or MMBH) of a heating plant
SOx	Sulfur oxides – air pollutants implicated in acid rain caused by combustion of fossil fuels; modern wood systems have 1/6 the sulfur dioxide emissions of fuel oil
Stack temperature	The temperature of the combustion exhaust gases passing into the chimney
Suspension burning	A type of combustion in which fuel is blown into the combustion chamber, with some or all of the solid fuel particles burning in the air (in suspension)
Thermal efficiency	Effectiveness to transfer heat from the combustion process to the water or steam in the boiler, exclusive radiation and convection losses
Turn-down ratio	Range of rates that combustion can be achieved by a biomass burner. Calculated by dividing the maximum system output by the minimum system output.

Two-stage combustion	A combustion system in which the primary combustion furnace, or combustor, is separate from the boiler, with the two connected by a constricted opening or a blast tube. The boiler combustion chamber forms the secondary chamber
Under-fire air	Combustion air added under the grates
Volatiles	Fuel constituents capable of being converted to gases at fairly low temperatures
Whole-tree chips	Woodchips produced in the woods by feeding whole trees or tree stems into a mobile chipper

Summary

A clean, high-efficiency wood heat industry has significant potential for growth in New York State (NYS or the State). That potential includes promoting business opportunities and jobs in the thermal biomass and specifically, wood heating industry while reducing reliance on imported fossil fuels that drain dollars from the State's economy. A sustainably managed wood heat industry might also help support NYS climate mitigation efforts. Dependence on fossil fuel combined with the projected impacts of climate change, underscore the importance of increasing sustainable energy systems based on locally derived fuels. There are significant challenges, however, that need to be overcome with a move to biomass heating. Once installed, these units will operate for decades with little to no opportunities to improve efficiency or emissions performance. As NYS embarks on programs that encourage use of biomass as a renewable fuel for heating, policy options will be needed ensure that growth in this sector does not lead to future problems.

Today, NYS is the nation's second largest consumer of wood for heating, and its use is increasing rapidly. Between 2005 and 2012, the number of NYS homes using wood as the primary heating source grew about 60%. Although New York is a large segment of the wood heating market, in the overall thermal heating sector, wood heating currently provides less than 2% of NYS overall residential heating market and use in the industrial, commercial, and institutional (ICI) sector is insignificant. Although overall use for heating is low, this sector does have a significant impact on New York's air quality. Particulate matter emissions from wood heating operations – primarily residential – are larger than emissions from the transportation sector or all other heating fuels in the residential and ICI sector combined. Because it is already the largest source of carbonaceous fine particulate matter in rural NYS counties, it can have serious health impacts. Furthermore, excessive smoke from inefficient devices often generates smoke nuisance complaints that pit neighbor against neighbor even in these relatively less-populated areas.

This report provides an analytical framework to guide NYS in expanding the use of wood in heating applications, developing a viable industry and advancing energy and environmental goals. The report evaluates critical technical, environmental, public health, economic, and policy issues to inform its development. It assesses potential wood fuel feedstocks, their availability, biomass combustion technologies, and the implications of feedstock and technology choices. It identifies critical actions to create a pathway that: (1) stimulates the necessary research, investments, and policies to build appropriate capacity; (2) maintains feedstock supplies; and (3) ensures public health and environmental protection.

Given that the market for wood heat is growing, a key objective is to provide information to help inform the regulatory community, industry, and consumers about options for cleaner and more efficient wood-burning technologies.

The six elements of the report are summarized in the following sections:

- Wood heating markets and opportunities.
- Relative performance, cost, and availability of clean and efficient combustion technologies.
- Public health and environmental impacts associated with an expanded industry.
- Economic impacts of expanded wood use and the introduction of advanced technologies.
- Policy options for promoting the effective and efficient implementation of objectives.
- Future needs in pursuing objectives.

S.1 Wood Heating Markets and Opportunities

NYS is the second largest market for residential wood-burning devices in the country, and use of wood-burning devices continues to grow. The existing market for residential wood-burning devices is dominated by high-emitting, low efficiency devices that burn cordwood. The total number of units is greater in the New York City metropolitan area, but the percentage of regular use is much higher in Upstate areas. Wood heating in ICI applications is currently limited primarily to pellet and saw mills, and in a few schools and hospitals.

The cost-effectiveness of wood as a replacement fuel for home heating oil is highly dependent on the cost of home heating oil. Research suggests that in many installations, oil prices over $3 a gallon, combined with low wood prices, create conditions where wood can be competitive with oil as a replacement heating fuel. However, in some instances even with high oil prices, oil boilers may still be the most cost effective option in some situations because of low capital and installation costs. Analysis indicates that there is sufficient local wood supply for NYS to support increasing use of wood heating from 2% to approximately 5% of the State's total (current plus future) residential heating needs, assuming little growth in the ICI wood heating and biofuel production sectors.

More than 10 million tons of green wood are estimated to be available annually in NYS to support growth in the wood heating industry without impacting current wood uses. Of that amount, it is estimated that 5.25 million tons of green wood could be used for heating homes and businesses. Green wood is wood that has not been dried, or "seasoned" to reduce moisture content, which improves efficiency during combustion. Green wood is measured in green tons. By way of comparison, if a 5.25 million ton annual harvest level could be sustainably achieved, the volume would be capable of providing fuel feedstock for any one of the following three heating scenarios:

1. 437,500 homes using wood pellets (assuming 2 green tons of feedstock per 1 ton of wood pellets, and 6 tons of wood pellet use per home per year), representing 3.8% of NYS residential thermal heating needs. A similar number of homes could be heated using cordwood instead of pellets.
2. 10,500 schools or similarly sized community-scale facilities (assuming 500 green tons of wood used annually).
3. 262 college campuses or similarly sized district energy facilities (assuming 20,000 green tons of wood used annually).

It is unlikely, however, that wood heating markets alone can provide sufficient financial incentives for harvesting. Low-grade wood suitable for fuel use is typically obtained as a by-product of harvesting for high value products (sawlogs), forest management efforts, or when land is cleared for development.

S.2 Relative Performance, Cost, and Availability of Clean and Efficient Combustion Technologies

Efficiency and emission improvements in wood-burning devices are expected as a consequence of recently adopted federal emission standards in the United States and ongoing technology development efforts and policy initiatives in Europe. Oversizing, a common installation practice for all thermal systems, significantly reduces efficiency, increases emissions, and increases capital costs. The use of full thermal storage for residential central-heating cordwood units, as is common in Europe, leads to significantly improved performance.

Converting from oil and propane to wood heating can save consumers' money over time because of lower fuel costs when these petroleum fuel prices are high. Installing more advanced wood-burning units using "best available technology" yields greater lifetime cost savings due to higher efficiencies, lower maintenance costs, and significantly reduced emissions compared to current "business as usual" technologies.

Higher-efficiency, lower-emitting residential wood-burning units are recently available in the NYS market. A wider array of high performance units are commercially available in Europe but not yet marketed in the United States. Many of the cleanest and most efficient units are designed to burn wood pellets, a fuel market that is more mature in Europe than in the United States.

S.2.1 Public Health and Environmental Impacts Associated with Implementation

Wood combustion raises concerns from the public health community as this source category emits fine particulates at higher rates than liquid fuels such as propane and oil. Exposure to fine particulate matter in smoke can lead to increased risk for respiratory and cardiac mortality, lung function decrements, exacerbation of lung disease, lung cancer, and developmental and immunological effects. A large percentage of the general population (upwards of 50%) is susceptible to adverse health impacts as a result of acute and chronic fine particulate exposure, including children, asthmatics, persons with respiratory or heart disease, diabetics, and the elderly.

Although NYS meets federal fine particulate air quality standards as of March 2015, the air quality modeling of different wood devices analyzed in this report suggests that installation of some technologies have higher potential to degrade local air quality. This detail is of particular concern in areas with sensitive populations, such as people with cardiovascular and respiratory conditions at homes, schools, or hospitals, and illustrates the importance of proper installation with adequate controls and emission limits. The modeling results provide insight that otherwise is absent because air quality monitoring and stack testing are not typically performed at these types of installations and locations.

Air quality modeling indicates that where current conditions show elevated background air pollution levels, technology selection is of great importance; a single polluting, wood-burning boiler or stove can lead to pollution levels above health-based air quality standards in the immediate vicinity of the source. At the neighborhood level, modeling predicts that the choice of wood technology (and associated emissions) installed at a large institution (e.g., school) has a demonstrable effect on local air quality, especially in neighborhoods where wood burning is not already widespread. In neighborhoods where wood burning is already widespread, impacts from an institutional source can be exacerbated by the neighborhood impacts and vice-versa. The effect of change-outs (i.e. replacing older low-efficiency, high emission systems) in neighborhoods is noticeable, but results indicate that aggressive changeout regimes will be necessary to fully address potential problems.

The influence of surrounding terrain on dispersion of stack emissions is another key factor in the modeling analysis. The modeling results indicate that proper siting and stack design must go hand-in-hand, and that technologies must be designed to disperse smoke above trapping terrain features. For homes, terrain influences may dramatically increase concentrations, and adjustments to chimney design to improve dispersion may not be feasible. The “business as usual” wood technologies at institutional and residential settings had the highest potential adverse impacts on air quality, and in some modeled settings, certain technologies may produce unacceptable levels of fine particulates on an hourly, daily, or even annual timescale.

The most significant decision in controlling air impacts resulting from installation of a wood-fired heating unit is the choice of technology. Higher emissions from dirtier units may be mitigated through higher stacks, proper sizing, thermal storage, and improved fuel quality, but choosing a modern technology with advanced emission controls is likely the most effective strategy for reducing air impacts.

S.3 Economic Impacts of Expanded Wood Use and the Introduction of Advanced Technologies

For this report, a macroeconomic analysis was conducted for four statewide scenarios of future trends in the adoption of heating technologies. The analysis examined the local implications of converting conventional fuel oil heating equipment to advanced technology wood-heating devices using locally sourced wood fuel products (pellets, chips, and cordwood). Across all four scenarios, the regional economy would generate between 285 and 495 jobs[1] per year (not including numerous jobs related to feedstock supply), which translates into 5,000 to 10,000 jobs over a 20-year time frame. The largest driver of manufacturing sector economic impacts was the number of new wood-heating devices purchased by households and businesses and the associated manufacturing required to produce wood heating products. New pellet mill construction had a significant effect on outcomes. Depending on the scenario, between 509 and 849 million gallons of oil would be displaced over the 20-year time frame.

[1] Jobs include both temporary and permanent jobs.

S.4 Policy Options for Effectively Promoting Cleaner and More Efficient Biomass Industry

A review of state and federal rules indicates that the biomass industry has been primarily regulated through a patchwork approach. Currently, only a limited subset of residential devices and a few large ICI devices are subject to emission standards that reflect best performing equipment. In NYS, small ICI boilers and most residential devices are not subject to any emission standard. Emission standards for medium-sized units vary widely by state. Therefore, without further regulation, high-emitting, low-efficiency devices in ICI applications can be legally sold and installed in NYS. State environmental regulations and building codes do not cover all aspects of biomass installations that impact performance and emissions. To ensure best performance and emissions, systems using new technologies and standards must be properly sized and designed.

For both existing and new technology wood-burning devices, standardizing fuel and creating wood fuel specifications will lead to improved efficiency and emissions performance. In fact, low-emitting, high- efficiency devices will not work properly if used with mismatched fuels. Analysis of European regulations demonstrates that a comprehensive regulatory framework, combined with fuel standards matched to proper technology, can foster a robust, clean, wood-heating sector.

A comprehensive program that encourages consumers to choose high-efficiency, low-emission units can help NYS' wood heat market develop in a meaningful way. Well-designed incentives require standards be set to achieve improvements in efficiency, emissions, system sizing, and installation design; in other word, improvements that will help both consumers and the wood heat industry. Incentives alone do not move markets and the volatile nature of fuel prices (both fossil and wood prices) make it difficult to ensure long-term growth in this market. In the residential market, wood traditionally has been used for space (supplemental) heating rather than central (primary) heating. Use for supplemental heat means that users can fuel switch from year to year, which means wood use often trends with oil prices. Moving the market to primary heating might provide a key element to stabilize use and the market needs. Other necessary aspects of a multi-pronged program include assisting equipment manufacturers and fuel suppliers, training the design and installation workforce, providing outreach and training to energy auditors and code enforcement officers, supporting product certification and testing, updating building codes, providing targeted education and outreach to potential consumers, and supporting research and development that advances the technology while reducing manufacturing costs and improving air quality. Properly designed programs can also help address the significant emission issues surrounding the existing inventory of devices by encouraging the replacement of older low-efficiency and high-emitting devices.

S.5 Future Needs

To promote a robust market for cleaner and more efficient wood-burning devices in NYS, targeted education and outreach targeted to consumers will be integral so that they are better informed when considering the purchase, installation, and use of biomass units. General outreach and education is also beneficial, and can itself be a strategy for increasing the use of efficient biomass stoves and boiler. However, a targeted outreach and education strategy and plan tied to a specific policy or incentive program may produce greater results.

The education and outreach plan should be developed early in the planning process for any policy or incentive program, and should be adopted before the program is rolled out to the general public. This strategy will help maximize program benefits by combining the dissemination of information with clear opportunities for consumers.

Establishing a local presence through working with local organizations and individuals will be an important component for outreach and education in local communities. Relevant NYS agencies should partner with local municipal governments to design and execute an effective consumer education and outreach plan. Efforts should also include local groups, such as low-income assistance organizations, that have an understanding of local consumer needs, constraints, and market entry barriers. These organizations may also have established outreach and education platforms that are trusted by constituents. Involving consumers in the planning effort can help determine what will resonate with a larger audience.

In doing outreach, it is important to have clear messages, simple instructions, and streamlined administrative processes. The heating season is a heightened opportunity to increase education and outreach efforts when consumers are thinking about heating options.

Providing training for the proper installation of woody biomass units is also needed to develop a wood heat industry in NYS. To this end, NYS could establish minimum technical qualifications for installers, which could be tailored to the different types of units. This certification could be enforced through the establishment of a statewide registry and through NYS and local permitting and inspection practices. Consideration should be given to requiring NYS issued professional licenses.

NYS should expand training opportunities, such as NYSERDA's Renewable Heat NY (RHNY) training program, on the design and sizing of commercial systems and the integration of these systems with new or existing heating systems. Vocational schools, community colleges, and State universities may be interested in providing coursework on biomass heating units and systems as part of plumbing, HVAC, or other relevant programs. Schools may be able to certify installers, which could increase the number of installers who understand how critical it is to properly size biomass units for homes and businesses. Coursework offered by trade organizations, often for continuing education units (CEUs), is currently a major source of information transfer to consumers. By accepting biomass coursework for NYS-managed professional licenses, NYS could encourage the practice of offering CEUs for biomass boiler courses.

Efforts to improve technologies and fuels are another important element in boosting the growth of a wood heat industry. Manufacturers of wood heat units and suppliers of biomass fuels would benefit greatly from moving not only toward better technologies but also implementing best practices when designing, sizing, integrating, installing, and operating systems. The standard industry practice of oversizing heating systems does not work well for wood-fueled heating units as it can result in the heating unit mainly operating below its maximum performance level while leading to increased emissions. Adding thermal storage to wood-heating units can reduce the need for oversizing while improving system efficiency and lowering emissions, especially for units used for heating during spring and fall (shoulder season) months when load demand is not consistent. Furthermore, matching the appropriate fuel to the device is vital for ensuring clean, efficient operation.

S.6 Conclusion

For NYS to successfully grow its wood heat industry, it must proceed on a path that serves consumer needs and reduces fossil fuel consumption while protecting the public from adverse health impacts of wood smoke. Sustainable harvesting and efficient use of biomass fuels will also be necessary to justify wood burning as a credible climate mitigation measure. The long-term cost-effectiveness of a move to wood heating will be highly dependent on future prices of heating oil and wood.

Energy efficiency and environmental performance issues can be addressed, as they must be, if the NYS wood heat industry is to expand. Experience in Europe highlights the market growth and resource development opportunity that exists for wood heat through the development and promotion of clean and efficient combustion devices. Without improved efficiency and lowered emissions from wood-burning devices, the NYS market for wood heat is likely to remain limited primarily to rural and semi-rural locations.

Advanced technologies and appropriate fuel use coupled with proper installation, maintenance, and operation will be crucial to achieving a fuller measure of the NYS wood heat industry's potential. Tested and emerging policy options can help toward this end. Each of these options, however, has its own advantages and disadvantages that NYS must weigh in laying out a feasible approach to expanded biomass use. Ultimately, the path that NYS embarks upon will have long-term ramifications for the well-being of the State's citizens and environment.

1 Introduction

Renewable biomass resources can be used for heating in many settings, from residential to large-scale industrial applications. In the U.S., a wide selection of biomass thermal devices are available, ranging from highly polluting, inefficient technologies to cleaner-burning, highly efficient technologies. These devices can combust biomass feedstocks from a variety of agricultural and forestry sources. Growth of the renewable wood heat market presents an important opportunity for states to reduce dependence on imported fossil fuels and promote economic growth. However, a number of technology and regulatory issues should be carefully considered to eliminate or minimize long-term adverse impacts on the well-being of forests, air quality, and public health, and maximize the potential for local economic growth. This report is intended to provide information that will enable NYS to make policy choices that are informed by consideration of the impacts on public health, the well-being of the State's forests, and economic growth.

1.1 Purpose

This report assesses the current economic and regulatory framework for wood heating in NYS to assess different future scenarios for wood heating in the State. To understand the implications of different policy options, the Project Team assessed the current and future availability of potential wood fuel feedstocks and evaluated the performance characteristics of combustion technologies. From this analysis, the Project Team identified actions that would: (1) stimulate the necessary research, investments, and adoption of policies to build appropriate renewable wood heat capacity; (2) maintain feedstock supplies; and (3) ensure public health and environmental protection.

In particular, this report:

- Compares current and potential future wood-heating feedstocks and technologies to each other and to current and potential future fossil fuels in terms of trends, barriers, and policy trajectories.
- Assesses environmental and public health implications of wood heating options.
- Compares the environmental and public health impacts of wood heat with fossil-fuel heating options.
- Identifies best management practices to improve performance efficiency, reduce emissions, and promote sustainability, safety, and public health.
- Evaluates the commercial viability of wood-heating technologies, and the potential for job creation and other economic benefits to NYS.
- Delineates the need for additional research, workforce training, and public outreach.

- Analyzes policy options in the context of local, state, regional, national, and global events and markets.

This report gathered input from stakeholders through in-person meetings, webcasts and surveys, review of existing literature and data, and new economic and air quality modeling analyses. In addition, members of the Project Advisory Committee, which is comprised of experts from the public health and environmental field as well as experts from biomass technologies and markets, provided input on the various analyses.

The analysis was focused primarily on the use of woody biomass, although this report provides background information on other solid biomass heating fuels. The initial analysis concluded that heating technologies for utilization of other biomass sources are not fully developed nor have they been fully assessed for environmental impacts.

1.2 Report Structure

The report compiles information and analyses on the current use of wood heating technology and evaluates technical, environmental, public health, forest health, economic, and policy issues associated with the use of wood for heating. The report is divided into the following four parts:

- Part 1 focuses on research completed by the Project Team, including:
  - Market patterns and technology and fuel use trends (Chapter 2).
  - Regulations and policies affecting the biomass industry (Chapter 3).
  - Northeast incentive programs for biomass (Chapter 4).
  - Existing training framework for the biomass industry (Chapter 5).
  - Existing outreach and education initiatives to support growth of the market (Chapter 6).
- Part 2 details the information that was compiled for the technology and fuel analyses, including:
  - Fuel types and supply in NYS (Chapter 7).
  - Wood heating technology assessment (Chapter 8).
- Part 3 provides information on the analyses conducted by the Project Team, including:
  - Air Quality Impacts Analysis (Chapter 9).
  - Economic analysis (Chapter 10).
- Part 4 contains conclusions and recommendations based on the analysis in the preceding chapters, including:
  - Recommendations for best practices (Chapter 11).
  - Conclusions and recommendations for future NYS efforts related to wood heating efforts (Chapter 12).

1.3 NYSERDA Biomass Heat Programs

This report complements NYSERDA's considerable work on biomass heat-related efforts. Most recently, in Governor Andrew M. Cuomo announced in his 2014 State of the State address the launch of Renewable Heat NY, "a long-term commitment to help the high-efficiency and low-emission biomass heating industry reach scale." Through this program, New York State is pursuing a multi-pronged market development strategy to stimulate growth in a manner that will ultimately lead to a self-sufficient biomass heat industry. NYSERDA also has a Biomass Heat Research and Development program. Together, the programs support the following objectives:

- Increased installations of high-efficiency and low-emissions pellet-fired, and advanced cord wood boiler heating systems:
- A net reduction in particulate ($PM_{2.5}$) and carbon monoxide (CO) emissions through retirement of older inefficient systems and replacement with advanced technology heating systems, resulting in air quality and public health improvements in localized areas, entire valley communities, and perhaps regionally.
- A vibrant manufacturing base in New York for biomass heating equipment and fuel.
- Sufficient demand for bulk pellet fuel suppliers so they can invest in depots for storage and trucks for bulk delivery that will yield higher consumer (and potential investor) confidence and reduce delivered pellet fuel prices.
- A well-trained heating system design and installation workforce with sufficient demand for services, along with knowledgeable energy auditors and code enforcement officers, to promote properly sized and safe installations, reduced component failure, lower system design, installation, and O&M costs, and increased system longevity.
- Advances in heating system components, emissions control technology development, and wood biomass processing that will drive down $PM_{2.5}$ and CO emissions.
- Product certification, testing, and manufacturing automation to reduce production costs of advanced heating system components and emissions controls technologies.
- Animated financial markets offering reasonably priced financing alternatives to support continued, sustainable growth of the industry absent direct incentives.
- Health and safety studies and long-term monitoring and characterization of wood smoke to track health effects due to combustion by-products, and chart progress in improving air quality in rural communities.
- Evaluation of various feedstocks (wood pellets, cordwood, grass, wood chips) and physical/chemical composition to identify clean, low-emission fuels.

2 Patterns and Trends

This chapter provides recent market conditions related to wood heating applications for NYS' residential and industrial, commercial and institutional (ICI) sectors to gain an understanding of the current deployment of different fossil fuels and the environmental impact of woody biomass compared to those other fuels.

2.1 Methodology

The most recent comprehensive data available was compiled for various residential and commercial space heating applications. Obtaining data for the residential market was difficult as there are only a few recent estimates of existing residential installations of wood burning equipment, and all of them come with questions regarding accuracy. Obtaining data for the ICI sector also proved challenging. Limited data exist on ICI units sized 1 to 10 million British thermal units (MMBtu), and data for units less than 1 MMBtu were largely lacking. To the extent possible, the limitations of the analysis were highlighted based on the limitations of the underlying data.

The following data resources were used to compile information on the residential sector:

- **U.S. Energy Information Administration (EIA) -** Nationwide energy use information, publically available on the EIA website (www.eia.gov).
- **Residential Wood Combustion Tool -** The U.S. Environmental Protection Agency (USEPA) estimates residential wood combustion emissions using its Residential Wood Combustion (RWC) Tool for the National Emissions Inventory (NEI). As part of the process for developing the NEI every three years, state environmental agencies are given an opportunity to review, comment, and provide supplementary data for the estimates USEPA generated using the RWC Tool. The RWC Tool is a relational database tool built on a Microsoft Access framework that relies on estimates of annual activity, emission factors, and control factors to generate emissions for each county in the United States. The RWC Tool enlisted data from the American Housing Survey, U.S. Census, the Mid-Atlantic/Northeast Visibility Union (MANE-VU), and appliance sales data from various sources to estimate the number of wood-heating devices in NYS homes. Calculation of burn rates and emissions profiles are also discussed in these technical documents. The estimates for installations and emissions from the RWC Tool are, however, inexact. These estimates represent average emissions according to regional profiles of unit installations, burn rates, fuel quality assumptions, and control equipment.
- **Sales Data -** Domestic sales data of wood-burning devices are publicly available from the industry's trade group Hearth, Patio & Barbecue Association (HPBA). Information about data collection methodology is not available on the group's website. Data are available for equipment shipped from 1998 through 2012.

The following data resources were used to compile information on the ICI sector:

- **U.S. Energy Information Administration (EIA) -** Nationwide energy use information, which is publically available on the EIA website (www.eia.gov).
- **New York State Permitting Database -** Staff from the Division of Air Resources of the NYS Department of Environmental Conservation provided NESCAUM with information from an internal permitting database. This included information on ICI boilers that have obtained a State Facility permit or a Title V permit, as well as a limited number of sources that have permit registrations. Note that this information largely does not include boilers less than 10 MMBtu per hour burning fuels other than coal or wood, as those sources are considered exempt activities per NYCRR Part 201.
- **New York Oil and Propane Database -** This subset of a database from the USEPA Area Source Boiler inventory database was last updated in April 2010. It includes ICI boilers that are 100,000 Btu and larger. Visit http://www.epa.gov/ttn/atw/boiler/boilerpg.html for additional information.
- **Oak Ridge National Laboratory Report -** Information was used from the "Characterization of the U.S. Industrial/Commercial Boiler Population" report, submitted to Oak Ridge National Laboratory in May 2005 and written by Energy and Environmental Analysis, Inc. Visit http://energy.gov/sites/prod/files/2013/11/f4/characterization_industrial_commerical_boiler_population.pdf to find this report.

2.2 Residential Heating in New York State

In contrast to other areas of the United States, oil is the primary fuel used for residential heating in the Northeast and in particular, New York State. According to the EIA, NYS uses 1.8 billion gallons of No. 2 heating oil (distillate) each year,[2] much of it for residential heating. At the same time, use of wood heat in residential applications is increasing. Approximately one million wood-burning devices utilized for generation of heat are currently installed in homes across NYS. These units provide primary (main) heating, secondary heating, and recreational heating to homes.

Fuels used for heating homes in New York have waxed and waned in popularity over the years. In the 1940s, coal was the predominant residential heating fuel in NYS. In the 1950s, there was a shift to heating oil, and the current shift is to natural gas. The percentage of NYS homes heated with fuel oil peaked around 1960 at 65.2%. At that time, only 22.8% of NYS homes were heated with natural gas. In 2010,

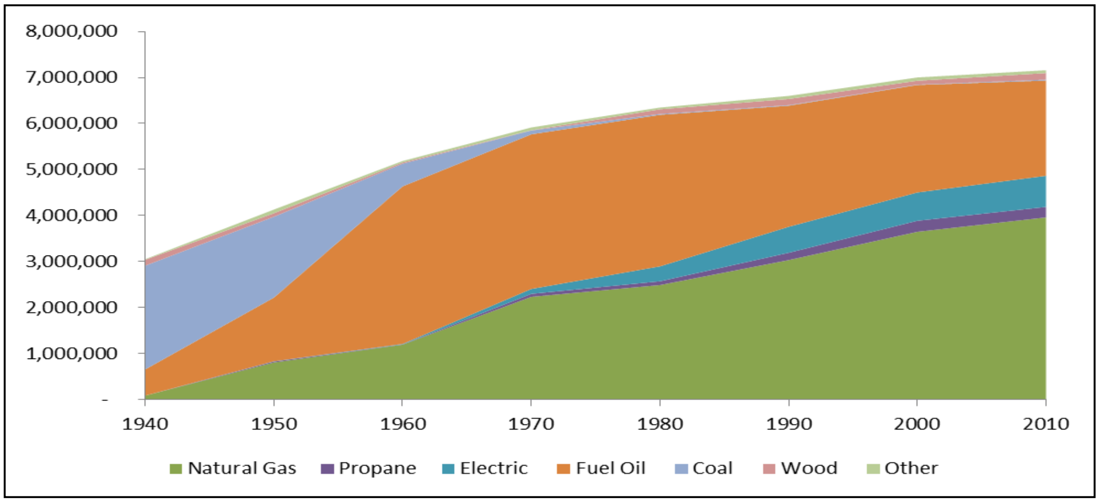
natural gas was the primary heating fuel in 55.0% of NYS homes; use of fuel oil had dropped to 28.7%. The percentage of homes heated by electricity rose from a negligible amount to 9.4% in 2010. Growth

[2] New York Biomass Energy Alliance, http://www.newyorkbiomass.org/default.aspx?PageID=3449

in the number of homes heated primarily by propane has been limited, increasing from 1.1% in 1970 to 3.2% in 2010. Residential heating trends in NYS are depicted in Figure 2-1.

Figure 2-1. Primary Heating Fuels in New York State Homes 1940-2010

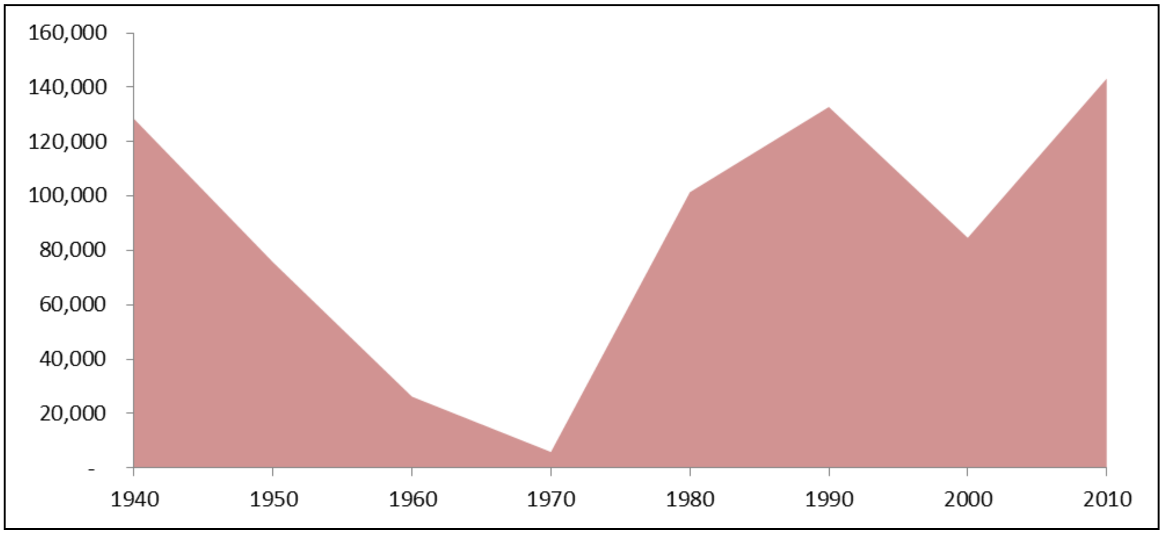
Source: US Census 2010, 2011



This shift in use patterns applies to wood heating as well. The percentage of homes heated with wood declined dramatically in the 1940s and fell to nearly zero in 1970. Since the 1970s, however, use of wood has steadily increased and the number of homes heating with wood now exceeds the previous peak in the 1940s. Figure 2-2 shows the number of homes in the State heated primarily by wood during the period from 1940 through 2010.

Figure 2-2. Homes Heated Primarily with Wood in New York State 1940-2010

Source: US Census 2010, 2011



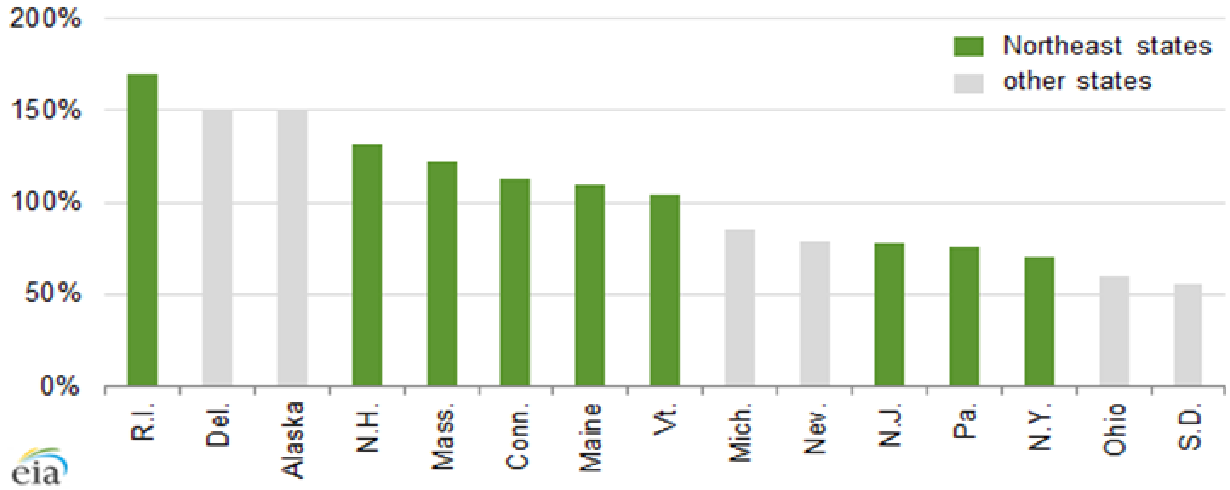
The number of homes heating with wood continues to grow at a significant rate. Between 2005 and 2012, NYS experienced a 60% increase in the number of homes using wood as the primary heating fuel, as shown in Figure 2-2. This trend is not unique to NYS. The entire Northeast region has experienced significant growth in wood heat in recent years.

Figure 2-3 depicts increases in residential use of wood in Northeast states. The increases range from 60% to 160%.[3]

[3] EIA, Energy Today, *Increase in Wood Heating Most Notable in the Northeast* (March 17, 2014), http://www.eia.gov/todayinenergy/detail.cfm?id=15431.

Figure 2-3. States with the Highest Percentage Increase in Wood Home Heating (2005-2012) Using Wood as their Primary Heating Source.

Source: U.S. Census Bureau, 2005 and 2012 American Community Survey.



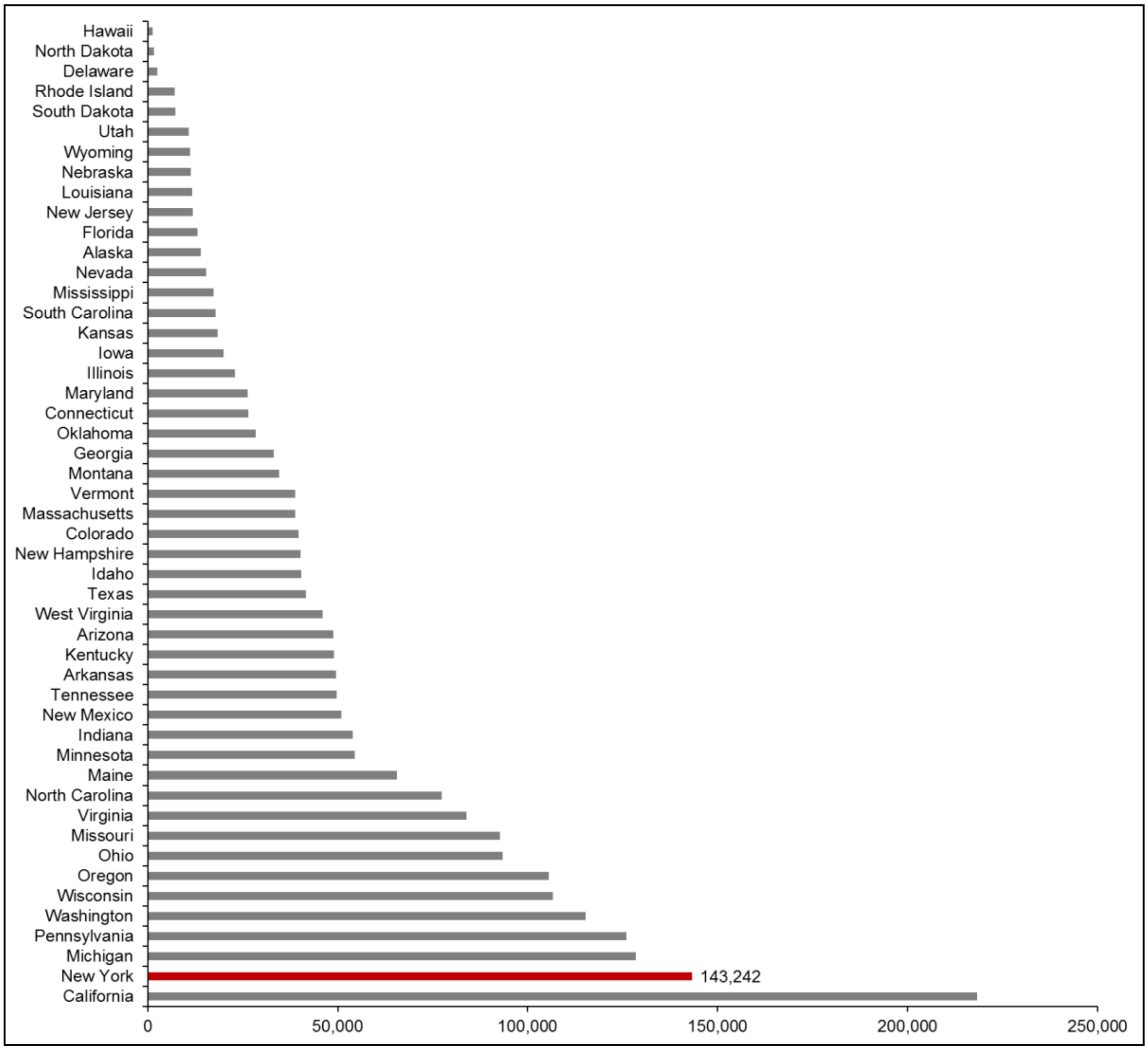
Only California exceeds NYS in the total number of homes using wood as the primary heating fuel. A state-by-state summary of wood consumption for residential use is in Figure 2-4 Approximately 2.0% of NYS homes (143,342 NYS households) are heated with wood, significantly less than some other nearby states in proportion to the number of households, notably Vermont (15.1%), Maine (12.0%), and New Hampshire (7.8%). NYS' unique character, however, being home to both densely urban and distinctly rural areas, makes per household comparisons against more rural states less meaningful.

The increased use of wood for home heating depicted in does not correspond to other data showing lower national sales figures for new residential wood burning devices. This could mean new sales are concentrated in the Northeast, units being put in place are being purchased on the secondary (used) market, or that existing units are being used more heavily. While 143,342 NYS homes use wood for primary heat, an additional 500,000 NYS homes use wood for supplemental heat. Increased use by these units could account for a portion of the increase in wood fuel, but there are no data to support this hypothesis.

Figure 2-4. Total Number of Households Using Wood for Heating, Ranked by State

No data available for Alabama.

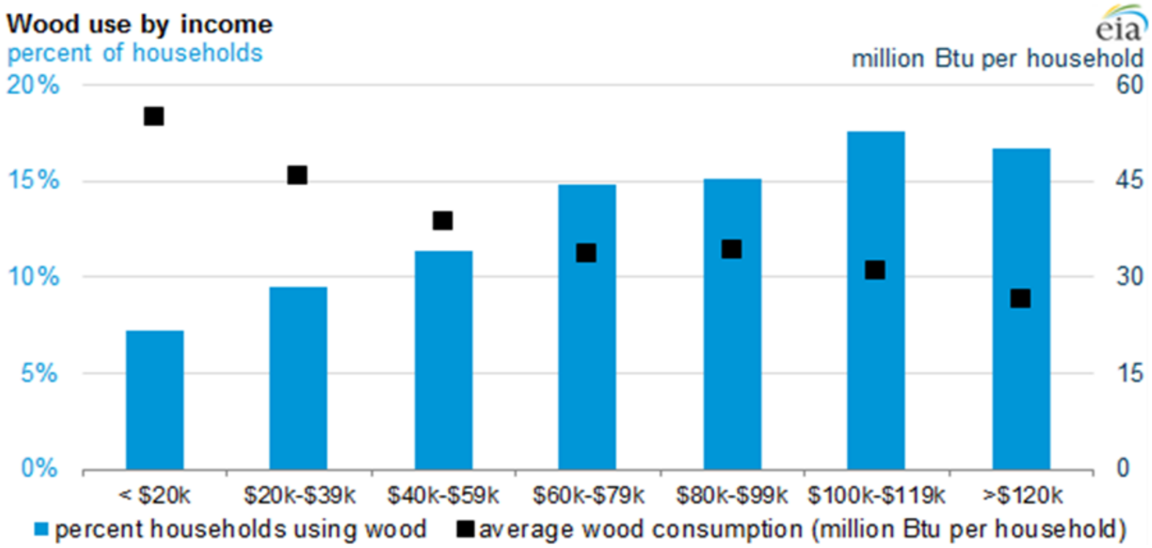
Source: US Census 2010.



Conventional wisdom often assumes that wood is predominantly used for home heating by lower income households. EIA data shown in Figure 2-5, however, indicate that higher income households are more likely to own and use a wood-burning device, while lower income families are more likely to burn larger amounts of wood. This trend may be due to a number of reasons, including use of less efficient devices, lower quality housing that may be poorly insulated, or heavier reliance on wood for primary heating.

Figure 2-5. Use of Wood Heating Appliances by Income

Source: U.S. Energy Information Administration, 2009 Residential Energy Consumption Survey



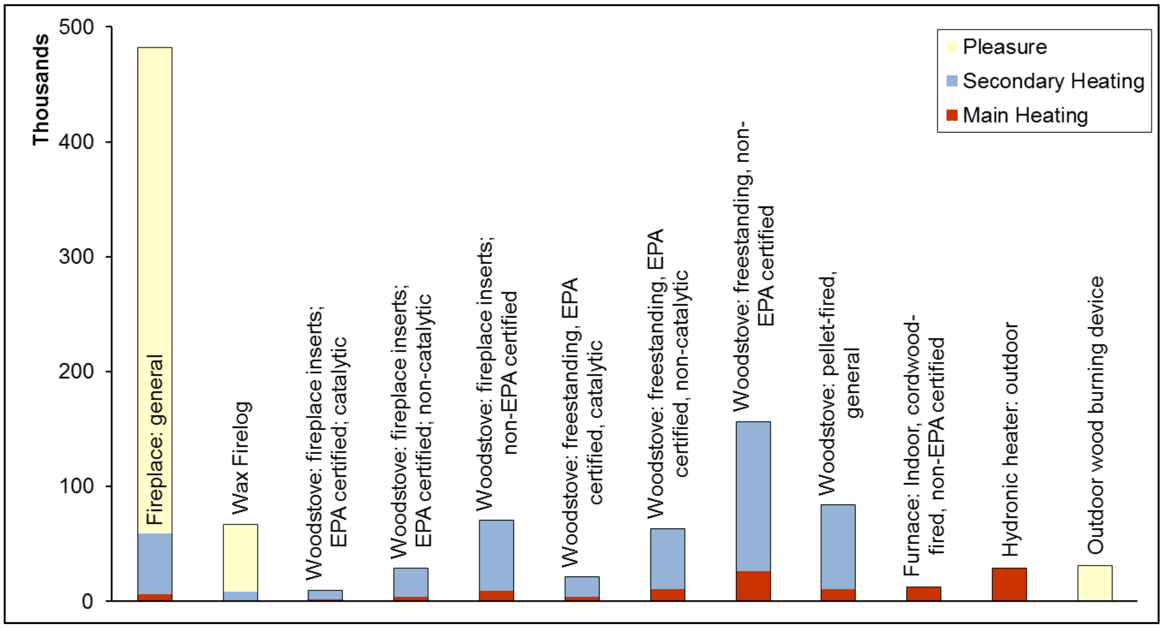
2.2.1 Current Inventory

Woodstoves and fireplaces dominate the current NYS inventory of wood-burning devices. In 2011, there were approximately 549,000 fireplace installations in the State, of which approximately 88% were used for pleasure heating. Woodstoves—including fireplace inserts as well as freestanding and pellet-fired woodstoves—account for an additional 433,000 units. Of that number, approximately 224,000 devices are uncertified either because they are exempt from regulations or were manufactured prior to 1988. Woodstoves and fireplace inserts are typically used for secondary heating (85%), and to a lesser extent, as the primary heating source (15%).

In addition to woodstoves and fireplaces, there are approximately 84,000 pellet units, 30,000 uncertified hydronic heaters (i.e., outdoor wood-fired boilers [OWBs] used as a primary heating device), 12,000 uncertified cordwood-fired furnaces (used for primary heating), and 31,000 other wood-burning thermal devices (e.g., fire pits, chimneys). Units intended for aesthetic or decorative purposes consume much less wood than do units that provide primary or secondary heating. For this reason, it is useful to assess not only the number and type of unit installations across the State, but also their intended use. Figure 2-6 depicts statewide wood-burning devices by technology type. The underlying data are presented in Table 2-1.

Figure 2-6. Residential Wood Burning Equipment by Technology Type in New York State in 2011

Source: USEPA 2012



The mass of wood burned in each type of device reflects the unit's use profile. For instance, devices generally used for pleasure heating (i.e., fireplaces and outdoor wood burning) consume less wood than units used for primary and secondary heating, even though they may be less efficient. Device efficiency strongly correlates with wood consumption. Because less efficient units consume more wood to achieve the same heat output as more efficient units, devices that are not certified as fuel-efficient by USEPA consume more wood for a given heat output than those that are. In addition, non-certified devices are more prevalent in NYS than certified devices, and thus use a much greater share of wood burned for residential heating than do certified units (see Figure 2-7 and the supporting data in Table 2-1). As seen in Figure 2-7, a relatively small number of devices (25%) burned the majority of wood (60%) at NYS residences in 2011, with non-USEPA certified woodstoves accounting for 38% of wood burning, OWBs for 17%, and furnaces for 6%.

Figure 2-7. Wood Mass Burned by Equipment Type in New York State in 2011

Source: USEPA 2012.

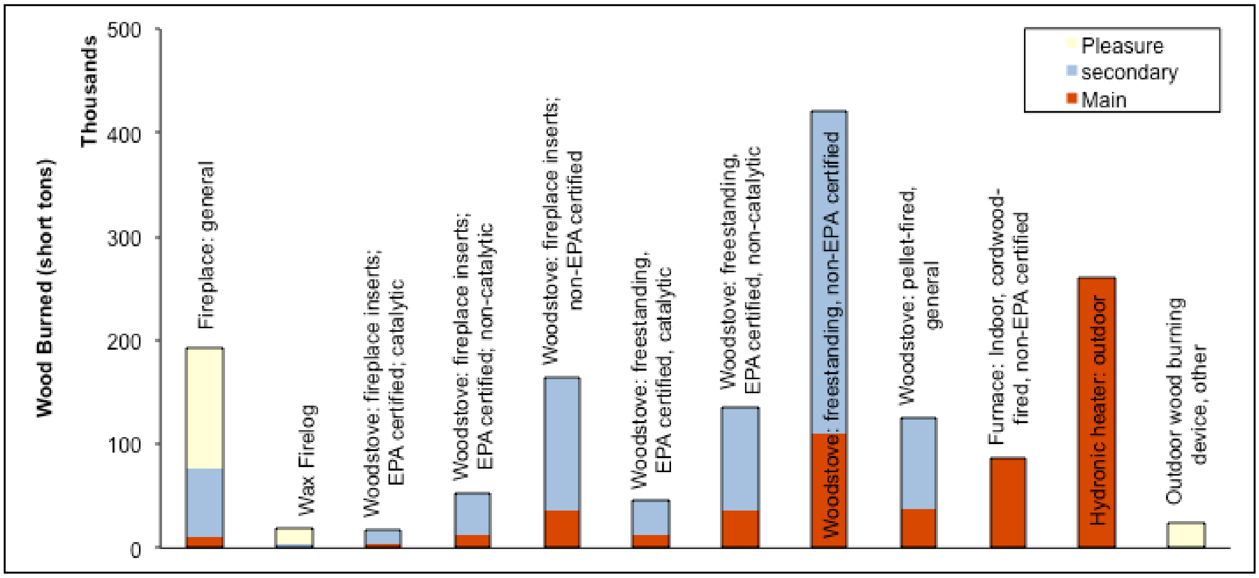


Table 2-1. Residential Wood Burning Equipment and Mass of Wood Burned by Technology Type in New York State in 2011

Source: USEPA 2012

Equipment Type	Number of Devices	Wood Mass Burned (tons)
Fireplaces	**548,585**	**212,118**
General	482,040	192,400
Main	*6,329*	*10,192*
Secondary	*52,359*	*66,505*
Pleasure	*423,352*	*115,703*
Wax fire log	66,545	19,718
Secondary	*8,169*	*4,667*
Pleasure	*58,376*	*15,051*
Woodstoves	**433,026**	**964,199**
Fireplace inserts; USEPA certified; catalytic	9,584	17,902
Main	*1,286*	*4,105*
Secondary	*8,298*	*13,798*
Fireplace inserts; USEPA certified; non-catalytic	28,507	52,956
Main	*3,664*	*11,701*
Secondary	*24,843*	*41,255*
Fireplace inserts; non-USEPA certified	70,476	164,472
Main	*9,151*	*36,551*
Secondary	*61,325*	*127,921*
Freestanding, USEPA certified, catalytic	21,171	45,622
Main	*3,581*	*12,096*
Secondary	*17,590*	*33,526*

Table 2-1 continued

Equipment Type	Number of Devices	Wood Mass Burned (tons)
Freestanding, USEPA certified, non-catalytic	63,182	135,880
Main	*10,544*	*35,659*
Secondary	*52,638*	*100,221*
Freestanding, non-USEPA certified	156,303	421,469
Main	*25,990*	*110,319*
Secondary	*130,313*	*311,149*
Pellet-fired, general	83,803	125,898
Main	*10,239*	*38,150*
Secondary	*73,564*	*87,748*
Other	**72,137**	**372,338**
Furnace: Indoor, cordwood-fired, non-USEPA certified – *Main*	12,272	87,199
Hydronic heater: outdoor – *Main*	28,626	261,172
Outdoor wood burning device – *Pleasure*	31,239	23,966
TOTAL	**1,053,748**	**1,548,655**

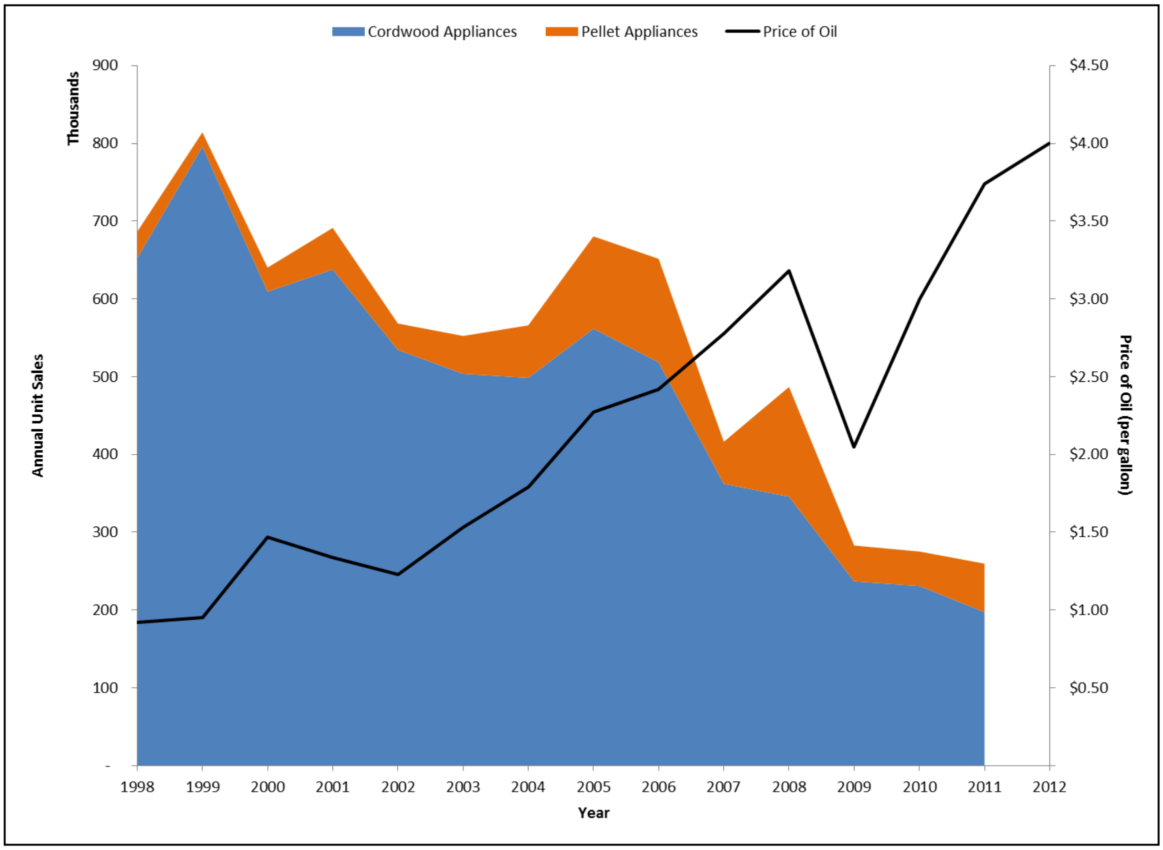
2.2.2 Trends in the Residential Wood Heating Market

Nationwide sales figures provided by HPBA (2013) for the years 1998 through 2011 indicate a steady decline in sales of cordwood-burning appliances. Over that same time period, pellet appliances have captured a greater share of wood-burning appliance sales. In 1998, pellet appliances accounted for just 5% of total wood-burning appliances, whereas in 2011, that number had jumped to 24% (Figure 2-8). The sales figures do not correlate with the cordwood use data provided in Section 2.2.1, as data indicate that NYS has experienced significant growth in the use of cordwood fuel. This lack of correlation could be attributed to several factors, including increased installation of central heating devices that use four times more wood than space heating devices, greater use of existing equipment, use of units purchased on the secondary market (installation of used devices), or sales of new units in the Northeast simply do not track national trends. Lack of regional sales data on new and secondary market sales for wood appliances make it difficult to identify the reasons for the conflicting information.

Trends noted in the HPBA data indicate a significant increase in sales between 2003 and 2005 that coincided with dramatically increasing costs for residential heating oil (EIA 2013). Because the Northeast and New York in particular have a much higher proportion of homes heating with oil than other areas of the country, sales patterns for wood appliances in this region may differ from sales patterns elsewhere. Equipment sales declined dramatically nationwide in 2007 and have remained below historical levels since then. This decline coincides with the decline in the national housing market and subsequent economic downturn, during which many homeowners chose not to make new investments in housing equipment.

Figure 2-8. Annual National Residential Wood Burning Appliance Sales and Heating Oil Prices

Sources: HPBA 2013; EIA 2013.



In terms of geographic distribution of residential wood burning, USEPA data (2012) indicate that 7 of 62 counties in NYS were responsible for approximately one-third of statewide wood consumption in 2011. These counties are:

- Erie – 6.4%
- Monroe – 5.9%
- Suffolk – 5.1%
- Oneida – 4.5%
- Saratoga – 4.3%
- Onondaga – 4.1%
- Westchester – 3.6%

On a per capita basis, 2011 annual per capita emissions from wood combustion in 14 counties were greater than or equal to 500 pounds per person. Of those 14 counties, only Oneida and Saratoga Counties were also among the top wood consuming counties, due to their large populations—more than 200,000 each. The other high per capita wood burning counties have populations that are generally well below 100,000 people. Figure 2-9 depicts 2011 NYS total and per capita wood burning by county. The counties described in this section as having high total or per capita emissions are highlighted in red.

The use of wood burning equipment in NYS is geographically distributed in rings around the following major population centers: the suburbs of New York City; the eastern half of Long Island; and areas in Upstate New York around Albany, Saratoga Springs, Syracuse, Utica, Rochester, and Buffalo.

Figure 2-10 is a map depicting wood burning by county in 2011, based on USEPA data (2012). Per capita residential wood combustion is presented by county in Figure 2-11. It is clear from comparing these two figures that while most of the wood burned in New York is consumed near population centers, the highest rates of residential wood burning are found in the northern portion of NYS from Lake Ontario to Vermont.

Figure 2-9. Total and Per Capita Wood Burning by County in New York State, 2011

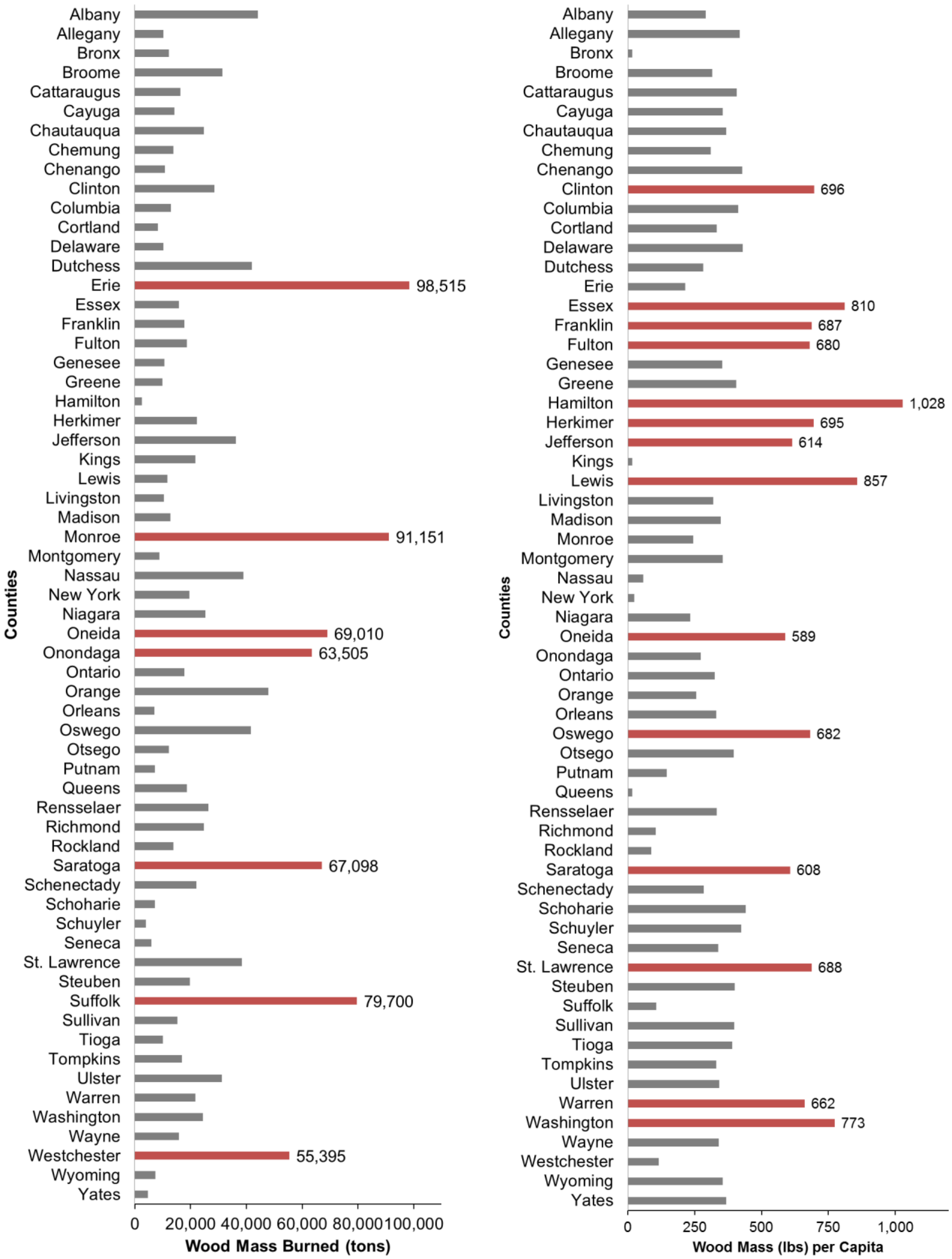


Figure 2-10. Residential Wood Combustion by County (tons) in 2011

Source: USEPA 2012

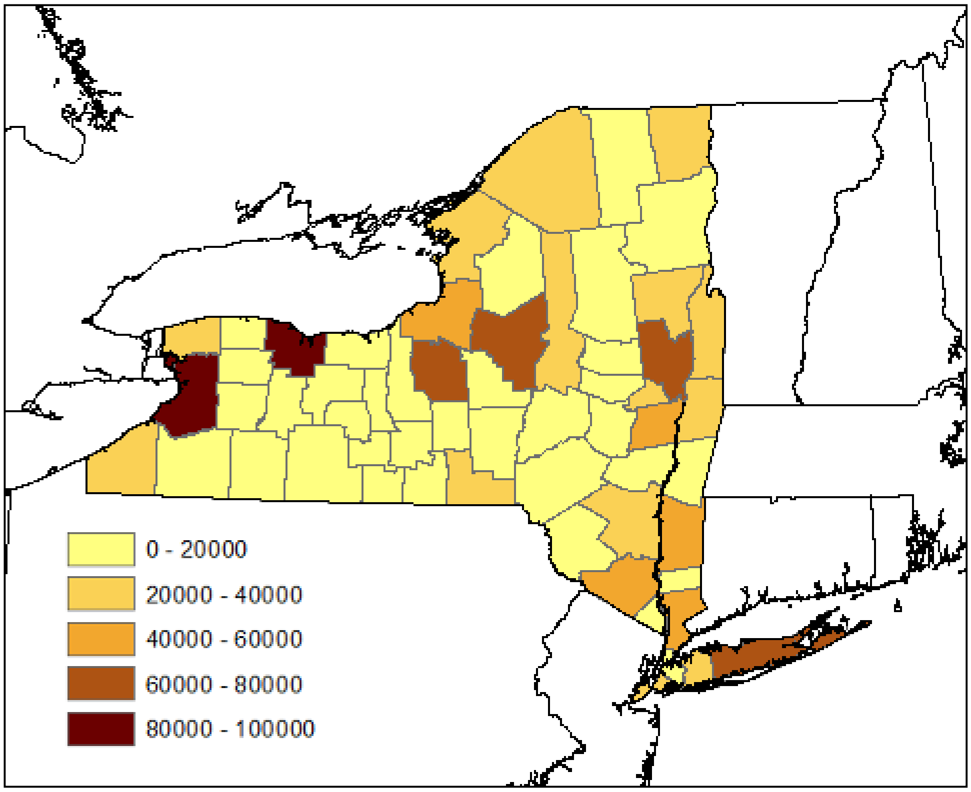
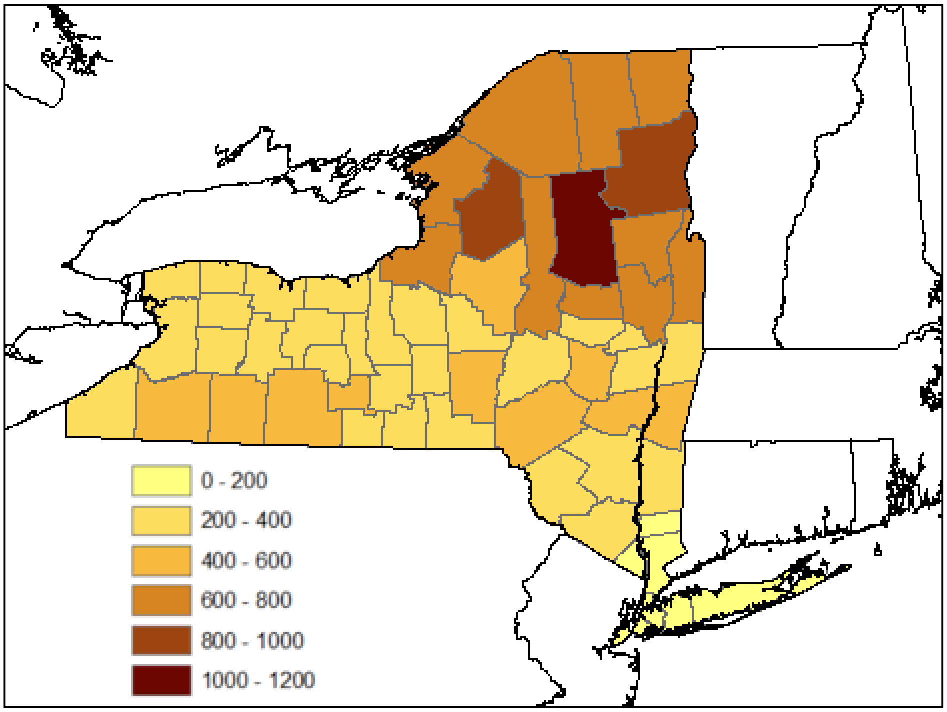


Figure 2-11. Per Capita Residential Wood Combustion (pounds) by County in 2011

Source: USEPA 2012



2.2.3 Wood Heating Equipment Manufacturing in New York State

The Northeast is home to a large concentration of wood-fired central heating equipment manufacturers and distributors of high-efficiency, low-emitting equipment. Of the approximately 30 central heating manufacturers and distributors in the U.S., eight are located in the Northeast. Of that number, five manufacturers are located in NYS (Table 2-2).

Table 2-2. Cordwood and Pellet Boiler Manufacturers and Distributors in New York State

Company	Location	Technology
Advanced Climate Technologies (ACT) Bioenergy	Schenectady, NY	Commercial pellet boilers and thermal storage
Econoburn	Brocton, NY	Advanced cordwood boiler for residential and very small commercial applications
Hydronic Specialty Supply	Cassadaga, NY	Advanced cordwood boiler for residential and very small commercial applications, thermal storage
Evoworld	Troy, NY	Commercial and residential pellet and chip boilers and thermal storage
Kedel	Portland, ME 1 NYS distributor	Residential pellet boiler
Maine Energy Systems	Sunday River, ME 2 installers in NYS	Residential pellet boilers
TARM USA	Lyme, NH 10 installers in NYS	Advanced cordwood boiler for residential and very small commercial applications, and residential and commercial pellet boilers
ThermoControl	Cobleskill, NY	Advanced cordwood boiler for residential and very small commercial applications

2.2.4 Industrial, Commercial, and Institutional Heating

This section provides an overview of the current population of oil and propane industrial, commercial, and institutional boilers in NYS that might be candidates for replacement with biomass units and information on the known ICI wood boilers in New York. This study focused on the institutional and commercial sectors and not the industrial. Industrial fuel switching tends to happen infrequently and due to site-specific requirements, making it difficult to complete broad scale analysis. Conversely, small and medium-sized boilers used solely for thermal purposes represent a larger component of the existing inventory. Conversion of a larger number of smaller and medium-sized units from oil/propane to wood offers a greater potential for wide-scale application of biomass units.

The USEPA estimates that 1.37 million small industrial, commercial, and institutional boilers are in use nationwide. Small boilers are defined as smaller than 30 MMBtu. There is little data on these units as they typically do not require federal or state permits. Industrial boilers are defined as those used in manufacturing, processing, mining, refining, or any other industry. Many industrial sector boilers may be used for purposes other than heating. In the commercial and institutional sectors, however, a large number of boilers are used solely for thermal purposes. Commercial boilers are installed at stores and malls, laundries, apartments, hotels/motels, and other similar commercial establishments. Institutional boilers are located at health services (hospitals, nursing homes, and clinics), educational facilities (schools and universities), churches, and municipal facilities (government offices, courthouses, prisons).

Within the universe of small boilers, an estimated 53% are installed in institutional settings, 46% in commercial settings, and less than 1% in industrial settings. Table 2-3 provides a breakdown of the named locations for small boilers identified by the USEPA analysis.

Table 2-3. Breakdown of Industrial, Commercial, and Institutional Boilers by Facility Type

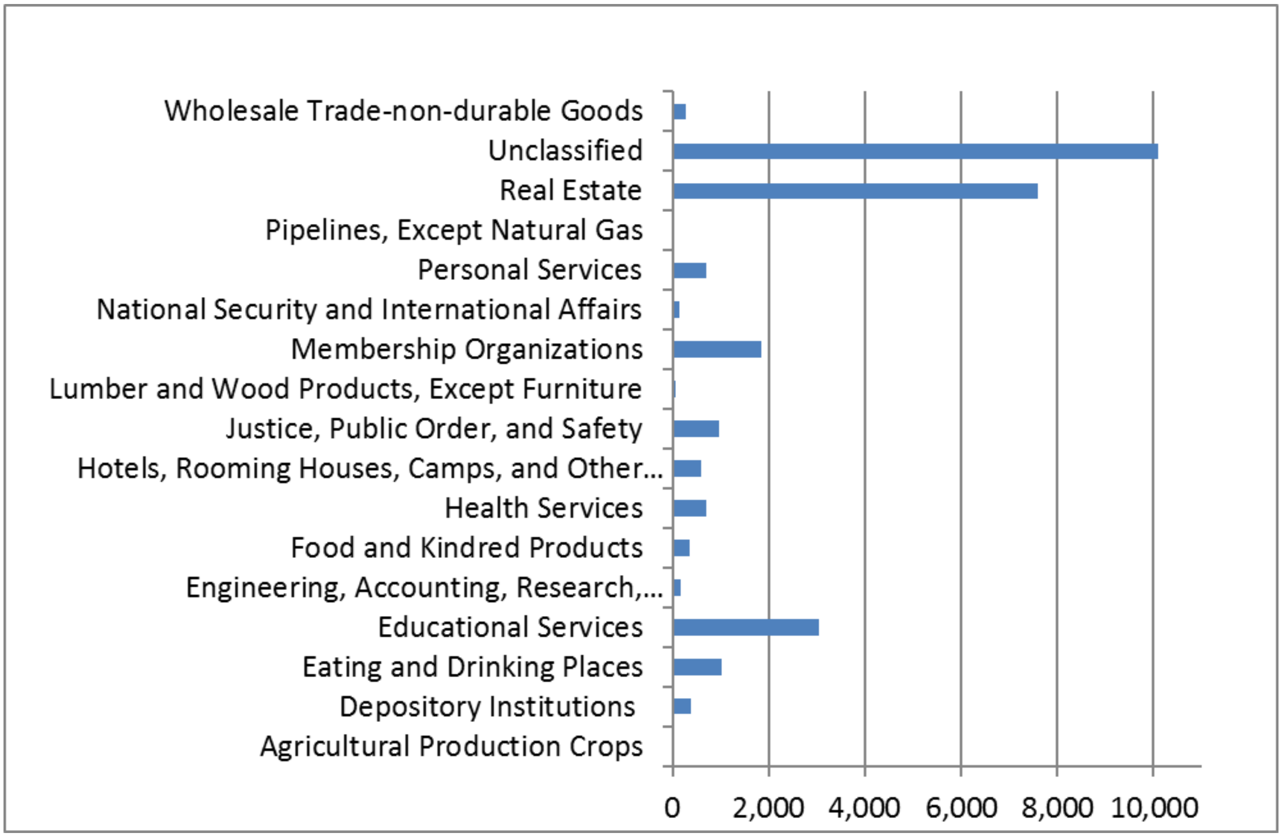
Source: NYSERDA 2015

Facility Type	Estimated Number of Facilities
Educational Facilities	221,500
Church/Temple	97,000
Hotel/Motel/Inn	44,500
Apartments	332,500
Health Services	48,500
Restaurant	21,500
Municipal Facilities	31,000
Food	20,700
Lumber	1,400

Within these source categories, a variety of fuels are combusted. Nationally, the USEPA estimates that there are 123,000 fuel oil boilers, of which 95% of are smaller than 10 MMBtu/hr (Eddinger 2009). The universe of boilers combusting biomass nationwide is much smaller. The USEPA estimates that roughly 10,500 boilers combust biomass. Of that number, 93% are smaller than 10 MMBtu/hr.

The New York Oil and Propane Boiler database was used to develop an inventory of oil and propane boilers in NYS that might be candidates for replacement with biomass units. Only oil and propane units were considered to be good candidates for conversion because the low cost and convenience of natural gas make replacement of natural gas units with wood-fired units unlikely. Because the database does not provide complete information for several categories that were of interest in this analysis, such as industry classifications for the entities using the boilers, the number and distribution of boilers between various industry sectors is only a rough estimate. The distribution across industry sectors of the 28,042 boilers included in the database is depicted in Figure 2-12. A clear limitation of the data set is that nearly one-third of the boilers listed in the database (10,106 units) are not assigned an industry.

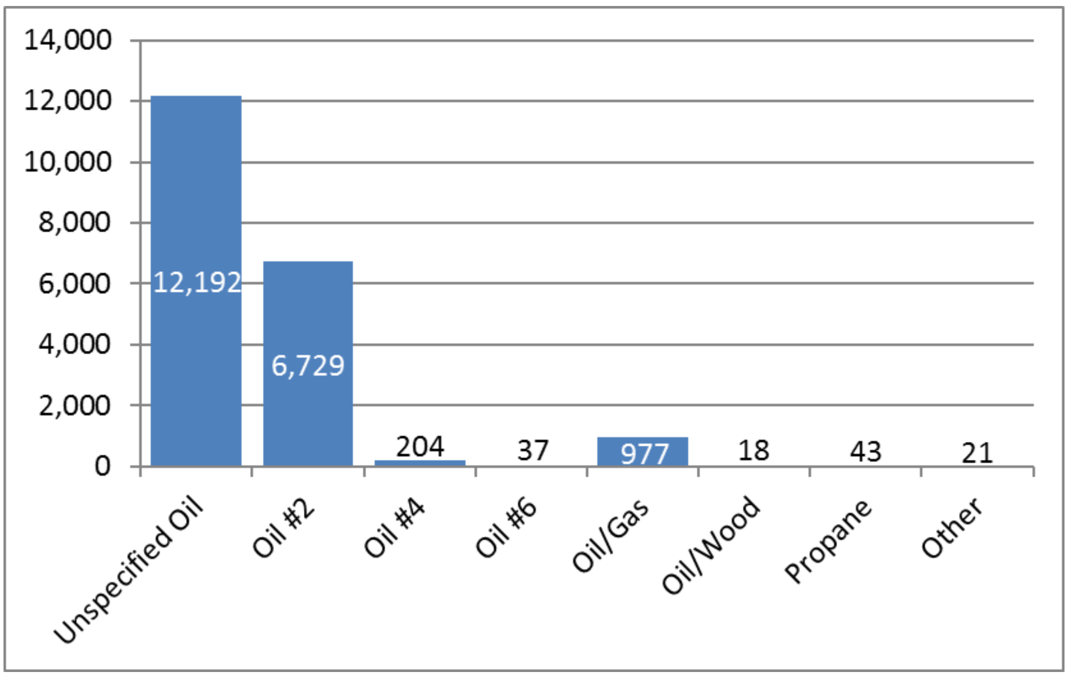
Figure 2-12. Space Heat Boilers in New York State by Industry (all fuels)



The database also provides limited information on the fuel used in the boilers. The overwhelming majority of the boilers in the database use fuel oil, either alone or in a dual fuel configuration, which means they are capable of using different fuels with the same device. Most of the oil units in the database did not specify what class of fuel oil is used, but among units for which fuel oil class is listed, No. 2 distillate is utilized significantly more than No. 4 or No. 6 fuel oils. Since NYS implemented ultra-low sulfur diesel (ULSD) regulations in July 2012, sulfur content of No. 2 distillate is limited to 15 ppm, and sulfur content of No. 6 oil is limited to 0.50% by weight (except in New York City and in Nassau and Westchester Counties, where the limit is lower).[4] Figure 2-13 illustrates the number of boilers by fuel type.

Figure 2-13. Number of ICI Space Heat Boilers by Fuel Type[5]

A total of 21 "Other" fuels include: Coal (1), Coal/Oil (4), Coal/Oil/Wood (4), Gas/Petroleum (3), Gas/Propane (3), Oil/Gas/Wood (2), and Not Listed (5).



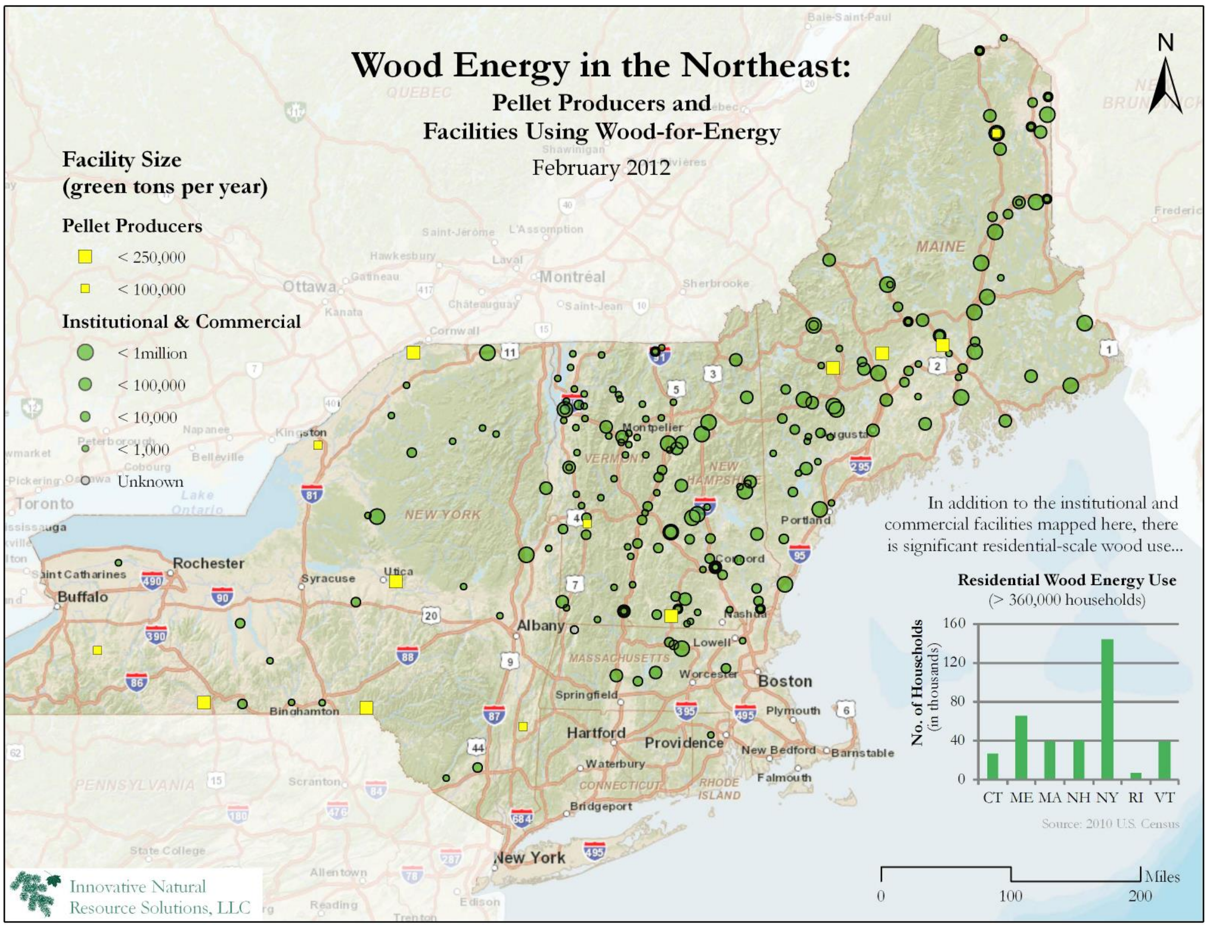
4 3 NYCRR Part 225-1.2 Sulfur in fuel limitations. These regulations do not explicitly name No. 4 oil, which is a mixture of distillate and residual oils.

5 New York Oil and Propane Database 2010.

Unlike the residential sector, use of wood for industrial heating is rare and is most commonly found in facilities associated with the wood products industry. A database developed by the Project Team estimates that NYS' current inventory of ICI boilers fueled by wood includes 62 sawmills, 13 schools, 7 pellet mills, 3 industrial users, 2 paper mills, 2 commercial buildings, 2 greenhouses, and 2 hospitals. Figure 2-14 depicts the location of these facilities. Use of wood pellets appears to be higher in neighboring states where access to natural gas is limited. However, use of biomass in ICI applications is higher in NYS than in other states such as Connecticut, Massachusetts, and Rhode Island.

Figure 2-14. Pellet Producers and Key Industrial and Commercial Wood Fuel Consumers in New York State and Nearby States

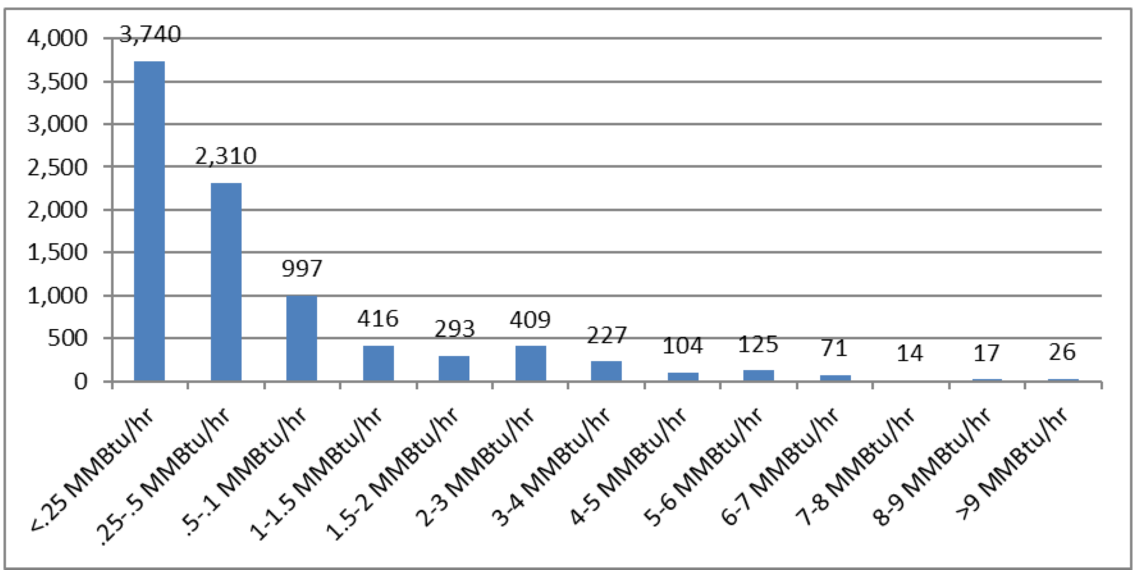
Source: INRS 2013



2.2.4.1 Size Distribution of Units

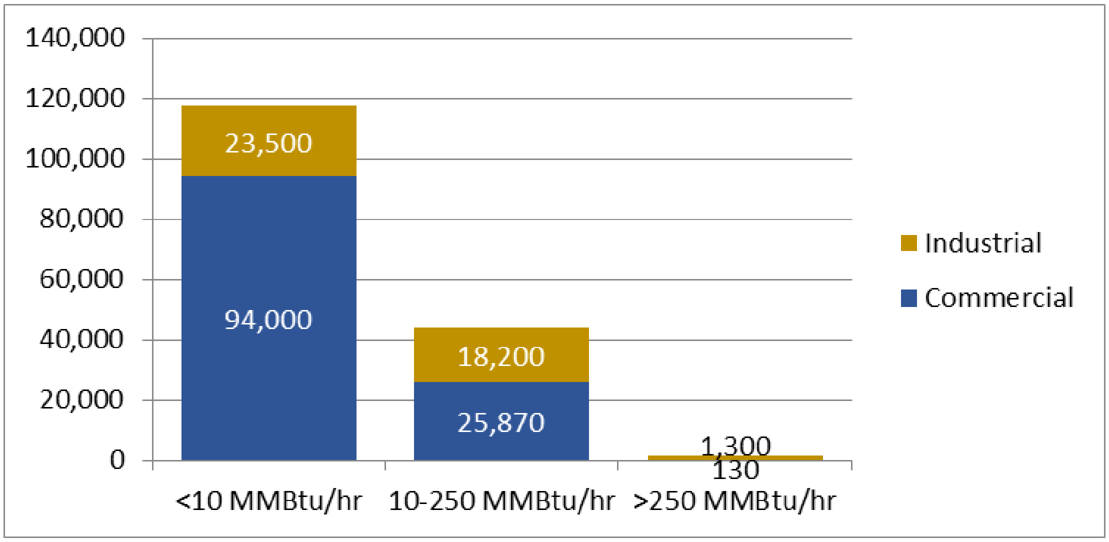
Because the Oil and Propane Boiler database does not consistently include information on boiler capacity, it provides limited information on the size distribution of ICI oil and propane boilers in NYS. Analysis of the database indicates that of the 8,749 boilers for which size is specified, the majority are small, with an average operating capacity of less than 250,000 Btu per hour. This means that more than 80% of NYS ICI boilers, primarily in commercial applications, are not subject to either state or federal emission standards (shown in Figure 2-15). The NYS ICI boiler inventory appears to show, on average, boilers that are smaller in size relative to the nationwide size distribution of commercial and industrial heating units (shown in Figure 2-16). According to the Oak Ridge National Laboratory Report, 28% of the total industrial and commercial boilers nationwide have an operating capacity greater than 10 mmBtu/hr.[6] The Oak Ridge Report also indicates that installation of new boilers are most likely to occur at food-related facilities, chemical plants, educational institutions, and health care facilities. The smaller size of boilers in NYS may be due to more frequent use of multiple small boilers working in tandem in a single facility, rather than one large unit.

Figure 2-15. NY ICI Propane and Oil Boilers by Size



6 Oak Ridge National Laboratory, 2005, Characterization of the U.S. Industrial/Commercial Boiler Population Report.

Figure 2-16. Number of U.S. Industrial & Commercial Oil-fired Boilers by Size in 2005

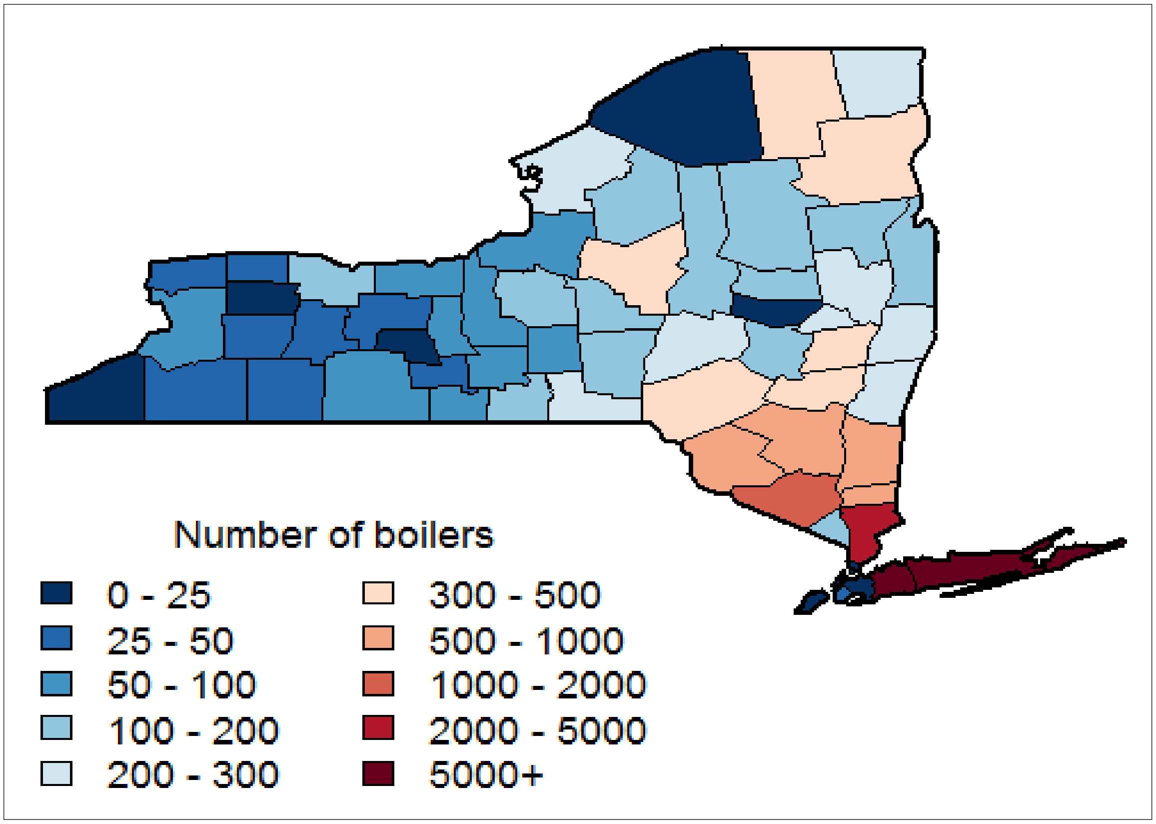


2.2.4.2 Geographic Distribution of Units

The distribution of ICI boilers used for space heating in NYS is shown in Figure 2-17. In many areas with the greatest concentration of boilers, there is ready access to natural gas. Given the small cost differential between wood and natural gas, consumers are more likely to switch to natural gas than biomass in these locations. Reasons for switching to natural gas over wood when prices are comparable relate to ease of integration and use, higher efficiency and emissions performance. Therefore, identification of areas with large concentrations of oil-fired boilers that have limited access to natural gas is likely to be more informative and useful in predicting where wood may be installed.

Figure 2-17. Industrial & Commercial Oil-fired Boiler Installations by County in 2005

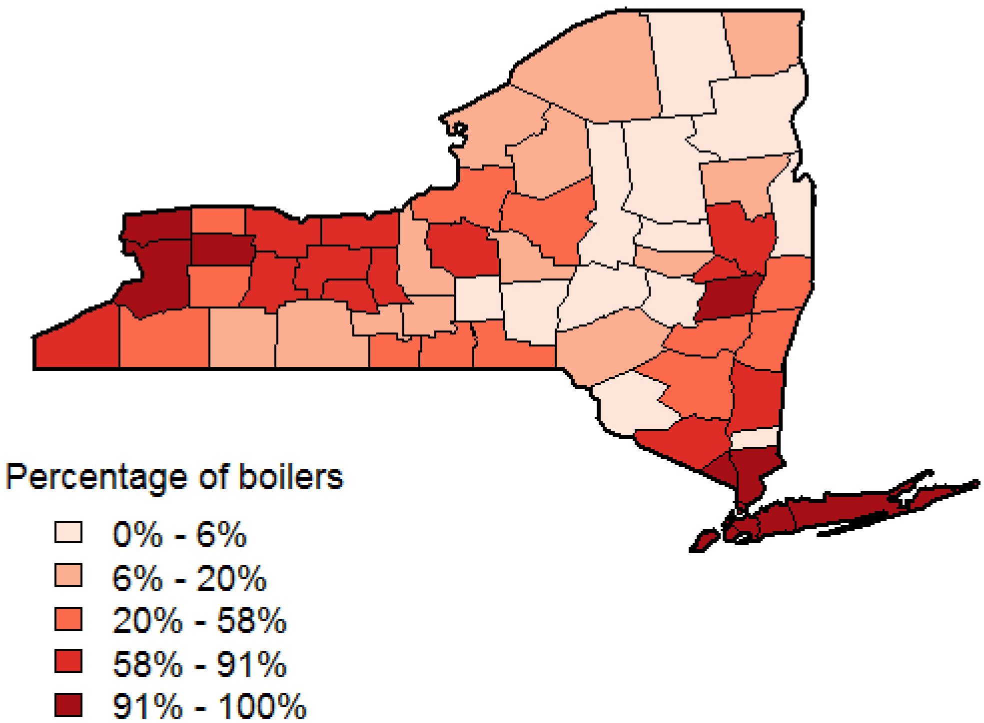
Source: New York Oil and Propane database 2010.



Comparing Figure 2-17 and Figure 2-18 shows that many space-heating boilers are located in areas with access to natural gas (13,462), while in other regions of NYS, ICI boilers do not have easy access to natural gas lines. Approximately 6,739 space-heating boilers are located in areas without access to natural gas.

Figure 2-18. Number of ICI Oil- and Propane-Fired Boilers in the Institutional, Commercial, and Industrial Sectors, by County, Located Near Natural Gas Lines

Source: New York Oil and Propane database 2010



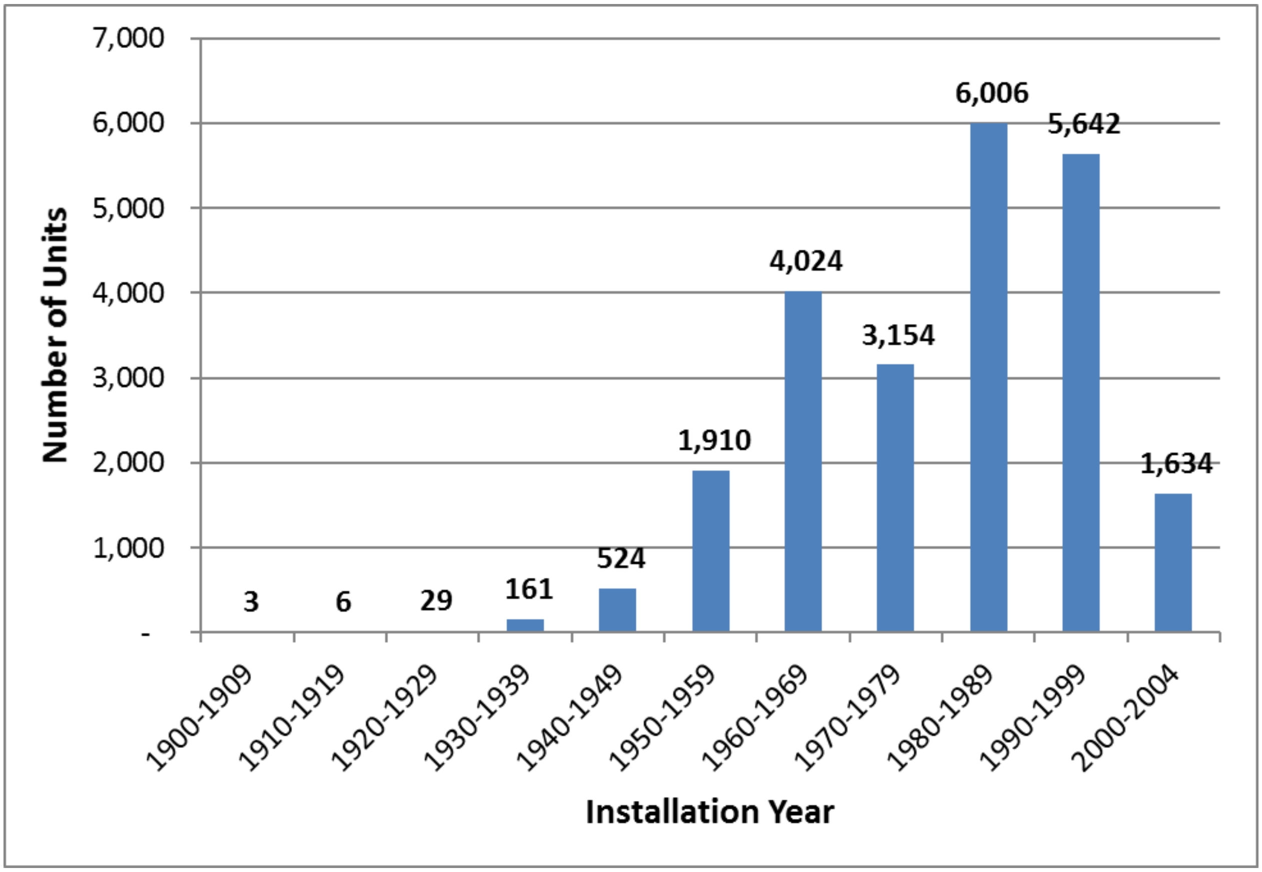
2.2.4.3 Age of Units

The year of installation is specified for 23,093 of the boilers in the New York Oil and Propane database obtained from an analysis of boilers for US EPA's boiler rules. In many cases, however, the actual year of installation year appears to be unknown or installation dates were rounded to the nearest five or 10 years. Therefore, in Figure 2-19, installations are shown by decade of installation rather than by the exact years.

Figure 2-19. Industrial and Commercial Boilers by Decade of Installation

Source database only includes installations dated 2004 and earlier; there is insufficient data to include a distribution of sizes within each age category.

Source: New York Oil and Propane database 2010.



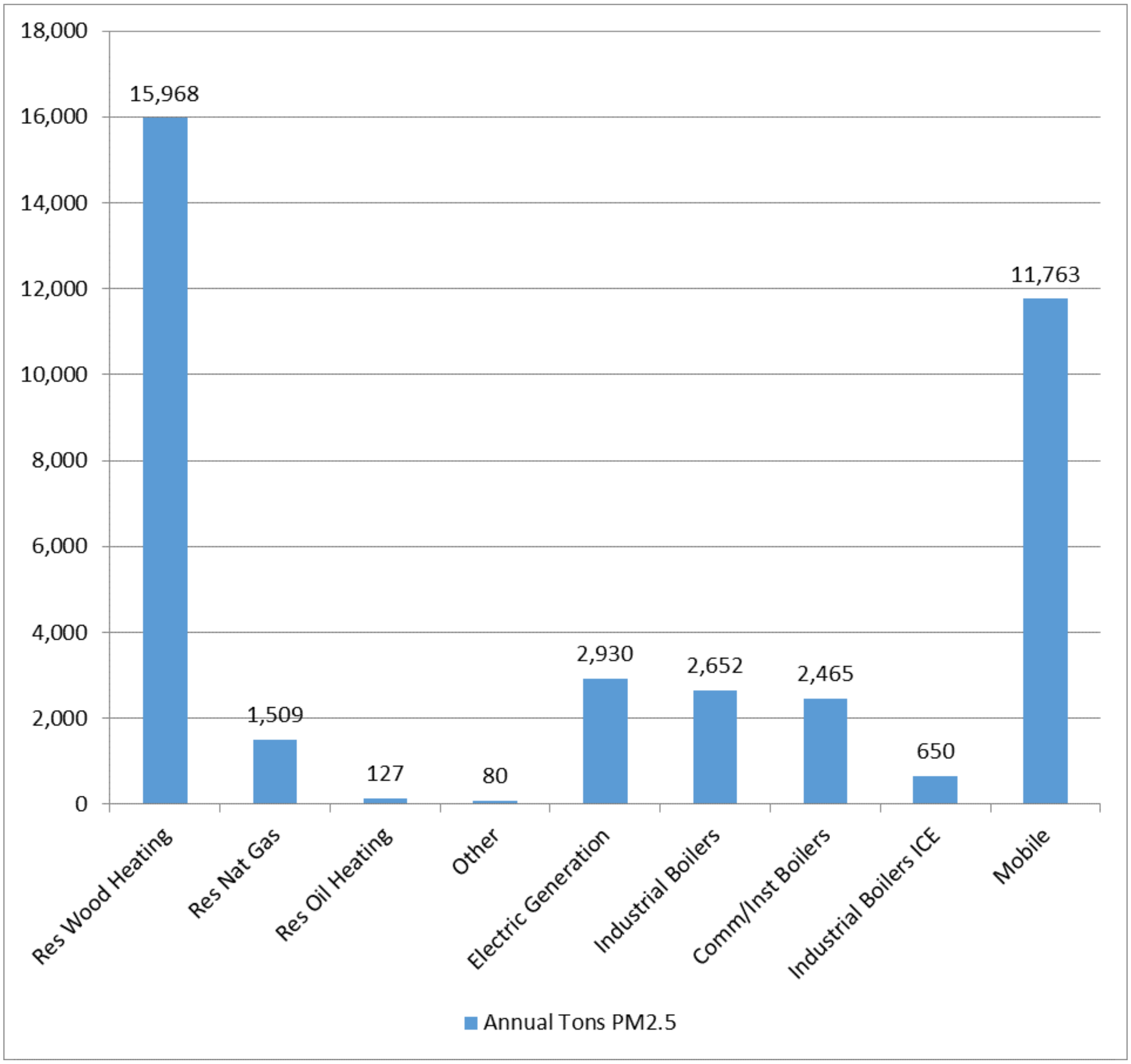
2.3 Summary of Findings

Use of wood for home heating purposes is a small but growing market in NYS. A small but growing number of in-state manufacturers are producing high-efficiency, low-emission residential heating devices. Based on available data, although wood use represents a small fraction of space heating needs in New York, the amount of wood fuel use in NYS has grown exponentially over the last decade. The lack of state-level data on device sales and cordwood harvesting, however, make it impossible to precisely characterize what segment of the residential heating market is growing and if the growth is occurring in cordwood, chip, or pellet fuels. The use of wood heating in the ICI sector is insignificant and primarily found in wood processing operations, with a few NYS schools also heating with wood.

While the overall use of wood for heating purposes is minimal compared to other fuels used for heating, its impact on NYS' air quality is significant. Figure 2-20 highlights the fine particulate ($PM_{2.5}$) contributions by source category. While wood heat provides less than 2% of NYS' overall heating needs, the residential wood heating sector contributes more than 90% of the $PM_{2.5}$ emissions in NYS. To put this in perspective, residential wood heating currently contributes 275% more $PM_{2.5}$ than all ICI heating emissions combined, 550% more $PM_{2.5}$ than the electricity generation sector, and 35% more $PM_{2.5}$ than the transportation sector. High emissions from the residential wood heating sector are attributable to the large inventory of unregulated devices in NYS.

Figure 2-20. Annual Tons of $PM_{2.5}$ Emissions in 2012 by Sector

Source: NEI 2012



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3 Woody Biomass Regulatory Framework

This chapter provides an overview of the federal, New York State, and European regulatory requirements, fuel standards, and emission testing protocols for residential and ICI woody biomass devices. In the United States, wood-heating devices and fuels are regulated at the federal, state, and local government levels. Significant differences exist between state and federal regulatory requirements for wood-heating devices, and between United States and European requirements.

3.1 U.S. Federal Requirements

Federal emission standards apply to most new residential wood heating devices and ICI wood heating units with a heat output in excess of 10 MMBtu/hr. ICI units with a heat output of less than 10 MMBtu/hr are subject to a federal work practice standard, which only requires a tune-up every two or five years.

3.1.1 Federal New Source Performance Standards

New source performance standards (NSPS) are authorized under Clean Air Act (CAA) § 111, and codified in 40 CFR Part 60. NSPS standards establish technology-based standards for specific source categories, such as ICI boilers, that reflect the degree of emission reduction that is achievable through application of the best system of emission reduction (BSER). NSPS standards generally contain emission limits for air pollutants such as carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NO_x), and sulfur dioxide (SO_2). ICI boilers and residential wood heating units are subject to separate NSPS standards: 40 CFR Part 60 Subpart Dc—*Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units)* and 40 CFR Part 60 Subpart AAA and QQQQ—*Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces.*

3.1.1.1 NSPS for ICI Boilers

Subpart Dc establishes a PM emission limits for ICI boilers with a heat output greater than 30 MMBtu/hr. The PM emission standard is 0.03 lb/MMBtu. The NSPS for ICI boilers does not apply to any wood boiler smaller than 30 MMBtu/hr. Additional requirements for these units are contained in National Emission Standards for Hazardous Air Pollutants (NESHAP) and state regulations.

3.1.1.2 NSPS for Residential Wood Heaters

In 2015, USEPA revised the NSPS for residential wood devices (*Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces*), updating and expanding the sources covered under the previous residential wood heaters NSPS adopted in 1988. It should be noted that this NSPS is the only one to regulate a consumer product. All other NSPS regulations apply to industrial, institutional, or commercial units. Typically, individual NSPS units are required to conduct periodic stack testing to demonstrate compliance with the emission standard. For consumer products, however, USEPA established a certification process that requires a single emission test for each model line to certify compliance with the standard.

The 1988 NSPS expressly exempted a broad suite of devices, including those with one or more of the following characteristics:

- An air-to-fuel ratio less than 35-to-1.
- A usable firebox volume of less than 20 cubic feet.
- A minimum burn rate of less than 5 kg/hr.
- A maximum weight of 800 kg excluding fixtures.

In addition, the regulation specifically exempted the following types of units:

- Wood heaters used solely for research and development purposes.
- Wood heaters manufactured for export (partially exempt).
- Coal-only heaters.
- Open masonry fireplaces constructed on site.
- Boilers.
- Furnaces.
- Cookstoves.

Additionally, the 1988 NSPS differentiated between units with catalytic controls and those with non-catalytic controls. The emission standard for catalytic devices was lowered to compensate for anticipated degradation of the catalytic controls over the expected lifetime of the unit. Catalytic units could not emit more than a weighted average of 4.1 grams per hour (g/hr) of PM, and no stack test run could exceed 15 g/hr. Noncatalytic models could not emit more than a weighted average of 7.5 g/hr of PM. The rule did not require efficiency testing, but rather allowed companies to advertise a default value of 63% efficiency.

On March 16, 2015, USEPA published revised standards for residential heating devices that take effect on May 16, 2015. Under this rulemaking, USEPA expanded the types of devices regulated by the NSPS, eliminating many of the previous exemptions and adopting a new subpart to regulate central heating devices. Under the 2015 rule, 40 CFR Part 60 Subpart AAA regulates wood-fired room heating devices, including cordwood stoves currently subject to the NSPS, and adds pellet stoves and single burn rate cordwood stoves. (These cordwood stoves do not have adjustments to vary device burn rate). The new rule narrows definitions for exempt appliances to ensure that all room heating devices, except fireplaces, are subject to the regulation. USEPA adopted new Subpart QQQQ, which regulates residential wood-fired central heating devices, including indoor and outdoor hydronic heaters and forced air furnaces. The 2015 rule establishes PM emission standards for these devices and requires reporting to EPA of CO emissions and device efficiency. Implementation of final more stringent standards will take effect in May 2020. Currently, this rule is being litigated by industry, which is challenging the Step 2 emission limits and USEPA's authority not to use ASTM International methods. Table 3-1 provides an overview of the new standards. The 1988 rule exempted many devices from the emission standard requirements, including single burn rate woodstoves,[7] pellet stoves, wood furnaces, wood boilers, and hydronic heaters; however, under the 2015 rule, these units now must comply with testing and emission standard requirements.

[7] These woodstoves do not have built-in air controls.

Table 3-1. Overview of 2015 NSPS Emission Standards for Wood-fired Residential Heaters

Device	Step 1 Emission Standard	Step 1 Effective Date	Step 2 Emission Standard	Step 2 Effective Date	Step 3 Emission Standard	Step 3 Effective Date
Room Heater	4.5 g/hr (WA)	May 16, 2015	2.0 g/hr (WA)crib OR 2.5 g/hr (WA)cord	May 16, 2020	Not applicable	
Hydronic Heaters	0.32 lb/MMBtu/hr (output) (WA) no run to exceed 18 g/hr	May 16, 2015	0.10 lb/MMBtu/hr (output) (IR) (crib) OR 0.15 lb/MMBtu/hr (output) (IR) (cord)	May 16, 2020	Not applicable	
Forced Air Furnaces <65,000 Btu/hr	Work practice standard	May 16, 2015	0.93 lb/MMBtu/hr	May 16, 2016	0.15 lb/MMBtu/hr	May 16, 2020
Forced Air Furnaces >65,000 Btu/hr	Work practice standard	May 16, 2015	0.93 lb/MMBtu/hr	May 16, 2017	0.15 lb/MMBtu/hr	May 16, 2020
Masonry Heaters	No federal regulations apply					

3.1.1.3 National Emission Standards for Hazardous Air Pollutants

The Clean Air Act requires USEPA to list categories of "major sources" of hazardous air pollutants (HAPs) and to issue NESHAPs for such sources (CAA § 112(c)(1)). Major sources are defined as any stationary source or group of stationary sources that emits, or has the potential to emit (PTE), at least 10 tons/year of any HAP, or 25 tons/year of any combination of HAPs (CAA § 112(a)(1)). NESHAP standards "require the maximum degree of reduction in emissions of the hazardous air pollutants subject to [CAA § 112]" that the USEPA determines is achievable, taking into account certain factors such as cost, energy requirements, and other impacts. The HAP standards are commonly referred to as MACT (maximum achievable control technology) standards (CAA § 112(d)(2)).

Section 112(b) includes a specific list of 188 HAPs. Pollutants on the HAPs list emitted by woody biomass boilers include polycyclic organic matter (POM),[8] formaldehyde, naphthalene, and a number of metals, including mercury. USEPA has the legal authority to impose NESHAP emission standards on both new and existing units, but often the standard for new sources is more stringent than that for existing units.

In 2012, USEPA finalized a rule under 40 CFR Part 63, Subpart DDDDD that establishes emission limits and work practice standards for HAPs emitted from ICI boilers and process heaters classified as major sources. Subpart DDDDD further establishes requirements to demonstrate initial and continuous compliance with the emission limits and work practice standards. The rule includes limits for new and existing units, and different standards apply to units according to boiler size. A large boiler is larger than 10 MMBtu/hr while a small boiler is smaller than 10 MMBtu/hr. Table 3-2 and Table 3-3 cover the emission standards for large biomass-fired boilers. The requirements for small boilers are the same as listed for area source units detailed in the next section.

Table 3-2. New Large Biomass Boilers

Unit type	Mercury TBtu/hr	Hydrogen Chloride lb/MMBtu/hr	CO ppm at 3% O2 (st=stack test or cm=continuous emission monitor)	PM lb/MMBtu/hr
Wet Stoker	0.8	0.022	620 ST 390 CEM	0.030 ST 0.000026 CEM
Kiln Dried Stoker	0.8	0.022	460 ST	0.030 ST 0.0040 CEM
Fluidized Bed	0.8	0.022	230 ST 310 CEM	0.0098 ST 0.000083 CEM
Suspension Burner	0.8	0.022	2,400 ST 2,000 CEM	0.30 ST 0.0065 CEM
Dutch Oven/Pile Burner	0.8	0.022	330 ST 520 CEM	0.0032 ST 0.000039 CEM
Fuel Cell	0.8	0.022	910 ST	0.020 ST 0.000029 CEM
Hybrid Suspension Grate	0.8	0.022	1,100 ST 900 CEM	0.026 ST 0.00044 CEM

8 The CAA § 112 HAPs list uses the term polycyclic organic matter (POM) essentially as an indicator of incomplete combustion products. POM is a fairly broad term, and is inclusive of benzo(a)pyrene and other polycyclic aromatic hydrocarbons that are commonly emitted from wood combustion.

Table 3-3. Existing Large Biomass Boilers

Unit type	Mercury TBtu/hr	Hydrogen Chloride lb/MMBtu/hr	CO ppm at 3% O2 (st=stack test or cm=continuous emission monitor)	PM lb/MMBtu/hr
Wet Stoker	5.7	5.7	1,500 ST 720 CEM	0.037 ST 0.00024 CEM
Kiln Dried Stoker	5.7	5.7	460 ST	0.32 ST 0.004 CEM
Fluidized Bed	5.7	5.7	470 ST 310 CEM	0.11 ST 0.0012 CEM
Suspension Burner	5.7	5.7	2,400 ST 2,000 CEM	0.051 ST 0.0065 CEM
Dutch Oven/Pile Burner	5.7	5.7		0.28 ST 0.0020 CEM
Fuel Cell	5.7	5.7		0.020 ST 0.0058 CEM
Hybrid Suspension Grate	5.7	5.7		0.44 ST 0.00045 CEM

3.1.2 Area Source Program

USEPA is required under CAA § 112(c)(3) and (k) to issue emissions standards for "area sources." An area source is any stationary source that is not a major source.[9] Under CAA § 112(d)(5), USEPA may, in lieu of MACT standards under § 112(d)(2), elect to promulgate standards or requirements for area sources, "which provide for the use of generally available control technologies (GACT) or management practices to reduce emissions of hazardous air pollutants." The following lays out the GACT standards developed for the Area Source Boiler rule:

- For new solid fuel units larger than 30 MMBtu:
  - PM – 0.03 lb/MMBtu
  - Conduct an energy assessment
- For new solid fuel units sized 10 - 30 MMBtu:
  - PM – 0.07 lb/MMBtu
  - Conduct an energy assessment
- For new solid fuel units (no size limit):

[9] Specifically, these provisions require USEPA to ensure that area sources emitting 90% of the emissions of 30 specific HAPs be subject to regulation under CAA § 112.

- Biennial tune up, unless a seasonal or limited use boiler. Seasonal or limited use boilers need to conduct tune-ups every five years.

3.1.2.1 PM National Ambient Air Quality Standards

The Clean Air Act requires USEPA to set national ambient air quality standards (NAAQSs). States are responsible for achieving compliance with the NAAQS through the development and implementation of air quality control plans called State Implementation Plans (SIPs). Counties where monitors measure ambient pollution levels above the standard, and nearby upwind areas with emissions that contribute to the downwind pollution problem are designated in nonattainment. For wood boilers, the relevant NAAQSs are those for $PM_{2.5}$, of which there are two standards - an annual averaged NAAQS and a 24-hour daily NAAQS.

USEPA completed a review of the $PM_{2.5}$ standards in 2012. The annual standard was reduced from 15 micrograms per cubic meter ($\mu g/m^3$) to 12 $\mu g/m^3$, while the 24-hour NAAQS was retained at 35 $\mu g/m^3$. EPA is also required to set a secondary standard. Under the last revision, emission levels for the secondary standard were set to match the primary standard. To attain the 24-hour NAAQS, the three-year average of the annual 98th percentile of 24-hour concentrations at each “population-oriented” monitor within an area may not exceed 35 $\mu g/m^3$. There is no standard for sub-daily standard under the NAAQS.

In December 2014, USEPA issued final designations for nonattainment areas for the 2012 PM NAAQS. No areas in NYS were designated as nonattainment. The nearest designated nonattainment areas to NYS are in Ohio and Pennsylvania, while no other Northeast states had areas in nonattainment.

The process to revisit and potentially further revise both the annual and the daily PM standards is now underway. Any revision of the standards is likely to be proposed in 2018. Given the significant contribution of particulate emissions from combustion of wood to airsheds in NYS and elsewhere, additional regulation of this source category may become necessary if PM NAAQS levels become more stringent.

3.2 State Emissions Standards

Many states regulate sources not covered under federal requirements in their minor source permitting and state air toxics programs. The applicability thresholds and emission standards for these programs vary significantly from state to state.

3.2.1 Minor Source Permitting

Within the Northeast, regulations for PM vary across the eight states analyzed. Typical regulations in the Northeast require a case-by-case review and Best Available Control Technology (BACT) analysis. This means that the emission limit can change to reflect improvements in boiler design and control technologies. Five states (Connecticut, Maine, New Jersey, Rhode Island, and Vermont) in the eight-state region have adopted BACT requirements for these boilers. In these states, emission limits are in the range of 0.03 – 0.10 lb/MMBtu. Three states have an emission standard. In Massachusetts, the standard is 0.10 lb/MMBtu. In New Hampshire, the standard is 0.30 lb/MMBtu. NYS' 0.6 lb/MMBtu standard is notable insofar as it was adopted more than 40 years ago and is significantly less stringent than those subsequently adopted by other states in the region. Table 3-4 provides an overview of thresholds and emission limits for the eight northeastern states.

Table 3-4. Overview of Northeastern State Requirements

State	Boiler Size Threshold	Emission Standard
Connecticut	PTE of 15 tons per year (tpy) of any air pollutant	• Case-by-case BACT determination • Most recent determination 0.10 lb/MMBtu heat input
Maine	10 MMBtu (aggregated)	• Case-by-case BACT determination • Most recent determination 0.30 lb/MMBtu heat input
Massachusetts	1 MMBtu	• 0.10 lb/MMBtu heat input
New Hampshire	Larger than 2 MMBtu	• 0.3 lb/MMBtu heat input
New Jersey	1 MMBtu	• Case-by-case BACT determination • No recent determinations
New York	Larger than 1 MMBtu	• 0.6 lb/MMBtu heat input
Rhode Island	Larger than 1 MMBtu	• Case-by-case BACT determination • Most recent determination 0.10 lb/MMBtu heat input
Vermont	Larger than 90 horsepower (HP) (approximately 5-6 MMBtu/hr)	• Case-by-case BACT determination • Most recent determination 0.03 lb/MMBtu heat input

3.2.2 State Air Toxic Programs

Some state air toxics programs have adopted emission limits for small- and medium-sized wood chip boilers (e.g., Rhode Island and Vermont). State programs for air toxics vary widely from state to state, but they typically seek to identify and regulate sources of toxic emissions with the potential to adversely impact public health. Standards may be in the form of emission rates or concentrations derived from modeling.

Regulatory requirements for the NYS air toxics control program are principally contained in 6 NYCRR Part 212. This regulation uses a rating system to specify the degree of pollution control required for sources of toxic air pollutants. Ratings are based on a contaminant's toxicity (high, moderate, or low), predicted ambient impacts, the proximity of ambient impacts to neighboring communities, existing background concentrations, and the potential future growth of the impacted area. By definition the Part 212 regulation excludes combustion installations such as solid, liquid or gas boilers from these requirements so no state regulations apply.

3.2.3 Outdoor Wood Boiler Regulations

In NYS, inconsistencies exist in emission and siting regulations for biomass units. NYS currently regulates outdoor wood boilers (OWBs). The regulation requires that OWBs meet an emission standard of 0.32 lb/MMBtu heat output.[10] Additionally, the regulation states that residential OWBs may not be used or installed within 100 feet of a property line and a commercial unit cannot be installed within 200 feet from the nearest property line of any kind, 300 feet from a residential property line, or 1,000 feet of a school. Because schools tend to install units that are larger than OWBs, the emission rates of chip boilers used in school settings have higher mass over time emissions than OWBs and in some cases may even have higher emission rates on a Btu per hour basis. The current regulatory system allows ICI units sized 1 to 10 MMBtu/hr to emit pollution at significantly higher rates than residential units or smaller commercial cordwood-fired systems, even when adjusting for size differences.

[10] It should be noted that a heat output emission rate will be higher than a heat input rate since the efficiency of the device is calculated into the final value.

3.2.4 New York State Education Department Requirements

For installation at schools, wood-fired boilers must comply with draft State Education Department requirements. In school settings, New York requires biomass boilers to be designed to minimize potential health and safety effect, which includes:

- Perform an evaluation of the potential health and environmental effects to include a comparison of potential biomass boiler emissions and thermal efficiencies to displaced fuels systems (e.g., oil, gas, etc.), discussion of proposed fuel delivery mechanisms and storage, consideration of potential wind patterns and terrain as it may influence emission impacts.
- Obtain approval from the Department of Environmental Conservation Division of Air Resources by way of an issued air permit or registration.
- Obtain approval by the Commissioner of Education is contingent upon Department of Environmental Conservation approval.

The design of the unit must include:

- Boiler room and fuel storage areas attached to student-occupied buildings must be fully equipped with fire sprinklers.
    - Final fuel feed delivery system to boiler must be interlocked with the boiler to operate at all times the boiler is operating, or otherwise maintained clear of fuel when the system is not actively calling for fuel.
    - Final feed and portion of feed system delivering fuel to the final feed system must be provided with an automatic fire suppression system, designed to flood the feed system, upon detection of a fire in feed system.
    - Control system must incorporate a time lag prior to reducing air supply when going from high fire to low fire.
    - Upon loss of draft the fuel feed system must shut down.
    - Fuel storage areas, attached to occupied buildings, shall be separated from the occupied portion of the building by two-hour, fire rated construction.
    - Fuel storage areas, attached to occupied buildings, must be designed to prevent dust, odors, and potential, toxic gases from entering the occupied portion of the building.
    - Electrical devices, located in fuel storage areas shall be designed for expected hazard.
    - Carbon monoxide detector(s) and alarm system are required in all building spaces, located adjacent to pellet storage areas that are attached to occupied buildings.

NYS Education Department also strongly recommends that schools consider installing a high-efficiency pellet boiler (minimum efficiency of 85% at high load); emission controls; thermal storage; boiler optimization controls; pellet storage; stacks designed and positioned to minimize wake effects from buildings or terrain; sample ports in the combustion vent stream; and other technologies or equipment arrangements to minimize emissions and have active ventilation systems in pellet storage areas.

3.3 European Emission Standards

In Europe, regulations for wood heating systems differ significantly in approach and form. Unlike the U.S. system, European regulations are based on maximum heat output and all units are subject to emission standards. Additionally, European requirements extend beyond PM; typically standards are established for efficiency, CO, volatile organic compounds, and NO_x.[11]

3.3.1 European Residential Emission Limits

In Europe, as in the U.S., several standards apply to residential units, and they are based on European Norm (EN) standards (EN 14785 for pellet stoves, EN 13240 for cordwood stoves, EN 303-5 for pellet, chip and cordwood boilers). Unlike the U.S., however, there is no single emission standard but rather devices are placed into different performance categories based on their emission tests. Emission standards for these performance categories are revisited and revised at regular intervals (typically every five years). When examining European units, it is important to look at not only whether the unit passes the standard, but at what classification level. Much like the states with USEPA standards, individual European nations can set stricter requirements than the EN standards.

In Europe, residential boilers and stoves with a nominal power below 1 MMBtu/hr have to be tested using the relevant European test method. As a result, every boiler or stove model sold in Europe has a certificate demonstrating emissions and efficiency performance using one of the three test methods previously referenced. Unlike the U.S., there are also standards for CO, NO_x, and VOC, as well as minimum efficiency levels.

11 More detailed information on European Emission Standard programs can be found in Section 5 of the European Wood-Heating Technology Survey at nyserda.ny.gov/Cleantech-and-Innovation/EA-Reports-and-Studies/Other-Technical-Reports/European-Wood-Heating-Technology-Survey

3.3.1.1 European Space Heating

Much like the USEPA 2015 NSPS, the European program has multiple test methods for different types of devices. The EN standards only provide limits for CO and efficiency. Individual countries have built on these requirements adding emission standards for NO_x, VOCs, and PM. The emission standard for CO is 1 % (12,500 mg/m³) based on 13% O_2 in the flue gas, and the minimum efficiency based on the gross calorific value (GCV) must be equal to or exceed 50 % (EN13240 p. 21). These numbers are minimum requirements for entry into the EN classification schema.

3.3.1.2 European Emission Standards for Pellet Stoves

For stoves fed with wood pellets, the European standard EN 14785 "Residential space heating appliances fired by wood pellets" defines European requirements. As it is possible to change the heat output in pellet stoves, the efficiency as well as the CO emission limits are set for two cases: nominal heat output and partial output. The efficiency has to be at least 75% when the stove operates at maximum load and at partial load it must not be less than 70%. Regarding the CO concentration in the flue gases, the defined limit is 0.04% (500 milligrams per cubic meter [mg/m³]) at nominal load and 0.06% (750 mg/m³) at partial load. These CO limits are based on 13% oxygen content in the flue gas (EN 14785 2006, p. 23).

3.3.1.3 European Emission Standards for Wood-fired Central Heating Units

In Europe, all central heating devices below 1 MMBtu/hr must meet the same European EN 303-5 standard. This standard applies to automatic and hand fed units, as well as pellet and cordwood units. The rule establishes construction/material requirements, limits for efficiency, and comprehensive emission standards.

Separate unit efficiency standards are established for three different unit classes to reflect diverse combustion standards across Europe. The required efficiency (η_K) is calculated based on the nominal heat output (QN) of the boiler as follows (EN 303-5, p. 26):

- Class 3: $\eta_K = 67 + 6 * \log(Q_N)$
- Class 2: $\eta_K = 57 + 6 * \log(Q_N)$
- Class 1: $\eta_K = 47 + 6 * \log(Q_N)$

The particulate emission limit ranges from 200 mg/m³ at 10% O_2 (class 1) to 150 mg/m³ at 10% O_2 (class 3) for manually stoked boilers (EN 303-5, p. 29). Conversion factors developed by BioEnergy 2020 translate performance European emissions data to U.S. metrics. Based on the conversion factors, EN standards requires an emission rate of 0.22 lb/MMBtu for Class 1 status and 0.17 lb/MMBtu for class 3 status (Musil-Schlaeffer 2010, p. 30-31). Table 3-5 contains the performance standards for the EN 303-5 performance categories.

Table 3-5. Performance Standards for the EN 303-5 Performance Categories

Stoking Method	**Nominal Heat Load in MBtu/hr**	**Emission Limits at 12% O_2**								
		CO in mg/m³			VOC in mg/m³			PM -filterable- in mg/m³ (lb/MMBtu/hr)		
		Class			class			class		
		1	2	3	1	2	3	1	2	3
Manual	≤ 170	20455	6545	4090	1635	245	120	165 (0.22)	145 (0.20)	125 (0.17)
	170 – 510	10227	4090	2045	1230	165	80	165 (0.22)	145 (0.20)	125 (0.17)
	510 – 1025	10227	1635	980	1230	165	80	165 (0.22)	145 (0.20)	125 (0.17)
Automatic	≤ 170	12270	4090	2455	1430	165	80	165 (0.20)	145 (0.18)	125 (0.15)
	170 – 510	10230	3680	2045	1020	120	65	165 (0.20)	145 (0.18)	125 (0.15)
	510 – 1025	10230	1635	980	1020	120	65	165 (0.20)	145 (0.18)	125 (0.15)

3.3.2 European ICI Emission Limits

For combustion systems with nominal heat rates over 1.7 MMBtu/hr, there is no European-wide standard, but national standards do exist. Austrian standards (“Feuerungsanlagenverordnung” (FAV) – Regulations for Combustion Plants) for units larger than 10 MMBtu/hr are shown in Table 3-6.

Table 3-6. Emission Standards for Austrian Wood Chip Furnaces (1-10 MMBtu/hr)

Sources: FAV, 1997, p. 2747; FAV, 2011, p. 3

Pollutant/Performance Value	NL 0.34-1.19 MMBtu/hr	NL 1.19-6.8 MMBtu/hr	NL 6.8-17 MMBtu/hr
Efficiency (%) GCV-based at full load (FL)	81.05 [a]	81.05 [a]	81.05 [a]
PM emissions (lb/MMBtu) at FL	0.2013	0.0671	0.0268
CO emissions (lb/MMBtu) at FL	0.3355	0.3355	0.3355
OGC emissions (lb/MMBtu) at FL	0.6709	0.5367	0.5367
NOx emissions (lb/MMBtu) at FL	0.3355	0.3335	0.3355

[a] Value from reference plant (1.32 MMBtu/hr NL) from Kaltschmitt, Streicher, 2009, p. 448.

Germany regulates wood-fired ICI applications under the Federal Emission Control Act ("Bundesimissionsschutzverordnung"-BImSchV), with the standards listed in Table 3-7. Combustion units installed after December 31, 2014 are no longer distinguished by their nominal loads, but rather their emission rates. After December 31, 2014, the emission limits decrease to 0.03038 lb/MMBtu for particulate matter and 0.6075 lb/MMBtu for CO (BImSchV 2010).

Table 3-7. Emission Standards for European (Germany) Wood Chip Furnaces (1-10 MMBtu/hr) Effective December 31, 2014

Source: BImSchV, 2010, p. 41.

Pollutant	Emission Standard
PM emissions (lb/MMBtu) at full load (FL)	0.03038 lb/MMBtu
CO emissions (lb/MMBtu) at FL	0.6075 lb/MMBtu

The Austrian regulation for combustion plants (FAV) is valid for ICI units sized 1.7 to 17 MMBtu (FAV 1997 and FAV 2011). Compared to small-scale applications, units that are subject to this standard are required to continuously monitor emissions. Austrian emission standards are set forth in Table 3-8. Exceedances of these limits trigger requirements for installation of secondary pollution controls or measures.

There is no European-wide standard for large-scale combustion systems. Emission standards adopted by Austria for large-scale systems are provided in Table 3-8. U.S. and European standards for PM are similar, but European standards regulate additional pollutants and standards for ICI boilers sized 1-10 MMBtu/hr are significantly more stringent.

Table 3-8. Emission Standards for Large-scale Heating Systems in Austria (>10 MMBtu/hr)

Sources: FAV, 1997, p. 2747; FAV, 2011, p. 3

Pollutant	Minimum requirements[a] (NL 17-34 MMBtu/hr)	Minimum requirements[a] (NL >34 MMBtu/hr)
PM emissions (lb/MMBtu) at full load (FL)	0.0268	0.0268
CO emissions (lb/MMBtu) at FL	0.1342	0.1342
Organic gaseous carbon (OGC) emissions (lb/MMBtu) at FL	0.5367	0.2684
NOx emissions (lb/MMBtu) at FL	0.3355	0.2013

[a] Reference fuel is wood chips.

3.4 Test Methods

Relevant to U.S. and European emission standards for wood-fired heating devices are the related test methods. This section provides a short summary of applicable approved U.S. and European market test methods and identifies differences between the methods.

3.4.1 Residential Applications

The emission and efficiency requirements for residential applications differ depending on the fuel and the combustion technology. A summary of European and U.S. standards is provided in the following sections.

3.4.1.1 Cordwood Stoves

The U.S. test method to measure emissions from woodstoves is USEPA Method 28, which was adopted in 1988, and is codified in 40 CFR part 60, subpart AAA. The test method specifies the use of untreated, air-dried, Douglas fir lumber (note that this is dimensional lumber, not cordwood) with a moisture content range of 16% to 20% on a wet basis or 19% to 25% on a dry basis. The test method also specifies the size of the wood, depending on firebox volume, how it is to be loaded, and fuel ignition procedures. There are slight variations for catalyst-equipped heaters. The rule includes a fueling protocol for emission testing and requires four test runs at specified burn rate categories as indicated in Table 3-9. The method recognizes that not all stoves can operate in all four burn categories. Accordingly, the method allows stoves that cannot operate in the Category 1 range to conduct two complete runs in the Category 2 range. The average emission rate is determined by calculating a weighted average based on Table 28-1 in the 1988 NSPS.

Table 3-9. Burn Rate Categories for USEPA Method 28

	Category 1	Category 2	Category 3	Category 4
Average Burn Rate on kg/hr (dry basis)	< 0.80	0.80 to 1.25	1.25 to 1.90	Maximum burn rate

USEPA Method 28 specifies two methods (Method 5G and 5H) for measuring particulate matter. Method 5G uses a dilution tunnel method to measure PM emissions. In this method:

- Exhaust gas is collected via the stack of a wood heater under a total collection hood.
- Stack exhaust gas is combined with ambient dilution air. The purpose is to mimic the expected conditions in the real world.
- Material is drawn under a specific dilution ratio in the sampling tunnel onto two glass fiber filters in series.
- Filters must remain at a temperature of no more than 32 °C (90 °F).

Method 5H is somewhat akin to typical PM field measurement protocols and uses the following process:

- Exhaust gas is withdrawn from a single point in the stack.
- Material is collected on two glass fiber filters separated by impingers immersed in an ice water bath.
- Filter #1 is maintained at a temperature of no greater than 120 °C (248 °F).
- Filter #2 and the impinger system are cooled so that the exit temperature of the second filter is no more than 20 °C (68 °F). The purpose of the second filter and cooling system is to ensure collection of the condensable PM.

Under both methods, filters, probes, and impingers are measured gravimetrically and desiccated in a humidity controlled environment to ensure removal of water. Measurements are taken at prescribed intervals, final measures are determined after filter measurements have stabilized. The final emission result is a mass over time number based on a weighted average of the emission rates of the four burn categories.

Europe uses EN 13240 as the method to measure emissions from woodstoves. This method was prepared by the European Committee for Standardization (CEN) through its technical Committee CEN TC 295, and adopted in April 2001. Unlike the U.S. method, the EN method is not in the public domain and is protected under copyright. Therefore, purchasing a copy of the method is the only way to obtain the complete method. The EN method varies significantly from the U.S. test method in several key areas: measurement method, fuel type, burn rates, pollutants measured, calculation methods, and metrics reported. An overview of test components is in Table 3-10.

Table 3-10. Comparison of USEPA Method 28 and EN 13240

Metric	USEPA Method 28	EN 13240	
		Full load	**Partial load**
Test Type	Hot to Hot Test	Hot to Hot Test	
Measurement Method	Dilution tunnel or direct flue gas to cooled impingers	Direct flue gas	
Fuel	Dimensional lumber Douglas Fir	Cordwood Multiple species allowed including birch and beech	
Test Duration	Returns to weight prior to loading the fuel charge	Entire fuel charge has been burnt and only ash remains	Returns to weight prior to loading the fuel charge
Burn Rates	4 burn categories: Low Med-low Med-high Maximum burn rate	2 burn categories Maximum burn rate Partial load, 30% of maximum burn rate	
Pollutants	Total PM	Filterable PM Carbon Monoxide Nitrogen Oxides VOCs	
Metric	Grams per hour	Gram per megajoule	
Emission rate calculation	Weighted average	Reported by load, no averaging	
Efficiency	No efficiency measurements; anticipate proposal to use CSA-B415	Efficiency testing is required	
Heat Value of Wood	Higher heat value	Lower heat value	

One of the critical differences between the two methods is the capacity to capture the condensable fraction of PM. Unlike the U.S. method, in which the flue gases are cooled to collect both the filterable and condensable fraction of PM, the European method utilizes a heated filter media similar to those required for particulate testing in stacks. The heated filter method only captures the filterable particulate matter and does not have the capacity to capture the condensable fraction of PM. Although condensable

PM makes up a significant percentage of emissions in low efficiency devices, it is estimated that the amount of condensable PM in high efficiency devices may be as low as 10%. Therefore, the difference in measurement methods is likely to create a larger gap in results for less efficient devices than in more efficient devices.

Another significant difference is the required test fuel. The U.S. method specifies what type of wood can be used, the size of the wood, and the placement of wood, while the EN method allows various species of wood and random placement. The use of cordwood in the EN method rather than dimensional lumber allows wood to be placed in random patterns, as opposed to the USEPA NSPS prescribed methods that detail how a fuel charge must be built, including specifications for the size, placement, and spacing of wood.

Finally, the lack of various burn categories in the European method makes it difficult to compare test results. In the U.S. method, testing is required at very low load, while the European method requires one test at the maximum output and one test at a partial load.

3.4.1.2 Residential Central Heating Devices

In the 2015 NSPS, the USEPA identified five test methods that could be used to determine compliance with emission standards. These tests include USEPA Method 28 WHH, ASTM E2618-13, CSA B415.1, USEPA Method 28 Partial Thermal Storage, and EN 303-5. These tests vary significantly across major test parameters, including PM measurement methods, fueling protocols, operational parameters, and emission profile measurements. Table 3-11 provides an overview of the differences between these methods.

Table 3-11. Wood Hydronic Heater Test Method Measurement Parameters

	USEPA Method 28 WHH	ASTM E2618-13	CSA B415.1	EPA Method 28 Partial Storage	EN 303-5
Manual Loaded Fuel: Crib, Cord, or Both Addressed	Crib	Cordwood	Crib and cordwood	Cordwood	Cordwood
Feed: Manual/Automatic/Both	Manual	Both	Both	Manual	Both - wide range including coal
PM Measurement method	Dilution tunnel	Dilution tunnel	Dilution tunnel	Dilution tunnel	In stack, hot filter
PM measurement	Total PM	Total PM	Total PM	Total PM	Filterable PM
PM Emission Metric	Annual average lb/MMBtu output	Annual average lb/MMBtu output	Simple average of test runs - lb/MMBtu output	Annual average lb/MMBtu output	Average over two periods at full load. mg/m[c]
Wood Fuel Species	white or red oak	Any within specified density range	Any within specified density range	white or red oak	5 species
Moisture range (dry basis)	19-25%	19-25%	18-28%	19-25%	13.4-20%
Method of Efficiency Determination	Thermal Output	Thermal Output	Stack Loss Method	Thermal Output	Thermal Output
Number of Burn Rate Categories	4	4[e]	4	4 with 2 as optional	2
Lowest Output Tested - Manual Feed	15%	15%	35%	15%	50%[d]
PM Emission Rate (g/hr)	YES - RUN AVERAGE	YES - RUN AVERAGE	NO	YES - by phase of burn cycle	NO[c]
Measures Startup	NO	NO	NO	YES	NO
Thermal Storage? No, partial, full	NO	No, partial, or full	NO	PARTIAL	NO
Cold Start?	NO	YES- If used with storage[f]	NO	YES- Cat I and II	NO
CO Required to be measured?	YES	YES	YES	YES	YES
CO emission metric?	NO	NO	YES	YES	YES
CO Emission Rate (g/hr)	NO	NO	NO	YES	NO
Emissions measured for phases of burn cycle?	NO	NO	NO	YES	Measurement during 2 segments only
CO Emission Rate vs Time Required	NO	NO	NO	YES	NO

Table 3-11 continued

	USEPA Method 28 WHH	ASTM E2618-13	CSA B415.1	EPA Method 28 Partial Storage	EN 303-5
Upper size limit	350,000 Btu/hr[a]	NO - typical apps described	500,000 Btu/hr	350,000 Btu/hr[b]	500 kW (1.7 MMBtu/hr)
Fuel Loading for hand-fed units (minimum)	10 lb/ft^3	10 lb/ft^3	10 lb/ft^3	10 lb/ft^3	Manufacturer's Specifications

Notes:

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

More specifically, USEPA Method 28WHH does not integrate use of thermal storage. The BNL test requires a thermal storage tank capable of absorbing part of the energy from a charge of fuel, and the ASTM method allows for full, partial, or no storage. Four of these test methods require testing in four categories, while the EN 303-5 requires testing at just two loads (but requires thermal storage to be installed in the field). All five methods test at full load (Category IV) but the partial loads can vary among the test methods. The USEPA Method 28 WHH, ASTM and BNL methods all test at a low load (Category I) of 15% of the full load, but the CSA only tests as low as <35% load and the EN 303-5 tests a low load between 25% and 50% of full load (Table 3-11). In addition to these significant differences among test load categories, some test with a hot start only, while others also include a cold start. The USEPA Method 28 WHH, CSA B415, and EN 303-5 methods only test in a "hot to hot" duty cycle, while the ASTM includes a cold start if storage is used, and the BNL test requires a cold start. An additional important difference among test methods is the ability of the test to isolate the start-up, steady state, and end phases of the burn cycle. Only the BNL test method isolates the three phases. The EN 303-5 method captures the start-up and steady state at full load, but not at partial load.

In addition, USEPA Method 28 WHH uses crib wood, while all others use cordwood. (CSA may use either.) All methods use thermal output to determine the thermal efficiency, except for the CSA B425 method, which uses a stack loss method. All of the test methods use a dilution tunnel, except for the EN 303-5 method, which uses an in-stack method. The USEPA Method 28 WHH, ASTM, CSA, and BNL report PM in lb/MMBtu (output), while the EN 303-5 method reports in units of mg/m^3. In addition, the USEPA Method 28 WHH, ASTM, and BNL test methods also report in g/h.

3.5 Wood Fuel Specifications

Variability in wood fuel properties can have an impact on the heating device operations from the standpoint of equipment performance, emissions, and efficiency. Wood fuel variability can be affected by:

- Fuel density (hardwood versus softwood).
- Bark content.
- Moisture content.
- Fuel proportions.

The U.S. does not have regulatory specifications for wood fuels; however, Europe began developing wood fuel specifications in 1998 through the European Committee for Standardization process. Under this process, a technical committee (CEN/TC 335) developed standards to describe all forms of solid biofuels within Europe, including wood chips, wood pellets and briquettes, logs, sawdust, and straw bales. Currently, there are various specifications for wood fuels, including:

- Normative specifications for wood chips, including classification requirements for origin, size, moisture content, and ash content.
- Normative specifications for wood pellets, including physical and elemental content limits, moisture content, and ash content.
- Technical standards for specified parameters to ensure a standard measurement method.

The following sections detail information on the U.S. voluntary standards and EN requirements for wood chips.

3.5.1 Wood Chip Specifications

3.5.1.1 United States

In the United States, there are no standard fuel specifications for wood chips. Due to the lack of regulatory standards, U.S. equipment cannot be designed to be compatible with a specified fuel. This means that each installation may have slightly different fuel requirements, based upon the equipment choice and configuration. Some facilities, however, have developed specifications for wood chips. The following are wood fuel specifications for two scales of wood heat units developed by Innovative Natural Resource Solutions LLC. These specifications are intended to reflect the typical requirements for different U.S. units.

- Larger Unit (e.g., college district heating, approximately 20,000 tons per year).[12] This standard does not specify density requirements so fuel may be composed of both soft and hardwoods.
    - Whole tree chips, whole bole chips from forest thinning and cutting operations, and mill residue chips.
    - Nominal size range to be 2½ inches × 2½ inches × ¾ inch.
    - “Fines” less than 3/16” shall not exceed 10% of the total load.
    - Overs shall not exceed 12 inches in length and 1inch in diameter, and shall be less than 20% of entire load.
    - Moisture content shall not exceed 45%.
    - The fuel shall not contain noncombustible material such as dirt and rocks and contaminants that include, but are not limited to, paint, oils, salts, pressure treated material, and other contaminants.
    - Fuel shall contain less than 10% bark.
    - Total mineral/ash content of the total fuel mix shall be less than 2%.
- Community-scale Unit (e.g., high school, approximately 1,500 green tons per year).[13] This standard does not specify density requirements so fuel may be composed of both soft and hardwoods.
    - Clean, 100% wood residues from known sources, free from paint, chemicals, glues, metals, nails, or other nonwood substances. No rotten substances that are evidence of decomposition and no whole-tree chips.
    - Moisture content <45%.
    - Chip size 2.5 inches × 1.5 inches × 5/8 inch maximum.
    - Delivery via live floor truck, length ≤ 53 feet, height ≤ 14 feet.

3.5.1.2 European Chip Specifications

In Europe, wood chip specifications have been developed and codified in EN 14961-4 (edition 2011-07-15). These requirements lay out physical and elemental specifications, as shown in Table 3-12 and Table 3-13.

12 Colby College (Maine). *Request for Proposals: Biomass Fuel Supply.* March 22, 2011.

13 Winnisquam School District (NH). *Request for Proposals: Biomass Fuel Supply*. August 11, 2009.

Table 3-12. EN 14961 Wood Chip Sizing Requirements

Dimensions			
Classification	**Minimum 75 w-% in main fraction, mm**	**Fines fraction, (≤ 3.15 mm) w-%**	**Coarse fraction, (w-%), maximum length of particle (mm), maximum cross sectional area (cm^2)**
P16A P16B	3.15 ≤ P ≤ 16 3.15 ≤ P ≤ 16	≤ 12 ≤ 12	≤ 3 % > 16 mm, and all < 31.5 mm The cross sectional area of the oversized particles< 1 cm^2 ≤ 3 % > 45 mm, and all < 120 mm The cross sectional area of the oversized particles< 1 cm^2
P31.5	8 ≤ P ≤ 31.5	≤ 8	≤ 6 % > 45 mm, and all < 120 mm The cross sectional area of the oversized particles< 2 cm^2
P45	8 ≤ P ≤ 45	≤ 8	≤ 6 % > 63 mm and maximum 3.5 % >100 mm, all < 120 mm The cross sectional area of the oversized particles< 1 cm^2

Table 3-13. Specification of Wood Chips for Non-Industrial Use

Properties	**Unit**	**Pellet Classification**			
		A1	**A2**	**B1**	**B2**
Origin and source (according to EN 14961-1)		1.1.1 Whole trees without roots 1.1.3 Stemwood 1.2.1 Chemically untreated wood residues 1.1.4.3 Logging residues, stored broadleaf	1.1.1 Whole trees without roots 1.1.3 Stemwood 1.2.1 Chemically untreated wood residues 1.1.4.3 Logging residues, stored broadleaf	1.1 Forest, plantation and other virgin wood b 1.2.1 Chemically untreated wood residues	1.2. By-products and residues from wood processing industry 1.3.Used wood
Particle size, P	Mm	to be selected from Table 1	to be selected from Table 1	to be selected from Table 1	
Moisture, M	w-%	M10 ≤ 10 M25 ≤ 25	M35 ≤ 35	to be specified	
Ash, A	w-% dry	A1.0 ≤ 1.0	A1.5 ≤ 1.5	A3.0 ≤ 3.0	
Net calorific value, Q	MJ/kg or kWh/kg	Q13 ≥ 13.0 or Q3.6 ≥ 3.6	Q11 ≥ 11.0 or Q3.1 ≥ 3.1	to be specified	
Bulk Density, BD	kg/ loose m^3	BD150 ≥ 150 BD200 ≥ 200	BD150 ≥ 150 BD200 ≥ 200	to be specified	
Nitrogen	w-% dry	-	-	≤ 1.0	
Sulfur	w-% dry	-	-	≤ 0.1	
Chlorine	w-% dry	-	-	≤ 0.05	

3.5.2 Wood Pellets

3.5.2.1 United States

In the U.S., the Pellet Fuel Institute (PFI) has created a series of voluntary standards for wood pellet production primarily for labeling purposes and quality control.[14] Although the standards are voluntary, many manufacturers comply with them, as warranties on domestic or imported combustion equipment may not cover damage of equipment by nonconforming pellets.

The PFI designated quality grades are based primarily on ash content (the amount of ash left behind after fuel burning), and are as follows: Premium (less than 1.0% ash), Standard (less than 2.0% ash), and Utility (less than 6.0% ash).[15] The PFI has designated 10 labs throughout the U.S. and Canada to test wood pellets for compliance with its standards.[16] Table 3-14 shows the fuel grade requirements set by PFI.

[14] Pellet Fuels Institute. "PFI Standards Program." Pellet Fuels Institute. http://www.pelletheat.org/pfi-standards .

[15] Pellet Fuels Institute. "PFI Standard Specification for Residential/Commercial Densified Fuel." Pellet Fuels Institute. http://www.pelletheat.org/assets/docs/2015/Standards/standard%20specification%20july%209%202015.pdf

[16] Pellet Fuels Institute. www.pelletheat.org/

Table 3-14. PFI Fuel Grade Requirements

Source: http://pelletheat.org/wp-content/uploads/2011/11/PFI-Standard-Specification-November-2011.pdf

	Residential/Commercial Densified Fuel Standards See Notes 1 - 3		
Fuel Property	PFI Premium	PFI Standard	PFI Utility
Normative Information - Mandatory			
Bulk Density, lb./cubic foot	40.0 - 46.0	38.0 - 46.0	38.0 - 46.0
Diameter, inches	0.230 - 0.285	0.230 - 0.285	0.230 - 0.285
Diameter, mm	5.84 - 7.25	5.84 - 7.25	5.84 - 7.25
Pellet Durability Index	≥ 96.5	≥ 95.0	≥ 95.0
Fines, % (at the mill gate)	≤ 0.50	≤ 1.0	≤ 1.0
Inorganic Ash, %	≤ 1.0	≤ 2.0	≤ 6.0
Length, % greater than 1.50 inches	≤ 1.0	≤ 1.0	≤ 1.0
Moisture, %	≤ 8.0	≤ 10.0	≤ 10.0
Chloride, ppm	≤ 300	≤ 300	≤ 300
Heating Value	NA	NA	NA
Informative Only - Not Mandatory			
Ash Fusion	NA	NA	NA

Third-party testing and inspection are the basis for assuring compliance with the PFI program requirements. The program prohibits the use of chemically treated materials, but does not include testing for elements that would indicate the use of noncompliant materials. The program also allows up to 2% of additives whose compositions are not explicitly defined. Manufacturers meeting the PFI program requirements display the PFI quality label on the front lower third of their product bags.

3.5.2.2 European Standards

In 2010, the European Union established three quality classes for wood pellets (Table 3-15) that replaced existing country-specific regulations (CEN/TC 335 Biomass Standards). The European Union approach also includes a compliance assurance mechanism. Under this mechanism, an independent auditor annually evaluates the pellet plant and its quality management. There is some limited pellet analysis throughout the year in lieu of testing every delivered batch of pellets.

Table 3-15. Overview of the European Union Pellet Quality Classes

A1	A2	B
1.1.3 Stem wood 1.2.1 Chemically untreated residues from the wood processing industry	1.1.1 Whole trees without roots 1.1.3 Stem wood 1.1.4 Logging residues 1.2.1.5 Bark 1.2.1 Chemically untreated by-products and residues from the wood processing industry	1.1 Forest, plantation and other virgin wood 1.2.1 Chemically untreated, by-products and residues from the wood processing industry 1.3.1 Chemically untreated, used wood

The relevant wood pellet class for residential end users is A1 under the European Union approach. It contains the most stringent requirements overall. A1 wood pellets must have an ash content of under 0.5% when using wood from conifers and under 0.7% when using other types of wood. Apparent density, instead of bulk density, is specified. Apparent density better reflects the quantity of wood pellets conveyed into a pellet stove's combustion chamber if the rotation speed of the automatic stove feeder is constant. European residential applications use A1 graded pellets exclusively.[17] The primary feedstock for the A1 wood pellets comes from sawmill byproducts.

The European A2 and B wood pellet classes apply primarily to industrial applications, such as power plants or other large installations. Class A2 covers a wider spectrum of raw materials having an ash content up to 1%. The industrial standard Class B allows for even higher ash content and the expanded use of other raw materials, such as bark. Table 3-16 and Table 3-17 provide physical and elemental specifications for European pellets.

[17] BioEnergy 2020 presentation materials provided to NESCAUM.

Table 3-16. Physical Fuel Specifications for European Pellets

Source: BioEnergy 2020

Property	Unit	A1	A2	B	Analysis method
Diameter	mm	6 (±1) 8 (±1)	6 (±1) 8 (±1)	6 (±1) 8 (±1)	EN 16127
Length (L)	mm	≤ 402	≤ 402	≤ 402	EN 16127
Moisture (M)	as received, weight% wet basis	≤ 10	≤ 10	≤ 10	EN 14774-1, EN 14774-2
Ash (A)	dw%	≤ 0.7	≤1.5	≤ 3.0	EN 14775
Mechanical durability (DU)	dw%	≥ 97.5	≥ 97.5	≥ 96.5	EN 15210-1
Fines (F) (<3.15 mm)	dw%	≤ 1.0	≤ 1.0	≤ 1.0	EN 15210-1
Additives	dw%	<2 m-%; type and amount to be stated			
Net calorific value (Q)	MJ/kg or kWh/kg	≤ 16.5 or Q4.6,4.6 ≤ Q ≤ 5.3	Q16.3, 16.3 ≤ Q ≤ 19 or Q4.5,4.5 ≤ Q ≤ 5.3	Q16.0, 16.0 ≤ Q ≤ 19 or Q4.4,4.4 ≤ Q ≤ 5.3	EN 14918
Bulk density	kg/m³	≥ 600	≥ 600	≥ 600	EN 15103

Table 3-17. Elemental Fuel Specifications for European Pellets

Source: BioEnergy 2020

Property	Unit	A1	A2	B	Analysis method
Nitrogen (N)	% dw	≤ 0.3	≤ 0.5	≤ 1.0	EN 15104
Sulfur (S)	% dw	≤ 0.03	≤ 0.03	≤ 0.04	EN 15289
Chlorine (Cl)	% dw	≤ 0.02	≤ 0.02	≤ 0.03	EN 15289
Arsenic (As)	mg/kg dw	≤1	≤1	≤1	EN 15297
Cadmium (Cd)	mg/kg dw	≤0.5	≤0.5	≤0.5	EN 15297
Chromium (Cr)	mg/kg dw	≤10	≤10	≤10	EN 15297
Copper (Cu)	mg/kg dw	≤10	≤10	≤10	EN 15297
Lead (Pb)	mg/kg dw	≤10	≤10	≤10	EN 15297
Mercury (Hg)	mg/kg dw	≤0.1	≤0.1	≤0.1	EN 15297
Nickel (Ni)	mg/kg dw	≤10	≤10	≤10	EN 15297
Zinc (Zn)	mg/kg dw	≤100	≤100	≤100	EN 15297
Ash melting point	°C	characteristic temperatures should be stated (voluntary)			EN 15370

The European Union standards prohibit pellets containing any recycled wood or outside contaminants. Recycled materials such as particleboard, treated or painted wood, and melamine resin-coated panels are considered particularly unsuitable for use in wood pellets because of noxious air emissions resulting from the nonwood components and uncontrollable variations in the burning characteristics of the pellets.

3.6 Summary of Wood Heating Regulatory Framework

A review of state and federal regulations indicates that regulation of this sector has taken a patchwork approach. Currently, only a limited subset of residential devices and a few large ICI devices have emission standards that reflect best performing equipment. In NYS, many ICI boilers and most residential devices do not need to meet any emission standard. Units larger than 1 MMBtu/hr have an emission standard that is 20 times higher than those in Vermont. Of the total population of boilers in the New York boiler database, 69% are not subject to any environmental emission standards, 30.6% are subject to NYS emission standards, which are less stringent than those in surrounding states, and 0.2% are subject to federal emission standards. Therefore, without further regulation, high-emitting, low-efficiency devices in ICI applications can be legally sold and installed in NYS. For residential units, high emitting, low efficiency devices can be legally sold and installed in NYS until the Step 2 standards of the 2015 NSPS for residential wood heater take effect in January 2016. This rule, however, will have no impact on the secondary market (resale market) and does not address the significant emission issues surrounding the existing inventory of devices. Compounding this issue is the lack of mandated fuel specifications. Low-emitting, high-efficiency devices will not work properly, if used with improper fuels. Analysis of European regulations find that a comprehensive regulatory framework, combined with fuel standards matched to proper technology, can build a robust and clean wood heating sector.

3.7 References

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4 Government-Sponsored Heating Incentive Programs

Wood heat technologies have the potential to reduce NYS' dependence on conventional fuels and reduce consumers' heating costs. However, deployment of more efficient wood heat technologies is, to date, limited in the State and the country. Limited deployment is attributed to a lack of consumer and retailer awareness of, and confidence in, wood heat technologies; high upfront technology costs; and limited infrastructure for the delivery of wood fuels such as seasoned cordwood or pellets. Well-designed government policies that ensure protection of public health and the environment are likely to contribute to an increase in consumer and retailer awareness and confidence, help consumers overcome the high upfront cost of technologies, and induce growth of the distribution infrastructure for wood.

NYS has chosen to promote the use of high-efficiency, low-emission wood technologies to heat homes and commercial buildings as part of its Renewable Heat NY initiative. This initiative encourages development of the industry on a faster time line, raises consumer awareness, supports the development of New York-based advanced technology heating products, and develops local sustainable heating markets that use wood as fuel.

Several New England states have added, or are exploring the addition of, wood heating to existing renewable portfolio standards (RPS) or establishing alternative portfolio standards (APS) that would credit wood heating. Thoughtful policy design will be needed to ensure that the programs, which typically award credit as energy is produced, address the capital cost barrier. Established policy mechanisms, such as awarding production credit upfront based on industry standards, can help meet this challenge. Concerns related to metering and verifying the performance of wood heating technologies will need to be addressed.

States in the Northeast have also used the following approaches to promote wood heat projects:

- Cost supports, including incentive rebates, creative financing, and tax breaks.
- Pilot projects, including State and municipal lead-by-example programs.
- Change-out programs.

These measures have been beneficial, in varying degrees, to increase use and "prove" the viability of wood heat technologies in real-world settings. Planning and administrative requirements, the need for long-term monitoring, and resource constraints are among the challenges to implementing these types of programs.

4.1 Methodology

This section reviews the different types of policy mechanisms that could be used to incentivize wood heat, and provides an overview of lessons learned and recommendations for improvements from states that have implemented one or more of the measures. This review led to the development of the following set of "key factors" for consideration when developing a wood heat policy. Regardless of type and design, any policy to incentivize wood heat should:

- Address the high upfront cost of technologies.
- Address the need to encourage growth of fuel distribution infrastructure.
- Address measurement, monitoring, and verification.
- Incorporate minimum emission and efficiency standards.
- Establish proper sizing and installation requirements, including system integration, controls to protect the new and existing boilers, and heat distribution systems.
- Establish fuel standards and a vertical supply chain protocol.
- Establish fuel sustainability requirements.
- Address the need to incorporate standards into building and related codes by providing suggested standards and language for adoption at the county-level.
- Address safety requirements for biomass combustion appliances, including carbon monoxide monitoring, power failure safety procedures, and mechanisms to prevent burn-back.

The information contained in this chapter was derived from the following four components:

- A survey of industry representatives.
- A literature review of policy documents written by and for European countries and New England states.
- Meetings and informal discussions with state staff in New England states and NYS.
- A questionnaire for New England states.

These components are described in more detail in the following subsections.

4.1.1 Industry Survey

In March 2013, NESCAUM circulated a survey to self-identified members of the biomass heating sector, and received more than 160 responses. Responders included fuel producers, manufacturers and distributers, residential and industrial/commercial equipment manufacturers and retailers, forestry sector members, and government officials.

Survey results are discussed in Section 4.2. Policy-relevant questions and information requests in the survey included:

- What are the top three issues that you expect will drive demand of biomass for heating in NYS over the next 10 years?
- What do you expect to see as the largest barrier to expanded use of biomass for heating?
- What do you believe are the top three issues or needs that must be addressed to develop the wood heat industry?
- List the top barriers that you see as limiting the use of biomass for home heating purposes in NYS.
- List the most critical factors that could increase the use of biomass for residential heating in NYS.
- List the top barriers that you believe limit the use of biomass for thermal heating by the commercial or industrial sectors.
- List the most critical items that could create opportunities for the commercial, industrial, or institutional sector to increase the use of thermal biomass industry in NYS.
- What are the top three issues you expect will drive demand for wood heat feedstocks and/or fuels in NYS over the next 10 years?
- What current policies or actions discourage you from investing in the production/manufacturing of biomass feedstocks?
- Are there programs and/or policies related to thermal biomass and/or wood heat in place in other areas that you believe would be effective models for NYS to follow?
- What are your three highest policy or program priorities that you would like to see NYS undertake to promote the use of biomass heating in the State?
- Are there any policies or programs that create disincentives/barriers for your industry?
- In order of importance, please list actions that you would like to see NYS undertake to promote the use of wood heat in NYS.

4.1.2 Literature Review

NESCAUM reviewed key documents written by and for wood heat policymakers in the European Union and the New England states. These key documents included:

- *An Overview of Biomass Thermal Energy Policy Opportunities in the Northern Forest Region*, prepared for the Northern Forest Center by the Biomass Energy Resource Center.
- *Massachusetts Renewable Heating and Cooling Opportunities and Impacts Study*, prepared for Massachusetts Department of Energy Resources by Meister Consultants Group.
- *Including Alternative Resources in State Renewable Portfolio Standards: Current Design and Implementation Experience*, National Renewable Energy Laboratory.
- *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009*, European Union.
- *Intelligent Energy - Europe II Implementation Report 2012*, European Commission.
- *Biomass Heating in Upper Austria: Green Vision, Green Jobs*, a report of the O.O. Energiesparverband (Upper Austrian Renewable Energy Agency).

Additional resources were also reviewed to develop a complete picture of the European and Northeast U.S. thermal biomass policy landscape. Where appropriate, these additional resources are documented in footnotes.

4.1.3 Meetings and Discussions with Stakeholders

NESCAUM had informal discussions with a number of stakeholders, including policymakers from each of the New England states, to assist in developing this section of the report. NESCAUM also worked with a member of the Austrian Biomass Association. These informal discussions helped identify key resources, design both the thermal biomass sector survey and the questionnaire for states, and describe lessons learned and key policy considerations.

NESCAUM also convened or participated in meetings with policymakers. These meetings included a New York/New England Renewable Thermal Meeting in January 2014, and an afternoon session of the New York State Wood Heat Report Stakeholder Meeting in June 2014.

Research culminated in a questionnaire circulated to the New England states to better understand their experiences with policies and programs to incentivize thermal biomass technologies and uses.

The questionnaire for New England states included the following:

1. Do you have a renewable portfolio standard that includes thermal technologies? How was this accomplished? What types of technologies are covered? How are they credited?
2. If your renewable portfolio standard includes thermal biomass, what have been the successes? The challenges? The lessons learned?
3. In your opinion, what should a state consider when designing a portfolio standard that includes thermal biomass (e.g., mechanisms for addressing projects with high capital costs/ minimum efficiencies of units)?
4. What other types of thermal biomass policies and programs have your state implemented? Please describe any tax incentives, rebates, grants, changeout programs, other financing mechanisms, etc.
5. For each of the programs mentioned above, what have been the successes, challenges, and lessons learned with these programs?
6. Does your state have plans for future polices or programs (including for technologies or biomass incentives or standards)?
7. Are there success, challenges, and lessons learned from other programs (e.g., solar programs) in your state that might inform the development of thermal biomass policies and programs?

The survey was distributed to targeted key staff in governors' offices, utility commissions, energy offices, and environmental offices. Staff from Rhode Island and Connecticut reported that they are not aware of any thermal biomass policies in their states. Staff from Massachusetts, New Hampshire, and Maine worked within their states to provide coordinated state responses. Vermont directed NESCAUM to the report prepared by the Biomass Energy Resource Center at Vermont Energy Investment Corporation (VEIC).[18]

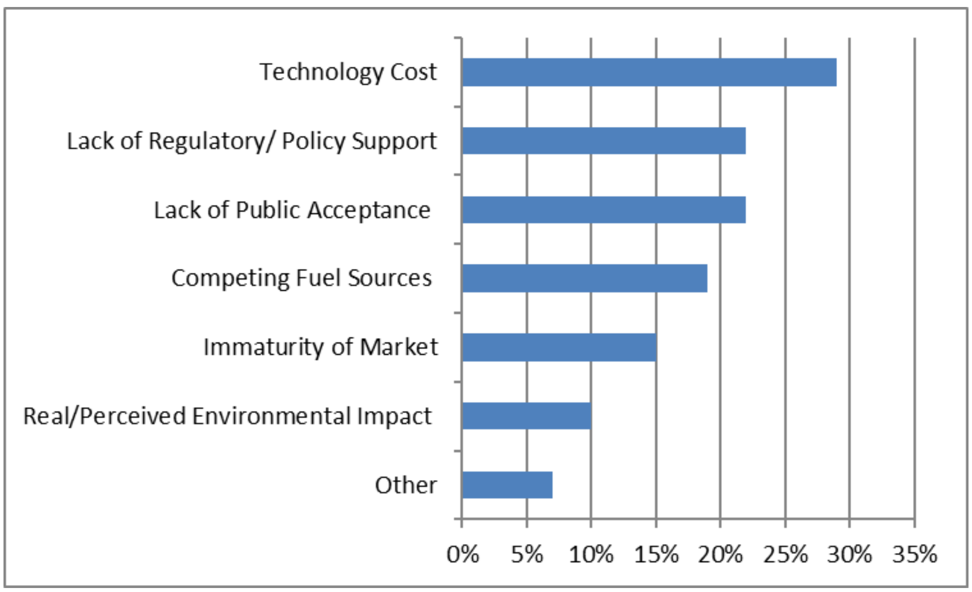
[18] Biomass Energy Resource Center. "An Overview of Biomass Thermal Energy Policy Opportunities in the Northern Forest Region." Prepared for Northern Forest Center. October 30, 2013.

4.2 Why Policies are Needed to Incentivize Wood Heating

Although wood heat technologies may be cost effective in the long run, they have high upfront capital costs, particularly residential units.[19] Homeowners and business owners may not have the capital needed to purchase these units. In addition, consumers may not understand that although the upfront costs are high and the payback periods are long, efficient biomass boilers on average have lower "leveled costs of energy" (LCOE) than conventional technologies.[20]

According to NESCAUM's survey of the thermal biomass industry representatives, the cost of technologies, followed by lack of regulatory and policy support and a negative public perception, were the largest barriers to expanded use of biomass for thermal heating. Figure 4-1 ranks these and other barriers to expanded use of residential thermal biomass heating technologies identified in the survey.

Figure 4-1. Barriers to Expanded Use of Biomass for Residential Thermal Heating

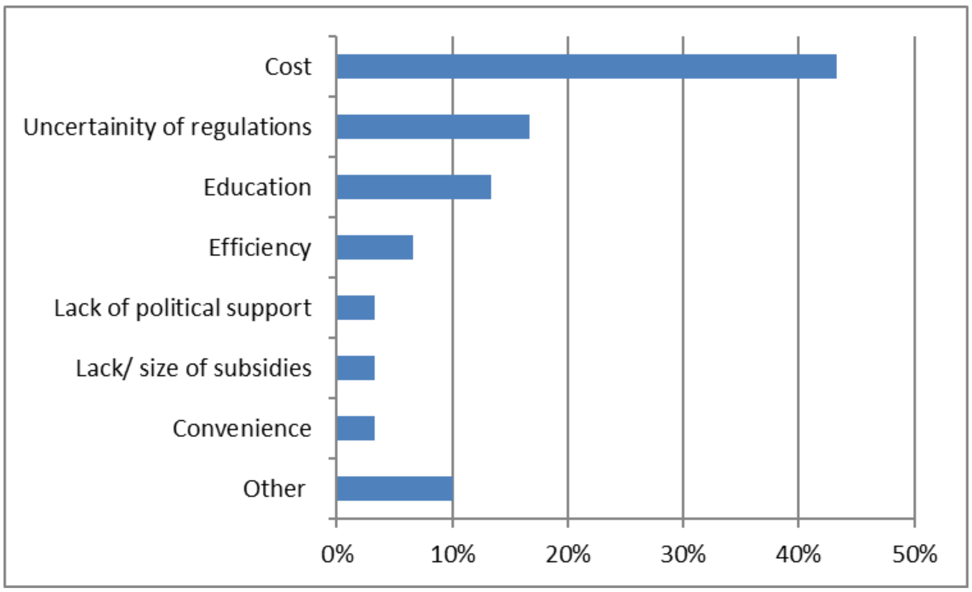


[19] Meister Consultants Group. "Massachusetts Renewable Heating and Cooling: Opportunities and Impacts Study." Prepared for Massachusetts Department of Energy Resources. March 2012.

[20] Although the upfront costs for technology are more expensive, the cost of wood fuel is often half of the cost of heating with fossil fuel on a Btu basis.

Cost was also identified as a barrier to adoption of thermal biomass technology for heating in the commercial and industrial sectors. Regulatory certainty, particularly for biomass boiler emissions standards,[21] and the need for education to address lack of public awareness were also named as barriers to expansion of thermal biomass for heating in the commercial and industrial sectors. Figure 4-2 ranks these and other barriers to thermal biomass heating in the commercial and industrial sectors.

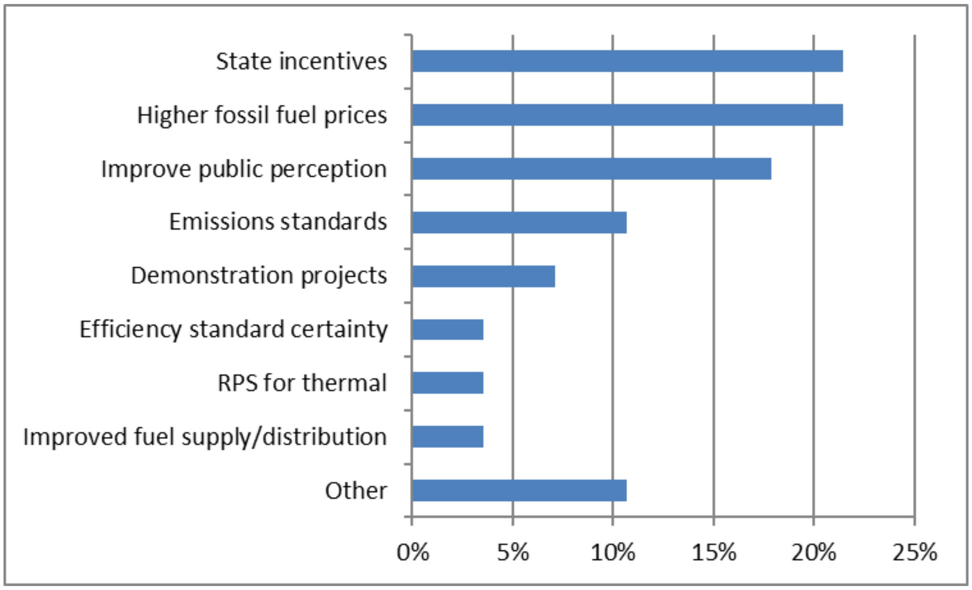
Figure 4-2. Barriers to Expanded Use of Biomass for Thermal Heating in the Commercial and Industrial Sectors



When asked what factors were likely to drive deployment of thermal biomass technologies over the next 10 years, survey respondents identified state incentives, increased fossil fuel prices, and improved public perception as the primary factors. Figure 4-3 ranks these and other factors that survey respondents identified as potential drivers to expanded deployment of wood heat technologies.

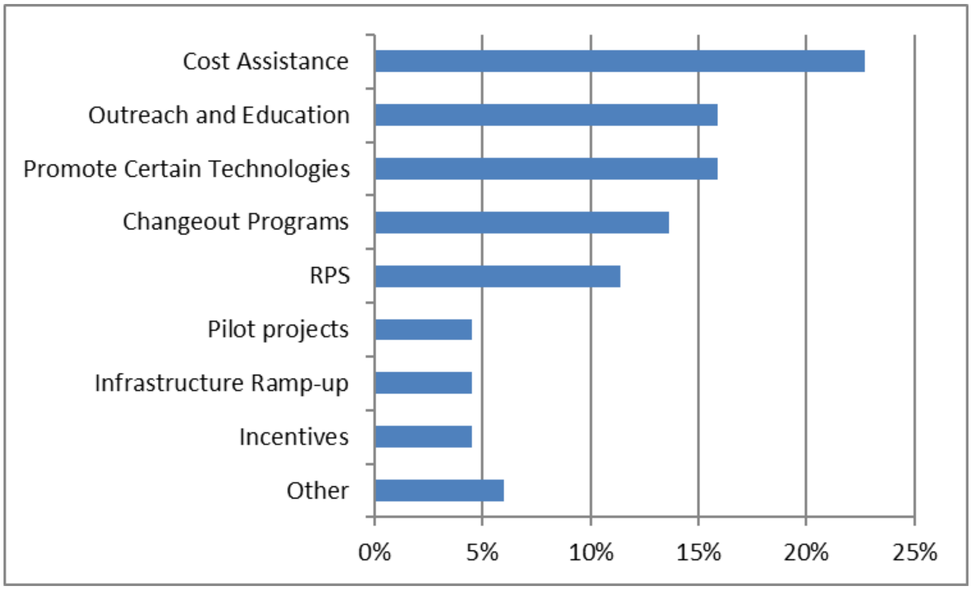
[21] Meister Consultants Group, 2012.

Figure 4-3. Drivers to Expanded Deployment of Thermal Biomass Technologies



When specifically asked what policies or programs NYS should implement to promote the use of biomass heating, respondents named cost assistance and outreach and education as key priorities. Promotion of newer, higher efficiency technologies, implementation of changeout programs, and a adoption of a renewable portfolio standard (RPS) that includes thermal biomass were also named as priority policies and programs. Figure 4-4 depicts these and other policies or programs identified by survey respondents as key policies for NYS to consider to promote thermal biomass. The lower levels of support for pilot projects and building infrastructure to support distribution of wood fuels might be explained, in part, by an assumption on the part of survey respondents that outreach and education included demonstration projects. Lower ratings for infrastructure might be explained by an unfounded perception that increased infrastructure benefits only the pellet segment of the industry.

Figure 4-4. Recommended Policy and Program Priorities to Promote the Use of Biomass Heat in New York State



4.3 Policy Options

This section reviews some of the policy options available for expanding the thermal biomass, including wood heat, market. NYS has experience with some policies. Later sections will review policy experience of other states and lessons learned from all states.

4.3.1 Federal Programs Supporting Thermal Biomass Development

4.3.1.1 Biomass Crop Assistance Program

The Biomass Crop Assistance Program[22] (BCAP) is administered by the USDA Farm Service Agency, and until recently consisted of the following two independent programs to provide funding to biomass growers, one of which has been effectively phased out:

- Matching payments to providers of biomass feedstocks for energy and heat production. This program, which was authorized in 2008, has been phased out and is not expected to return, except when used in conjunction with "project areas."
- USDA funding for "project areas" to help support the establishment of bioenergy crops. The establishment and support of project areas is expected to be the focus of the BCAP program going forward, subject to congressional authorization and funding.

22 http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap

Project areas are single counties or groups of counties where a group of landowners work with a biomass conversion facility to provide a stable supply of material. The focus is on planted crops, including woody crops, but is not intended to fund removal of biomass feedstock as part of an integrated timber harvest.

Enrollment of a “project area” is competitive and subject to a request for proposals. If selected, this program helps pay for 15 years of “soil rental,” based upon a predetermined agricultural rate, plus establishment costs (e.g., planting and weed control). Only marginal land that cannot be used for food crops is eligible for funding under this program.

The BCAP program has potential to support the establishment and growth of feedstock specifically dedicated to thermal uses. In NYS, this might include willow, perennial grasses, or other bioenergy crops. To date, the use of dedicated energy crops for thermal biomass production has been extremely limited, but this program offers an opportunity to support the development of new feedstock supplies for a thermal biomass facility or processor. NYSERDA has supported a large effort in short-rotation willow crops for many years. This crop has thus far been used primarily for electricity generation.

4.3.1.2 Advanced Biofuel Payment Program

The Advanced Biofuel Payment Program is an annually appropriated federal support payment made on a production and incremental production basis to biorefineries producing an advanced biofuel. Authorized in the 2008 Farm Bill, this program allocates a fixed pool of funding to eligible producers based upon a formula that accounts for both production and additional incremental production (increases from the previous calendar year). Payments to individual facilities have varied significantly from year to year. Because payments are subject to wide variability, this program is not one that can provide a reliable source of core funding. Rather, it is best suited to provide supplemental assistance for biomass production.

To be eligible for the Advanced Biofuel Producer Program, an applicant must sell, via a third-party transaction, an advanced biofuel in the form of a final product that is produced in the U.S. and is derived from renewable biomass (other than corn kernel starch), which includes:

- Cellulose, hemicellulose, or lignin.
- Sugar and starch (other than corn kernel starch-derived ethanol).
- Waste material, including crop residue, other vegetative waste material, animal waste, food waste, and yard waste.
- Diesel-equivalent fuel derived from renewable biomass, including vegetable oil and animal fat.

- Biogas (including gas from landfills and wastewater treatment plants) produced through the conversion of organic matter from renewable biomass.
- Butanol or other alcohols produced through the conversion of organic matter from renewable biomass.
- Other fuel derived from cellulosic biomass.

Importantly, wood pellets used for thermal applications have been recognized as an advanced biofuel. In 2014, 33 pellet producers received payments under this program ranging from $813 to $52,270, including at least two NYS wood pellet manufacturers.[23] At this level of support, however, it is unlikely that the program will have significant market impact. Each fiscal year, the USDA publicizes the production and incremental production payments for that fiscal year. A facility must apply to participate in the program, and file quarterly information reports to receive payments.

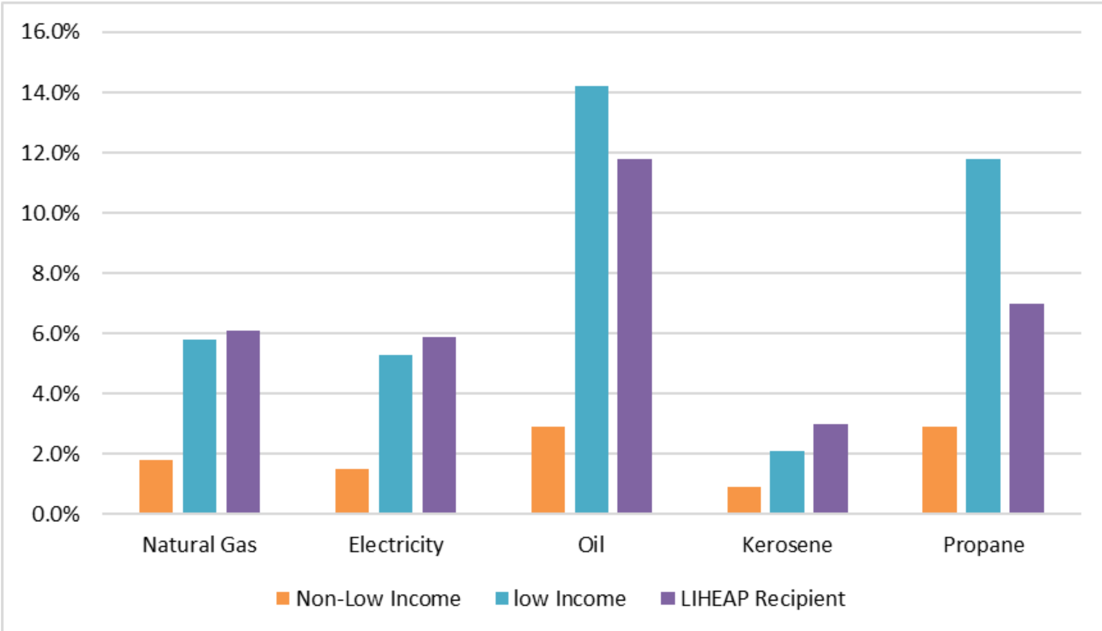
4.3.1.3 Low Income Heating Assistance Program

The Low Income Heating Assistance Program (LIHEAP) is a federally funded and state-administered program that provides funding to low-income households for the purchase of heating fuels. Figure 4-5 depicts the percentage of household income used in NYS for heating by primary heating fuel and income level group. In fiscal year 2014, NYS is expected to spend $316 million to assist 1.5 million households with their heating costs. In 2013, the State spent an average of $338 per enrolled household in this program, with benefits capped at $600 per household for oil, kerosene, and propane, and $500 per household for wood.

Data are not readily available regarding the geographic distribution of LIHEAP recipients in NYS by fuel type. A significant number of LIHEAP recipients are located in rural and suburban areas and use oil or propane as a primary fuel. Based on information in Figure 4-5, however, a meaningful number of recipients reside in urban areas where use of biomass fuel might not be an easily implemented heating option and they have access to natural gas.

[23] Voegele, E. 2014. Biomass Magazine, “USDA announces advanced biofuel payments, bioenergy grants,” http://biomassmagazine.com/articles/11272/usda-announces-advanced-biofuel-payments-bioenergy-grants

Figure 4-5. Percent of New York State Household Income Used for Heating Expenditures, by Primary Heating Fuel



Although using biomass is not a focus of the LIHEAP program, it does represent a sector that may add new biomass fuel demand while helping an existing public program use limited funding in a more efficient manner.

The New England Forestry Foundation recently completed a two-year effort to find ways to better integrate wood heating into the LIHEAP program.[24] This effort identified a number of opportunities and barriers to better integrate biomass heating into appropriate low income residential settings, including:

- Building on the existing knowledge of many administrators and LIHEAP recipients about the potential cost-saving benefits of wood heat.
- Eliminating existing barriers to use of biomass heat by LIHEAP recipients, including the relatively high capital cost associated with many wood-heating devices.
- Programmatic requirements for selection of a single fuel for subsidy payments. Recipients may not receive funding for supplemental heating sources. LIHEAP also places prohibitions on fuel switching during the heating season, which can have the unintended consequence of locking recipients into a high-priced fuel type.

24 New England Forestry Foundation, http://www.newenglandforestry.org/index.php/our-initiatives/special-programs

- The lack of an organized, transparent, and easily accessed fuel supply infrastructure (particularly for cordwood).
- The need for safety and emissions control, which could include proper operation, maintenance, and cleaning of units.

4.3.2 State-Based Programs

4.3.2.1 Renewable Portfolio Standards

Many states, including NYS, have established market-based systems to incentivize the development or growth of renewable energy production. State renewable portfolio standards (RPS) are traditionally designed to increase the contribution of renewable energy into the suite of traditional electricity generation sources by creating an additional market incentive for renewable energy production. Generators of renewable energy, such as wind, solar, and hydro, earn renewable energy credits (RECs) for every unit of energy produced. RECs are then sold to electric utilities to contribute towards the utility's state-set renewable energy mandate. REC prices are generally set by the market, and are a function of supply and demand, based upon the particular rules of each program.

Currently, 29 states have some form of RPS.[25] While RPS programs were designed around electricity, states are now beginning to explore inclusion of renewable thermal energy, in particular solar water heat, solar space heat, and wood heating, as eligible renewable energy sources. New Hampshire was the first state to include thermal energy as a component of its RPS; Maryland and Massachusetts are formally evaluating opportunities to do the same.

In states where thermal energy is eligible for RECs, or is under formal evaluation, careful consideration has been given to the establishment of a "tier" of RPS obligations specific to thermal energy. In New Hampshire, a small and growing requirement for thermal RECs (from any of a number of qualifying sources) was carved out of the existing requirement for "Class 1" RECs, which are from new electricity generation units.[26] Massachusetts is considering including thermal generation in its "Alternative Portfolio Standard,"[27] which is a program similar to, but separate from, that state's RPS that rewards combined heat and power projects, efficient steam systems, and other technologies. In these instances, RECs are generated concurrent with the generation of energy (electricity or thermal energy), but can be traded

25 Biomass Energy Resource Center, 2013.

26 http://www.puc.state.nh.us/sustainable%20Energy/Renewable_Portfolio_Standard_Program.htm

27 http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/rps-and-aps-program-summaries.html

independently for compliance purposes (e.g., a school can use its heat and sell its thermal RECs, in the same way a wind farm can sell its electricity to one customer and its RECs to another).

One issue that biomass (and other thermal technologies) face when utilizing an RPS-based incentive system is that RECs are a "performance based incentive" generated at the time the energy is produced, and sold after production has been verified. Although this structure has worked for electricity generation, it is an imperfect model for thermal biomass. Thermal biomass competes well against fossil fuels on a heat-cost basis, as wood fuel often costs 40 to 50 percent less than heating oil on a Btu-delivered basis, but monetary incentives are needed to defray the comparatively higher capital costs associated with installation of biomass technology.

If the goal is to incentivize the installation of new wood heating installations, the use of an RPS is an imperfect tool. Nonetheless, inclusion of wood heating in the group of energy sources eligible for RECs is supported by the wood heating industry, in part because this known and existing policy vehicle in many does not incur a large government expense.[28] If the RPS is used as a policy tool to support wood heating, there are some steps that can be taken to address the challenge of using a performance-based incentive (RECs) to address a capital cost challenge, including:

- Allowing (or mandating) that electric utilities purchase long-term (multi-year) strips of RECs from projects and provide a firm, creditworthy contract for purchase of RECs at a known price.
- Setting a "REC floor price," below which the price cannot drop to provide financial institutions with price security.
- Providing construction loans for projects, with the projected proceeds from REC sales used to guarantee and repay the loan.

It is important to note that although RPS programs have been in existence for more than a decade and New Hampshire has a thermal RPS law on the books, no state in the country has a functioning thermal RPS program.[29] Lessons can be learned from other states as they design and implement RPS programs to support thermal biomass.

In developing a wood heating to qualify for RECs, states might consider establishing thermal-specific portfolio standards that allow heating suppliers or electricity providers to purchase REC from individual

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28 In most cases, funding for an RPS is collected from electric ratepayers by utilities or electric suppliers, depending upon the state.

29 New Hampshire's program is in the final stages of rulemaking.

wood-fired thermal sources, such as schools or homeowners. RECs are typically awarded for each unit of energy that is produced and paid as units of energy displace fossil fuel use. As previously noted, a primary hurdle for the ramp-up of thermal biomass use is the high upfront cost of thermal biomass technology, so awarding RECs based on thermal output does little to incentivize their purchase. An alternative, and perhaps better, approach would be to award one-time “strips” of credits at the time thermal biomass technology is purchased; such a strategy is being implemented in Massachusetts.

NYS’ current RPS target is 30% renewables by 2015. Roughly 20% of the target is expected to be derived from existing renewable generation, 1% through green power sales, and the remainder through new renewable resources. Of these new resources, 8.5% are expected to be customer-sited resources, which, by regulation, may include solar water heat, photovoltaics, landfill gas, wind, biomass (for electric generation), hydroelectric, CHP/cogeneration, anaerobic digestion, tidal energy, wave energy, ocean thermal, ethanol, methanol, biodiesel, and fuel cells using renewable fuels.[30]

According to NESCAUM’s survey, the thermal biomass energy sector views inclusion of thermal biomass in an RPS as a key driver to expanding the thermal biomass sector in NYS, accompanied by clear emissions and other regulatory standards, improved financing options, growth of the fuel distribution system, and education.

4.3.2.2 Cost Supports

Incentives and Rebates

Rebate programs provide a direct incentive to overcome the high upfront costs of thermal biomass technologies. NYS has experience with rebate programs for other energy technologies, and has recently put forward the Renewable Heat NY initiative. It is designed to transform the market for emerging high efficiency and low emissions biomass heating technologies. The program requires installation of Renewable Heat NY-certified technology by a certified contractor.

Table 4-1 provides an overview of the technology types and incentive levels in the initiative.

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[30] New York State Public Service Commission, http://www3.dps.ny.gov/W/PSCWeb.nsf/All/1008ED2F934294AE85257687006F38BD?OpenDocument

Table 4-1. Technology Types and Incentive Levels for Renewable Heat NY

Technology	Incentive level
Residential Wood Pellet Stove[31]	• $1,500 (up to $2,000 for income qualified homeowners)
Residential Advanced Cordwood Boiler with Thermal Storage[32]	• Up to 25% of installed costs with a maximum payment of $5,000 per unit • An additional $5,000 for documented recycling of an uncertified outdoor or indoor wood boiler OR and additional $2,500 for removal and destruction of whole house wood furnace
Residential Wood Pellet Boiler with Thermal Storage[33]	• Up to 45% of installed costs with a maximum payment of $36,000 per unit • An additional $5,000 for documented recycling of an uncertified outdoor or indoor wood boiler OR and additional $2,500 for removal and destruction of whole house wood furnace
Commercial Advanced Cordwood Boiler with Thermal Storage[34]	• Up to 25% of installed costs with a maximum payment of $5,000 per unit • An additional $5,000 for documented recycling of an uncertified outdoor or indoor wood boiler OR and additional $2,500 for removal and destruction of whole house wood furnace
Commercial Small Pellet Boiler with Thermal Storage Less than 300,000 Btu/hr (88 kW)[35]	• Up to 45% of total installed cost up to $36,000 based on size
Commercial Large Pellet Boiler with Thermal Storage More than 300,000 Btu/hr (88 kW)[36]	• 40% of total installed cost ($200,000 maximum incentive)
Commercial Tandem Pellet Boiler with Thermal Storage More than 300,000 Btu/hr (88 kW)[37]	• 45% of total installed cost ($270,000 maximum incentive)

Tax Exemptions. States might choose to implement sales, income, or property tax credits for the purchase of residential thermal biomass technologies and biomass fuel. States may also provide investment tax credits to businesses that purchase biomass heating systems, or property tax exemptions for industrial and commercial thermal biomass projects.

31 See nyserda.ny.gov/All-Programs/Programs/Residential-Wood-Pellet-Stove

32 See nyserda.ny.gov/All-Programs/Programs/Advanced-Cordwood-Boiler

33 See nyserda.ny.gov/All-Programs/Programs/Small-Pellet-Boiler

34 See nyserda.ny.gov/All-Programs/Programs/Advanced-Cordwood-Boiler

35 See nyserda.ny.gov/All-Programs/Programs/Small-Pellet-Boiler

36 See nyserda.ny.gov/All-Programs/Programs/Large-Commercial-Pellet-Boiler

37 See nyserda.ny.gov/All-Programs/Programs/Large-Commercial-Pellet-Boiler

Washington State offers several incentive programs to the pellet industry that might serve as models for NYS. It provides a reduction of the business and occupation tax rate to 0.138% on gross revenues from manufacture of wood fuel compared to a typical manufacturing rate of 0.484%. A business and occupation tax credit of $5.00/green ton is available for forest-derived biomass sold or used to produce electricity, steam, heat, or liquid biofuel. Washington State also provides a six-year property and leasehold tax exemption on buildings, equipment, and property used to manufacture wood fuel.

NYS offers an income tax credit of 25% of the purchase price of solar electric and solar thermal systems, up to $5,000.[38] The State assesses a sales tax on biomass boilers, but exempts wood for heating residential and multifamily housing. State law also allows municipal governments to exempt fuel for residential use from local sales tax, and to waive property taxes for renewable energy projects, including biomass projects.

Financing. States might choose to create financing programs to overcome the high upfront costs associated with thermal biomass technologies. Creative financing options include low and no interest loans and revolving loan funds for community projects, which allow a state to issue loans from a self-replenishing pool of money.

Property Assessed Clean Energy Offering (PACE). States might also provide financing for renewable energy projects through a PACE offering. PACE programs allow property owners to borrow money from a taxing entity (e.g., a municipality) to pay for energy improvements, such as fuel switching to biomass for heating. The loan is repaid through a special assessment on the property over a period of years. In NYS, PACE program participants can finance up to 10% of the property's value and repay the loan over a period of up to 20 years through an assessment added as an additional line item to their property tax bill. As an added incentive to address high upfront costs, the financing term is longer than what is typically offered through bank financing.

38 Biomass Energy Resource Center, 2013.

In 2009, NYS enacted two separate bills: (1) A.B. 8862 in August; and (2) A.B. 40004A in November. The bills authorize local governments the option to offer PACE programs. Some, but not all, municipalities offer such programs:

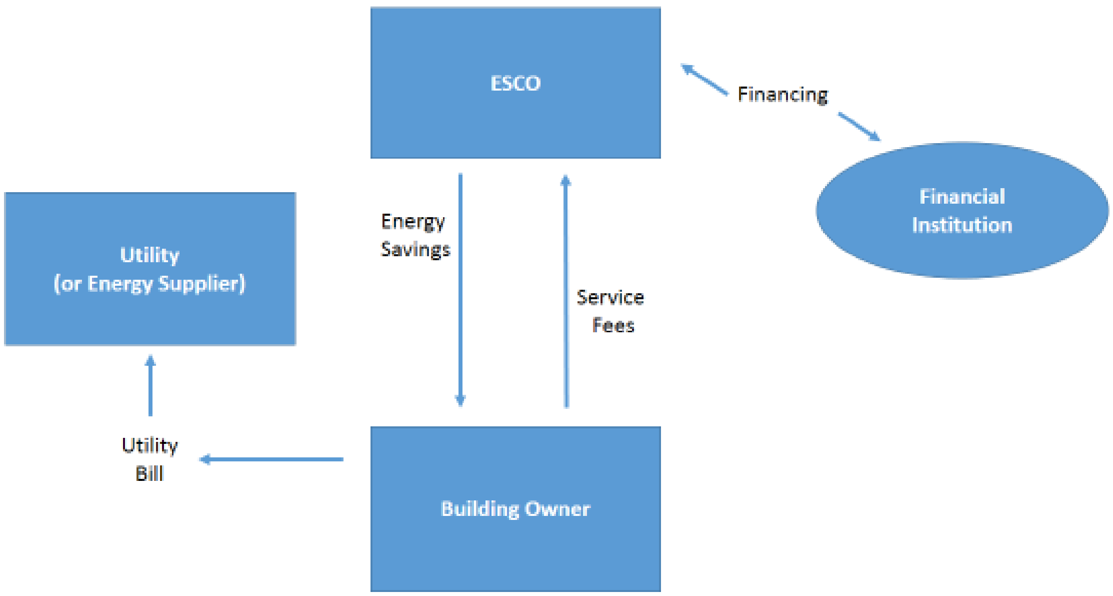
- The Municipal Sustainable Energy Loan Program can be used to pay for a variety of energy efficiency improvements, including installation of renewable energy systems. Loans are limited to 10% of the value of the real property, or the cost of improvements (whichever is less).
- Energy Waste Improvement Districts are residential home energy efficiency programs similar to loans. In towns that offer such programs, the town would be permitted to enter into contracts for home energy audits and energy efficiency improvements on behalf of participating residents. This program is similar in nature to the Municipal Sustainable Energy Loan Program, though administration differs.

PACE loans for residential applications, which are authorized in 31 states, came under scrutiny when, in 2010, the Federal Housing Finance Authority raised concerns regarding the use of such loans and their priority position over federally backed mortgages. As a result, the use of PACE loans for residential applications stalled, although PACE loans can be, and often are, used for commercial applications.

Business Models Supporting Wood Heating. One area of finance that has been successful in supporting the deployment of wood heating projects is the use of energy savings performance contracts (ESPCs), a tool used by energy service companies (ESCOs) to help finance energy improvements in a building. Under this model, an ESCO determines a suite of energy savings actions that a building owner can undertake (including the replacement of fossil fuel heat with wood heating) and then upon implementation of those actions guarantees a certain level of savings for a set pre-determined period of time. This model is attractive because it provides low- to no-risk opportunities for certain projects, and allows energy experts to focus on projects, while freeing building owners to pursue their core competency.

The ESCO often conducts not only the evaluation and engineering design of energy savings projects, but the construction and (sometimes) financing as well. The ESCO is paid by some of the guaranteed savings, thus providing both an opportunity for a building owner to save money and energy, and profit for the ESCO. The elements of a typical ESCO business model are shown in Figure 4-6.

Figure 4-6. Elements of Typical ESCO Business Model for Supporting Thermal Biomass Projects



Facilities using ESCOs to support wood heating projects often incur little, if any, upfront cost associated with a project, and the ESCO bears the performance risk. If energy is not saved, the ESCO does not profit, which is one of the key challenges for ESCOs in the biomass market. In the typical ESCO model, a participant is merely switching to more efficient technologies, and cost savings can be calculated based on estimated efficiency gains. In this model, the participant is switching to another fuel that has lower delivered efficiency rates than their previous fuel and the fuel itself is subject to significant price variability due to short-term supply disruptions and an inability to lock long term contract prices. For the ESCO model to work in the wood heating market, ESCOs will likely need assistance to manage fuel cost fluctuations.

The following challenges or limitations are associated with use of the ESCO market in the residential sector:

- Documentation of energy savings on projects can be complicated, and often require time and diligence by all parties to understand and agree upon the energy savings metrics.
- ESCOs have historically focused on the “MUSH” market – municipalities, universities, schools and hospitals – which tend to have stable, creditworthy, long-term owners rather than individual homeowners who represent a higher risk category.
- Some cutting-edge or advanced measures may be perceived as more risky, and be less likely to receive ESCO support.

The ESCO market is likely to focus marketing efforts on the lowest risk larger users, many of which utilize low cost fuels, such as wood chips. This conflicts with the target growth sector for many industry stakeholders, who see small commercial and residential owners as the largest growth area. If ESCOs can be persuaded to invest in this sector, more wood heating projects will likely receive funding and move to implementation.

4.3.2.3 State Grants and Change-out Programs

State grants and change-out programs can help spur market growth in new and emerging markets by allocating funding for specific types of wood heating projects. Change-out programs target the replacement of older technology with cleaner, more efficient units by providing upfront financial assistance for the purchase of a new unit when an old unit is surrendered or otherwise disposed of in a documented, specified manner.

NYSERDA periodically holds competitive solicitations for research and development and deployment grants that could potentially be used for wood-heating technologies and projects. To date, NYSERDA has offered $16 million in research and development support for technology development, commercialization, and demonstration projects in wood heating, along with evaluation and test method development for monitoring air quality health impacts from biomass boilers. NYSERDA has also offered $5 million in deployment support for advanced commercial and residential pellet heating technologies, pellet delivery infrastructure, and development of a wood heating-focused ESCO.

4.3.3 Pilot Projects and Public Awareness Campaigns

Pilot projects are relatively small-scale projects used to demonstrate the viability of an idea for implementation in a larger program or to gain commercial acceptance. Pilot projects offer the opportunity to prove technology, prepare for the administrative hurdles of larger program delivery, and increase public knowledge of wood-heating technologies. Pilot projects are often done in municipal buildings, schools, and not-for-profits, but may be implemented in any type of building the funding source allows. In February 2014, NYSERDA awarded $3 million to 18 research institutions, technology developers, and biomass fuel providers. With this funding, these institutions will be installing high efficiency boilers on-site, compiling data, and preparing case studies to document the results.[39]

Although pilot projects are a good vehicle for educating stakeholders about wood heating technologies, states may also choose to embark on public awareness campaigns to educate the general public about wood-heating fuels, technologies, and proper installation and operation techniques. These public awareness campaigns may be stand-alone programs or implemented in conjunction with a specific program to incentivize the purchase of wood heating technologies.

4.4 Examples of Wood Heating Policy

4.4.1 European Policy and Programs

In 2001, the European Union issued the Renewable Energy Directive (RED), which requires member countries to derive 20% of energy from renewables by 2020. Each member submits a National Renewable Energy Action Plan (NREAP) for reaching this target. Later iterations of RED required specific levels of renewable heating and cooling to contribute to the 20% goal. According to an analysis of the member states' NREAPs, biomass will comprise 19% of total renewable electricity in the year 2020, and 78% of total renewable heating and cooling in 2020. [40]

The guiding document and an accompanying template for developing NREAPs walk member countries through the process of establishing criteria for sustainable harvesting, setting emissions standards, establishing installer certification, and measuring and verifying wood-heating technology performance. Member plan strategies include suites of policies and programs that range from mandates for specific technologies to financial incentives promoting wood fuel supply.

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39 See https://www.governor.ny.gov/press/02142014-funding-heating-equipment

40 Beurskens, L.W.M., M. Hekkenberg, and P. Vethman. "Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States." November 2011. http://www.imeder.org/04_-_renewable-energy-projection_01.pdf

Austria has one of the leading renewable thermal markets in the European Union, meeting 27% of its heating needs with renewable energy. The Austrian federal government covers up to 30% of the cost of solar thermal and biomass heating units for use by businesses. Residential programs are administered by the Austrian states, and combine a mix of financial incentives, regulation, and promotional activities. A key to success has been the availability of incentives even after targets have been met, a willingness to continually increase the stringency of the renewable targets over time, and long-term promotional campaigns.[41]

Upper Austria meets 46% of its heating demand with renewables, including solar and biomass. Financial incentives are primarily issued in the form of grants. Regulations and mandates require installation of renewable heating and cooling in certain buildings, simplification of building codes, and streamlining of the permitting processes. Upper Austria has also embarked on a coordinated promotional campaign that includes a training component.[42]

4.4.2 RPS in New England States

In 2012, the New Hampshire legislature passed Senate Bill 218. The legislation allows for the inclusion of thermal energy in New Hampshire's existing RPS by amending the Class I Thermal Renewable Energy Certificate Program to include biomass, solar, and geothermal ground source heat pumps. As of January 2013, 0.2% of Class I REC requirements must be met with thermal resources, increasing by 0.2% annually until it reaches 2.6% in 2025.

The amendment also requires the New Hampshire Public Utilities Commission (NHPUC) to establish a methodology for tracking useful thermal energy production and behind-the-meter production of electricity. NHPUC must also establish a mechanism for metering, verifying, and reporting thermal energy output from systems generating RECs on a quarterly basis.

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41 Comment from Christoph Strasser, Austrian Biomass Centre, at the New York State Thermal Biomass Stakeholder Meeting on June 2, 2014.

42 http://www.nebioheat.org/pdf/Biomass_heating_2010.pdf

New Hampshire established an Alternative Compliance Payment (ACP) of $28/MWh. It is likely that RECs will sell for less than the ACP. The level of ACP, combined with the small percentage increase in the RPS mandate, results in an anticipated bill impact of $0.098 per month for an average residential electric bill for 600 kWh of electricity.

New Hampshire also established emissions standards as a condition of participation by biomass heating systems. Stack test emission rates for particulate matter must be less than 0.1 lb/MMBtu for biomass energy systems between 3 and 20 MMBtu/hr, and less than 0.02 lb/MMBtu for biomass energy systems above 20 MMBtu/hr.

Massachusetts passed legislation in 2014 that implemented in January 2015 for thermal heating to quality for RECs. This program creates a structure that allows thermal heating and cooling devices, such as solar panels, wood pellet stoves and boilers, and geothermal heat pumps, to generate RECs. Under the Massachusetts program, analysis will be conducted to calculate the amount of energy generated over a 10-year period and award those credits up front. The purchaser of the device would receive an upfront cash credit to help reduce purchase costs and the seller of the device could sell the REC credits to an ESCO or electricity company.

Some key considerations for evaluating the potential impacts of the legislation include understanding the types of units that might qualify, including efficiency levels and emission profiles, mechanisms to document the source of the biomass and to ensure biomass fuel is sustainably harvested, and the establishment of a biomass registry that could be used to upload data and trading information.

In Maine, legislation was introduced in 2012 to add thermal biomass energy to its RPS, which includes biomass for electricity generation. The Maine Public Utility Commission testified against the inclusion of thermal biomass in the RPS, stating that the RPS was intended to incentivize renewable electricity generation. It argued the policy mechanism for including useful thermal energy was unclear, and that metering would be too difficult. This legislation did not advance.[43,44] Maine does, however, have an electricity generation production incentive for renewable resources, including biomass. Maine's Community Based Renewable Energy Production Incentive pilot program offers eligible thermal technologies, including biomass, the opportunity to enter into long-term contracts to supply renewable electricity with the incentive of a REC multiplier (i.e., the value of the REC is 150% of the amount of

43 Response to NESCAUM questionnaire.

44 http://www.maine.gov/mpuc/legislative/reports.shtml

produced electricity). The program has had limited participation, which has been attributed to a $0.10/kWh long-term cap and the low price of Maine RECs.

A thermal renewable portfolio standard, alone, will not address key market barriers. Regardless of type and design, any wood heating incentive program will need to consider the cost of the technology, the cost of alternative technologies and fuels, and the current state of the market. Thermal RPS programs are complex to implement and operate, and will likely have the highest administrative costs.

4.4.2.1 Cost Supports - Incentives, Rebates, Financing, Tax Breaks in New England States

States have offered cost supports in the form of incentives and rebates over the last two decades to promote the installation of cleaner wood heating systems. These programs tend to operate as one-off programs, available until funding runs out, or are sometimes administered in phases of funding. Table 4-2 provides an overview of some of the financial incentive programs by state that are offered or have been offered.

Table 4-2. Current and Past Financial Incentives for Thermal Biomass in New England States

State	Program	Incentive Level and/ or Eligibility	Details
Connecticut	Energy Conservation Loans	For owners of 1-4 family homes that meet income limits	Funded by CT Housing Investment Fund; loan repaid over 10 years
Maine	Residential rebate	Up to $5000	Began in 2013 and funded by 3.5 million annually through RGGI funds
	Low interest loans	For residential units	
	Commercial and industrial cost share programs	Match 50% of system cost	Funded by mix of RGGI and other sources
Massachusetts	Rebates for residential high efficiency boilers[45]	$7,000- $15,000	Began in 2013; total funding $475,000
	Expanded Mass Save HEAT loan	0% interest loan up to $25,000 with terms up to 84 months for 1-4 family residential units; must have thermal efficiency rating of 80% or greater and emissions rating less than or equal to 0.15 lb/MMBtu and at least 2 tons of storage[46]	Program administered by MA Department of Energy Resources with $3.8 million grant from the US DOE
New Hampshire	Public Utility Commission's Bulk-Fuel Fed Wood Pellet Boiler rebate program	Rebates of 30% of system and installation cost or $6,000 (whichever is less)	Funded by ARRA funds
Vermont	Efficiency VT rebate	Up to $2,000 for new, high efficiency pellet boilers with 80% minimum efficiency, less than or equal to 200 MBtu/hr output, and minimum system capacity of 70% of heating load.	Part of Efficiency VT's larger HVAC rebate program

Some states in New England also make available tax exemptions and credits. Vermont offers a sales tax exemption for biomass boilers and fuel. Maine and Massachusetts exempt residential wood fuel from sales tax.[47] Vermont also offers an investment tax exemption for businesses for biomass and other renewable heating equipment.

45 See http://www.mass.gov/eea/pr-2013/discounts-for-high-efficiency-wood-pellet-boilers.html

46 See http://www.masssave.com/residential/expanded-heat-loan

47 All residential heating fuels in Massachusetts are exempt. New Hampshire does not have sales tax, and therefore there is no sales tax on the purchase of equipment or fuel.

Oregon, although not one of the states surveyed, offers a business tax credit of 50% of eligible costs for renewable energy equipment manufacturers.[48] Massachusetts has a similar law for other renewable energy sources, but does not include biomass in the list of eligible sources.[49]

4.4.2.2 Pilot Projects and Lead-By-Example

NYS, Massachusetts, and Vermont have used pilot projects and lead-by-example programs to demonstrate technology, gain experience with thermal biomass policies, and conduct outreach and education about thermal biomass heating options. NYSERDA has spearheaded a suite of activities to promote high efficiency biomass heating technologies. Vermont Buildings and General Services Department has installed biomass heating systems in many state buildings. The Massachusetts Department of Energy Resources (DOER) has implemented a wood pellet lead-by-example program for municipal buildings and not-for-profits. DOER has also worked with the Massachusetts Department of Housing and Community Development to launch the Schools and Public Housing Integrating Renewables and Efficiency (SAPHIRE) program. These programs will offer low-interest financing and capital funding grants from the Massachusetts Clean Energy Center. In addition to providing useful data through tracking and measuring energy inputs, outputs, and savings, these programs seek to reduce energy costs and create opportunities for public education.

Although not a thermal biomass policy, Bangor Hydro and Maine Public Service have launched a successful heat pump pilot program, including an evaluation conducted by an outside third party. The evaluator attributes success thus far to an aggressive, comprehensive marketing campaign, simple program design, and a significant incentive of $600 relative to heat pump costs. The program has administered about 1,000 rebates. The evaluator estimated a low level of free ridership; an estimated 88% of participants would not have otherwise installed a heat pump. Total pilot program costs were approximately $900,000; approximately $100,000 of this amount was spent on marketing.

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[48] Biomass Energy Resource Center, 2013.

[49] Biomass Energy Resource Center, 2013.

Often, government programs fail to include adequate budget for outreach and marketing activities. At the outset of the Bangor Hydro-Maine pilot project, only 20% of utility customers had any knowledge of heat pumps, and a subset of this 20% did not fully understand or trust the technology. However, the pilot project resulted in installation of three times the projected number of heat pump installations. At the conclusion of the pilot project, the Efficiency Maine Trust began offering a $500 rebate, but did not conduct further marketing. This rebate program has continued to be highly subscribed, which is attributed to the groundwork laid by the robust education and outreach effort for the pilot program.

4.4.2.3 Change-out Programs

Massachusetts, New Hampshire, and Vermont have experience with change-out programs. Beginning in 2012, Massachusetts, through a partnership between the Massachusetts Clean Energy Center and Department of Energy Resources, offered a voucher of either $1,000 or $2,000 to replace older non-USEPA certified stove models with high-efficiency stoves. The program was first offered to low income residents enrolled in the Low Income Home Energy Assistance Program (LIHEAP), Mass Health, or Women Infants and Children (WIC), who were eligible for the $2,000 voucher. Later, the program was opened to all residents at the $1,000 voucher level. Massachusetts established a comparatively high incentive level to generate interest, but would consider lowering it in the future.[50]

The city of Keene, New Hampshire offered a successful wood stove change-out program through a state and municipal partnership in 2009. The city of Keene was awarded $106,000 for the program, which replaced 86 devices.

Vermont offers a Wood-Fired Boiler Change-Out program and the VT Burn Clean Wood Stove Change-Out Program, both administered by the Vermont Air Pollution Control Division. The boiler program offers $6,000 to replace eligible (Vermont Phase 2 certified) outdoor wood boilers, while the woodstove program offers rebate vouchers of $450.

50 Comment from Rob Rizzo, Massachusetts Department of Energy Resources.

4.5 Lessons Learned from the European Union, New England States, and New York State

4.5.1 RPS Lessons Learned

A RPS can help accelerate the wood heat policy process because it is an existing policy vehicle. However, an RPS can be complex to implement, even without a biomass-heating component. Wood heating adds an additional level of complexity because there is a need to translate thermal energy into renewable energy credits for the electric sector. Issuing credits for thermal energy is also challenging because most thermal energy is not metered or measured in the way electric generation is. Requiring meters for thermal energy projects adds an additional cost to projects that already face high initial capital expenditures, and meters do not necessarily capture heat delivered to the building or "useful" thermal energy.

New Hampshire and Massachusetts provided insights on the inclusion of wood heating in an existing RPS and the development of an Alternative Portfolio Standard (APS). The primary challenge was the time and expertise needed to craft the rule and develop a path for implementation. This process may involve review and potentially revision of existing emission requirements, and coordination with energy offices on building codes and standards. Both states incorporated emission requirements into the rule for participating units, which required coordination with environmental departments.

New Hampshire was originally given six months to develop its rule, but ultimately needed to delay program rollout. Metering and verification has proved to be a large barrier for New Hampshire. The State first reviewed available metering standards, and determined that there was no heat metering standard for wood-heating systems. New Hampshire has begun the process of developing its own metering standard, which requires evaluating a suite of options. Considerations include the definition of "useful" wood heating and the decision on whether to account for parasitic and operating energy losses, accounting for rebound effect,[51] the tradeoffs between using estimated and measured data, and the development of a system for verification of REC applications and output.

[51] The rebound effect refers to the tendency of consumers to make up for any monetary savings associated with their electricity and heating costs by consuming more electricity or heat, e.g., by turning up the thermostat.

Massachusetts grappled with APS program design in order to design an APS that offsets the high upfront capital costs of wood heating. RECs typically pay once installed, and do not reduce upfront capital costs. Massachusetts is considering awarding one-time, upfront alternative energy credits (AECs) to account for an established time period (for example 5 or 10 years) of modeled net energy generation. Massachusetts is also considering a revolving fund to buy and sell AECs that could initially be funded by ACP funds.

Massachusetts noted that the volatility of the RECs market may be a disincentive to wood heating participation in the APS. Options for overcoming this barrier include:

- Increasing targets (requiring careful management).
- Establishing energy credit price floors.
- Promoting long-term contracts.
- Providing upfront rebates.

4.5.2 Cost Support Lessons Learned

NYS and most New England states provide, or have provided, some form of cost support for wood heating technologies. States reported that financial incentives could provide opportunities to "prove" technology, and to better understand potential administrative and technical hurdles to implementing wood heating policies, and a mechanism to increase confidence in the market and development of infrastructure.

Many states reported difficulty establishing the appropriate incentive levels. Financial support must be high enough to stimulate private investment, but low enough to generate enough program participation to help develop the market.[52] Another commonly reported barrier was a lack of staff expertise to address key issues, such as installation, sizing, and public health concerns. Finally, states reported that securing continued resources and conducting long term monitoring for financed projects was a challenge. Working with industry is an important component of designing cost support programs. New Hampshire met with the wood pellet industry to discuss infrastructure and the appropriate system requirements and rebate amount. As a result, industry informally pledged that if the State required three-ton storage systems, the industry would provide wood pellet delivery statewide.[53]

52 Biomass Energy Resource Center, 2013.

53 New Hampshire response to NESCAUM questionnaire.

4.5.3 Pilot Projects and Public Awareness Campaign Lessons Learned

Successful pilot projects benefit from careful program design with regard to marketing, incentive levels, and appropriate unit installation. One purpose of a pilot project is to demonstrate technology, so using skilled, experienced installers will help with program success. Determining the appropriate incentive level is a critical aspect to program success. Administering many pilot projects is ideal, but funding for each needs to be adequate. Funding should also compensate for uncertainties associated with the immature market and underdeveloped infrastructure, with the understanding that this level of funding will not always be necessary because the pilot projects and programs will help expand the market and drive down costs.

4.5.4 Change-out Programs

Successful change-out programs require outreach campaigns, preferably in advance of the rollout of the program. Significant upfront planning is also needed to determine the target audience and design promotional materials and a program framework that targets this constituency and develops a political and administrative framework. Considerations must be given to how to maintain fairness in the allocation of funding; for example, if applications are submitted for more funding than is available, how to monitor program success, and how to follow-up with applicants who claim vouchers, but do not proceed with change-outs.

New Hampshire also stressed the importance of partnerships between state and local governments, as well as manufacturers and retailers. Success with the Keene change-out program was attributed to the educational campaign that occurred before, during, and after the change-out program using "Burn Wise" materials from the USEPA. Finally, the city of Keene views flexibility as a key consideration for any program and program administrator, acknowledging that identifying potential challenges and having back-up plans in place is also important.[54]

[54] New Hampshire Department of Public Services, 2010.

4.6 Summary for Incentive Programs

Regardless of type and design, any program designed to incentivize wood heating will need to consider the cost of the technology, the cost of alternative technologies and fuels, and the current state of the market. Incentive programs also present an opportunity for states to move the market to better performing units by setting standards for efficiency, emissions, oversizing, installation, and inclusion in building codes. However states choose to address these issues, any policy or program designed to incentivize wood heating should consider the following issues:

- **Minimize high upfront cost of technologies:** Wood heating-technologies are emerging technologies and currently have higher capital costs than conventional heating systems. Policies to incentivize installation of wood-heating technologies should address the high capital costs by providing incentives at the time of installation. Economic development with manufacturers should seek to reduce production costs. Workforce development efforts should improve quality and proficiency of the installers and drive down the amount of time to install these systems, thereby reducing costs. Packaging of systems with some "pre-plumbed" components will also help.
- **Address lack of public awareness:** Public outreach and education, as well as education for policy makers and the heating and building industries, will be key to any program success. A campaign for public education and outreach can be built into many policies and programs.
- **Incorporate minimum emissions and efficiency standards and create proper sizing and installation requirements:** Wood-heating systems include a range of technologies and system components, including thermal storage, with varying efficiencies and emissions rates. Efficiency can only be realized when wood-heating technologies are properly sized and installed by a trained installer. Any policy designed to incentivize wood heating should include minimum emissions and efficiency standards and provide requirements about sizing, use of thermal storage, installation, system integration, and energy management controls. Members of the wood heating sector relayed that regulatory uncertainty around efficiencies and emissions standards were barriers to growth of the market. Choosing stringent, yet attainable, standards from the commencement of any policy may provide needed consistency for the market to grow, and quality installation of technologies that operate cleanly, efficiently, and reliably will assist with public perception. Incorporating these specifications into state building codes and standards could also help provide regulatory certainty for the industry.
- **Address system commissioning measurement:** Most commercial and many residential biomass heating systems will be added to an existing heating system and heat distribution system. These retrofits must be carefully integrated so the wood heating system operates optimally. Integration with the existing building energy management control system for a commercial building is a technical challenge that is often overlooked. Addressing this critical step assures that incentivized units met the efficiency and emissions targets set by these programs.
- **Address measurement, monitoring, and verification:** High costs and lack of a common methodology for measuring and reporting performance of wood heating technologies is a barrier

to demonstrating the successful installation and performance of a new biomass heating system and including wood heating technologies in an RPS. Improved and increased reporting of wood heating technology performance will help quantify the benefits of thermal biomass for future policy considerations, as well as assist in education and outreach about wood heating. A common methodology for monitoring installed wood heating systems will enable these systems to be included in additional heating sector policies and programs.

- **Require fuel sustainability requirements.** Although there is currently no common definition for sustainable biomass, standards could be established as part of individual policies incentivizing wood heating use and assure that use of wood supply is maintained and greenhouse gas impacts are minimized and forest health is maintained.

5 Biomass Training Programs

Careful system design and proper installation of a cordwood stove, pellet stove, or biomass boiler can dramatically improve the efficiency and safety of the heating system. System design requires an understanding of the building's heat demand and heat distribution system. Both residential and commercial systems require integration of the boiler, thermal storage, pellet storage, and other components into existing or new heat distribution systems with thought given to thermostats and other control technologies. System designers and installers may also need to consider heat dump zones, heat exchanges, expansion tanks, mixing valves, and other system components.

Training programs for wood heat system installers typically focus on determining the appropriate size and type of unit for a particular consumer, identifying the additional system components (such as thermal storage) that may be needed, understanding how to balance, vent, and plumb the unit, and educating the owner on proper use and maintenance. Proper training also helps improve consumer confidence in the distributors, dealers, and installers of biomass units, which could influence consumer decisions to purchase biomass units and communicate positively about their experience with others.

5.1 Methodology

Little has been written on the training and certification pathways for installers of wood heat systems. This section, therefore, is primarily a summary of numerous interviews with industry associations, nonprofits, manufacturers, dealers, and government. Course materials and certification requirements were reviewed where available.

Technical backgrounds were surveyed of workers currently installing wood heat systems, including training and certifications specific to the biomass field. Domestic policies were investigated in NYS and other states that might address the technical background, training, and certification of installers of biomass units. Training and certification requirements were reviewed for installers in similar industries (i.e., natural gas, oil, and solar) and for wood heat units in the European Union, where the market for high efficiency units is more mature. The statutes and regulations governing training and certification in these industries and in the European Union were examined. Finally, recommendations were developed for training and certification of installers for NYS to consider as it promotes use of high-efficiency, low emissions wood heat.

5.2 Training and Certification of Biomass Installers: A Current Look

There is currently no nationally consistent training program across the United States for installers of wood heating units. Instead, installers are typically trained through a patchwork of (1) trade associations; (2) the National Fireplace Institute (NFI), which focuses its training primarily on residential cordwood and pellet stoves; and (3) manufacturers, particularly manufacturers of larger biomass systems. Trade associations, manufacturers, and dealers were asked about the technical background, training, and certification of installers. The responses varied by the class of unit. The following sections provide an overview of the technical background, training, and certification process for installers of cordwood and pellet stoves and biomass boilers.

5.2.1 Cordwood and Pellet Stove Installers

In residences and smaller businesses, cordwood and pellet stoves might be installed by dealer technicians, contractors, plumbers, or even chimney sweeps. These installers may have some plumbing background or training and certification from NFI or the Chimney Sweeps Institute of America (CSIA). They also may have attended additional training and received certification from a manufacturer on installation and/or maintenance of a particular unit or line of units. It is reportedly common for a dealer to have an NFI certification and the technicians to have a manufacturer certificate.[55]

5.2.2 Biomass Boilers

Heating, ventilation, and air conditioning (HVAC) technicians, plumbers, and limited numbers of engineers and architects are likely installers of biomass boiler systems. There is currently no clear training and certification pathway for this class of installers, but they may seek out specialized training for credit toward the continuing education units (CEUs) necessary to maintain their respective licenses. CEUs are awarded for biomass courses by numerous trade associations, including the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the Green Building Council (GBC), the American Institute of Architects (AIA), the American Association of Engineers (AAE), and the North American Board of Certified Energy Practitioners. See Appendix A for a sample biomass boiler course description.

NYSERDA’s Renewable Heat NY program offers financial incentives for wood heat system purchases, on condition that consumers use contractors with installation training on hydronics for high efficiency

55 Crouch, John. Personal Interview. 4 June, 2013. John Crouch is the director of public affairs at the Hearth, Patio & Barbecue Association.

systems. The Renewable Heat NY program currently offers wood heat hydronics training and has sponsored shorter versions of this type of training in the past. See Appendix A for program slides.

Installers of biomass boilers are likely to be trained and certified on installation of a particular unit or line of units by at least one manufacturer. Although manufacturers do not require a specific technical background for certification, they may ask installers to self-certify that they are qualified and have the necessary credentials to install units in their field of practice.[56] Standardized credential programs would reduce or remove the need to self-certify. Such programs are available for oil and gas system installers. Developing and accrediting course offerings to count toward CEUs or designing some other pathway to training and certification of biomass boiler installers may have benefits beyond ensuring efficient and safe installations.

The U.S. Department of Agriculture's Forest Service Wood Education and Resource Center funded a national online survey that asked how HVAC professionals obtain technical information and what wood energy proponents can do to increase the familiarity of HVAC installers with wood heat technology. The key findings include supplying HVAC design engineers and architects with the facts about wood-based heating and cooling helps to increase their interest and willingness to introduce the option to consumers. The study stresses the importance of housing information and training with traditional trade membership organizations and not only with wood-specific industry groups.[57]

5.3 Overview of Current Training Opportunities

5.3.1 National Fireplace Institute

The National Fireplace Institute (NFI) is the education arm of the Hearth, Patio & Barbecue Association (HPBA). NFI provides distinct training and national certification for installers of wood burning, pellet,

56 Seymour, Joseph. Personal Interview. 18 September, 2013. Joseph Seymour is the executive director of the Biomass Thermal Energy Council.

57 Karakash, John T. and Daniel deB. Richter. Report of Key Findings: Architects and Energy Professionals-The Missing Link in Wood Energy. May, 2011.

and gas devices. Topics include clearances, vent pipes, safety requirements, and education of customers on the proper use of biomass units. There is a focus on “the house as a system,” and safety of the units and systems.[58]

The NFI certification is valid for three years, at which point recertification can occur through examination or a combination of CEUs and proof of recent unit installations. There are currently 619 certificates for wood-burning and 481 pellet certificates (compared to 1,002 current gas certificates). The highest concentrations of certificate holders are in the Northeast and Mid-Atlantic states.[59]

The predominant mechanism for training toward an NFI certification is through online coursework, training through the HPBA regional affiliates, and a few individuals that have developed courses for accreditation by NFI. NFI provides a six-hour review course and administers the exam at the HPBA annual tradeshow.

The Chimney Safety Institute of America (CSIA), the trade organization for chimney sweeps, also provides training for the NFI certification exam and administers the exam. The CSIA route to NFI certification is targeted toward chimney sweeps and inspectors, and includes additional content and hands-on experience. NFI considered offering the certification as part of vocational and community college plumbing programs.[60] NFI has also considered providing training and certification for installers of biomass boilers, which would expand on classes it already offers at its annual tradeshow and online. For example, at the Hearth, Patio & Barbecue Expo 2011, NFI held panel discussions about “Retrofitting Biomass Forced Air Furnaces in Residential Locations and Retrofitting Biomass Furnaces in Commercial Locations.”[61] See Appendix A, Sections A.2-A.4, for NFI and CSIA training course descriptions.

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58 Vlahos, R. Personal Interview. 5 June, 2013. Rick Vlahos is the Executive Director of the Hearth, Patio, and Barbecue Education Foundation and oversees the National Fireplace Institute certification program.

59 Vlahos, R. Email Communication.10 June, 2013

60 Vlahos, Interview.

61 Vlahos, Email.

5.3.2 Manufacturer Training

Several manufacturers require participation in a training program and certification before distributing or installing particular lines of biomass units. Some manufacturers also require that the first installation of a biomass unit be done with a manufacturer's technician present. In order to maintain the manufacturer's certification, an installer may need to complete installation of a minimum number of systems every year. Two manufacturer training and certification programs are described in the next two sections.

5.3.2.1 Tarm Biomass

Tarm Biomass sells cordwood, pellet, and wood chip boilers from the Froling line. Tarm Biomass has worked with Austrian government to develop a training program that includes disassembly and reassembly of a unit. The training program also includes plumbing diagrams for different installation scenarios, wiring diagrams, boiler control panels and background programming, codes and safety, service and maintenance (such as refractory replacement), oxygen sensor testing, cleaning, inspection, downloading operation, and error reports. Tarm Biomass provides a two-day training session and then works with installers to commission boilers in customer homes. The installers that come for training at Tarm Biomass are generally dealers with plumbing and heating backgrounds. A representative from Tarm Biomass reports that the most successful installers come from central heating backgrounds.[62]

5.3.2.2 Maine Energy Systems (MESys)

MESys provides two levels of training and certification to technicians that install its biomass systems. The Level I training is a week-long program culminating in an exam. Content ranges from the basics of biomass heating to complex adjustments to computer systems. The training also includes hands-on assembly and commissioning of biomass systems and storage units. Following Level I certification, a MESys technician accompanies the installer on the first install. Level II training, which is available to those with Level I certification, focuses on optimizing the system under different circumstances, including multi-boiler systems.

[62] Nichols, Scott. Personal Interview. 7 May 2013. Scott Nichols is the President of Tarm Biomass.

The company also provides training for facility managers and technicians several times per year. Those that attend the trainings are generally plumbers that are licensed in their territory. MESys provides a map identifying the location of certified contractors that install, configure, and maintain MESys autopellet boilers.

Manufacturers might also play a role in training and education at trade and vocational schools and community colleges. Both Tarm Biomass and Maine Energy Systems reported interest in providing units for schools to work with and offering to conduct training seminars at the schools.

Manufacturers ask individuals to self-certify that they are qualified and/or licensed to install in their local area. Manufacturers report that there is a need for improvement in this area. The installation issues most likely to arise will be those associated with connecting biomass heating systems to existing plumbing. The manufacturers trust that the installer will recognize when plumbing needs to be updated, but it is not within their purview to provide training or certification in this area. This could be addressed through state and local requirements for plumbing and HVAC certification, permitting, and licensing.

Beyond training and certification of biomass unit installers, there are additional opportunities for those interested in other aspects of the industry. In particular, there are opportunities for training designed for foresters and inspectors of biomass units.[63] The Wood Energy Technology Transfer, Inc., training platform is for inspectors. It is the national registrar of the Wood Energy Technical Training (WETT) program. It trains individuals that sell wood energy products, install or maintain systems, or conduct inspections. It offers three base level certifications: (1) technician or advisor; (2) chimney sweep; or (3) system inspections and technical evaluation (SITE) basic inspector. It offers three additional certifications for those with base-level certification: Central Systems Technician, Pellet Technician, and Pellet Sweep. Each certification requires prescribed weeks of field experience, letters of reference, and some require participation in a minimum number of inspections or installations prior to certification.[64]

[63] Northeast Forests, LLC offers workshops for landowners and forest enterprisers on harvesting woody biomass. The Northeastern Loggers' Association published a study for them entitled "A Biomass Demonstration Guide for Northern Loggers," by Steven Bick. See http://www.northeastforests.com/.

[64] Wood Energy Technology Transfer website. See http://www.wettinc.ca/

The Fireplace Investigation, Research and Education (F.I.R.E.) Service offers F.I.R.E. Inspector or Technician training programs and certifications. The F.I.R.E. certification is targeted toward individuals that conduct annual safety inspections and inspections during new construction, retrofits, and installation of new appliances. The F.I.R.E. course covers building codes, manufacturer specifications, product identification, design and application, report writing, and fire technology. The F.I.R.E. Service also offers a Wood Technician certification to those that are certified by NFI.

5.3.3 Current Regulations Influencing Training and Education

NYS does not currently have regulations defining the technical background, required training, or certification of biomass unit installers. Installation of indoor heating appliances (including swap-outs) and boilers typically requires a permit and code inspection. Procedures vary by municipality.[65] One NYS dealer reported that wood units and fireplace inserts are often installed without certification or the proper permits, to the detriment of the safety and efficiency of the units.[66]

The USEPA requires NFI or CSIA certified installers for its changeout programs, although there are some areas where this requirement is waived because there are not enough trained technicians.[67] Several states and counties, and many municipalities, have stipulated that NFI certification is required for installation, primarily for gas and wood-burning units (and to a lesser extent, pellet stoves). NFI reports that NFI certification is required by regulation or for participation in an incentive program by the states of Iowa, Massachusetts, and Rhode Island, as well as by Newcastle County (Delaware); Pitkin County (Colorado); and the Cities of Lawrence (Kansas), Lincoln (Nebraska), and Salina (Kansas).[68]

65 Addario, John. Personal Interview. 5 June, 2013. John Addario is the Assistant Director for Education Services, Division of Code Enforcement and Administration, New York State Department of State.

66 From 2013 NESCAUM interview with a retailer and installer of wood, pellet, and gas units in New York that has both an NFI and F.I.R.E. certification.

67 Crouch, Interview.

68 Vlahos, Email.

The states of Oregon and Maine are currently the only states that regulate the background, training, and certification of biomass boiler installers. Maine issues Oil and Solid Fuel Licenses, which are obtained from the state following an examination and practical hours.[69] Licenses include apprentice, journeyman, and master level technicians. In addition, Maine provides the option to certify as a limited wood pellet technician. These regulatory requirements are codified in the Maine Fuel Board Laws and Rules for Solid Fuel.[70]

5.3.4 Training and Certification for Installers of Gas, Oil, and Solar Units in New York State

Training and certification for installation of gas, oil, and solar units is similar to that for installation of biomass heating units in NYS. Installers are typically professional HVAC technicians. Trade associations train and offer certifications, although some are more stringent about the technical background required for certification, such as the Home Energy Professional certifications offered by the Building Performance Institute (BPI) and supported by the U.S. Department of Energy and its National Renewable Energy Laboratory.

In the past, NYS has used this higher level of scrutiny to its benefit. For example, BPI certification is a requirement when installing an energy efficient unit as part of NYSERDA's Home Performance with the ENERGY STAR® program. Similarly, NYSERDA's Solar Thermal Incentive Program requires installers to be certified by the North American Board of Certified Energy Practitioners.[71]

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69 Holmes, Peter. Personal Interview. 1 October, 2013. Peter Holmes is the Senior Inspector of the Maine Fuels Board.

70 State of Maine. Maine Fuel Board Laws and Rules. 2012. See: http://www.maine.gov/pfr/professionallicensing/professions/fuel/

71 New York State Energy Research and Development Authority. PON 2149-Solar Thermal Incentive Program. See http://www.nyserda.ny.gov/Funding-Opportunities/Current-Funding-Opportunities/PON-2149-Solar-Thermal-Incentive-Program.aspx.

5.3.5 The European Union Training and Certification Platform

The European Directive to Promote Renewable Heating and Cooling includes a provision requiring each member country to provide training and certification for installers in order to maintain a professional standard requiring all biomass heating units to be installed by a certified professional. Austria and its certifying body, the Austrian Biomass Association, have emerged as leaders in the effort to professionalize the biomass installation field.[72]

The Austrian Biomass Association organizes five-day training sessions for installers (plumbers) in Austria, including one practical day of training working directly with a biomass boiler. The course includes calculating the proper size of a boiler to avoid oversizing, as well as sessions on problem solving and security issues. The participant fee is currently 525 Euro. Following completion of the course, in order to receive a certificate from the Association, installers must pass a written examination, demonstrate that they have installed a biomass boiler, and provide a written report of how they selected the type and size of the boiler. This certificate fulfills the European Union directive that every member state require certification for installers, but to date has not been put up for accreditation by the international standard "ISO 17024 Conformity assessment — General requirements for bodies operating certification of persons." To remain certified, it is necessary to complete additional training within three years.[73] See Appendix A, Section A.5, for the Austrian Biomass Association Syllabus. The Austrian Biomass Association is also responsible for ensuring that biennial biomass boiler inspections and emissions testing occur. Inspections are performed by certified installers or chimney sweeps.[74] Additional trainings are offered by manufacturers on specific products, and include topics such as use of product control systems, adjusting the boiler, maintaining the boiler, and addressing error codes.

72 European Renewable Energy Council. Joint Declaration for a European Directive to Promote Renewable Heating and Cooling.

73 Strasser, Christoph, BioEnergy 2020. Personal Interview. 22 May 2013.

74 Ibid.

BioEnergy2020+ has developed a training platform for European countries that have not yet embraced biomass heating and cooling. The BioEnergy2020+ program provides a broad overview of biomass as a heating fuel, including discussion of the biomass production chain, sustainable combustion technologies, business concepts and new ideas, and real-world examples of programs. BioEnergy2020+ has conducted tours of fuel production facilities and large-scale biomass systems for government officials and other stakeholders. See Appendix A, Section A.6 for an example BioEnergy2020+ training schedule.

A program was recently initiated in Northern Ireland and in the Republic of Ireland to develop a platform for training, certifying, and registering biomass installers. The program was developed in response to a lack of specialized installers, limited training opportunities, examples of poor installations, and a lack of consumer confidence in the biomass heating industry.[75] Content and course materials were developed and administered by Action Renewables and the Sustainable Energy Authority of Ireland, in partnership with other organizations, including the Austrian Biomass Association. The program trained and awarded certificates to plumbers and electricians. These certified installers were registered in a database accessible to customers. The training courses are no longer offered by the original parties; instead, colleges in Ireland, as well as nine additional training centers, have been approved to deliver the courses.[76]

5.4 Summary of Findings and Recommendations

The following recommendations are derived from the interviews and information collected in developing the information presented in this chapter:

1. **Establish minimum criteria for the technical background of installers.**
   NYS could establish minimum criteria for the technical background of installers, which could differ for the class of unit, i.e., separate criteria for installers of cordwood and pellet stoves and installers of biomass boilers. This could be enforced through the establishment of a statewide registry and through state and local permitting and inspection practices. Consider professional licenses issued by the State as required in Oregon and Maine.

[75] Northern Periphery Programme and the Renewable Energy Installer Academy. Northern Ireland and Republic of Ireland: Best Practice Initiative. Project of the European Union Regional Development Fund.

[76] Northern Periphery Programme and the Renewable Energy Installer Academy.

2. **Consider endorsing the National Fireplace Institute (NFI) certification for installers of any cordwood or wood pellet stove.**
NYS could evaluate the training and certification pathway offered by NFI and determine if it is sufficient for installers of cordwood and pellet stoves in the State. NYS could coordinate with NFI, which updates the coursework and certification exam every three years, to provide input on new training topics and areas where information needs to be improved. If the NFI training and certification pathway is deemed sufficient, NYS could make a program requirement that an NFI-certified installer perform the installation of biomass units.
3. **Work with NFI, Austrian Biomass Association, and other organizations to design a clear training and certification pathway for biomass boilers.**
NYS could work with organizations that are already providing training on biomass boilers to design knowledge and installation requirements for a biomass boiler certification. This certification can be housed within one of the organizations or with the State licensing board. NYS can work with the organizations to design training curricula to prepare for the examination and consider sponsoring registry of certified biomass boiler installers.
4. **Work with New York State vocational schools, community colleges, and state universities.**
Vocational schools, community colleges, and state universities may be interested in providing coursework on biomass heating units and systems as part of plumbing, HVAC, or other relevant programs. The schools may be able to certify installers, which could help to professionalize the field. NYSERDA has ongoing funding opportunities for developing training curricula and applying for ANSI accreditation.[77]
5. **Encourage the practice of accepting continuing education units for biomass boiler courses.**
Coursework offered by trade organizations, often for continuing education units (CEUs), is currently a major source of information transfer to consumers. By accepting biomass coursework for state-managed professional licenses, NYS could encourage the practice of offering CEUs for biomass boiler courses. NYS could also make this a condition of participation in programs that provide incentives.
6. **Promote coursework on commercial system design, sizing, and integration.**
Continue and expand training opportunities, such as those developed for NYSERDA's Renewable Heat New York program, on the design and sizing of commercial systems, or for integrating these systems with new or existing heating systems. Coursework on this subject should include consideration of thermal storage, thermostat and system controls, heat distribution systems, commissioning, and monitoring and verification.

[77] Sterling Hughes, Rebecca. Personal Interview. 17 June, 2013. Rebecca Sterling Hughes works for NYSERDA Workforce Development.

6 Biomass Outreach and Education Programs

A consumer outreach and education plan is a necessary component in any effort to promote high efficiency biomass units. The scope of the outreach and education plan will range across a variety of activities, including working with communities to design biomass incentive programs, educating consumers on the proper use and maintenance of biomass units and securing funding for biomass systems.[78] The goals of the plan should include increasing opportunities and providing tools for consumers and communities to learn about the economic and environmental opportunities and potential drawbacks associated with biomass units or regulatory and incentive programs.[79]

Consumer outreach and education is initiated and executed by a variety of organizations, takes many forms, and targets different segments of the population. This section examines *generalized* outreach and education, typically done by manufacturers, trade associations, and biomass non-profits, to build consumer confidence and market presence, and *targeted* outreach and education campaigns associated with a particular biomass program.

6.1 Methodology

This section was developed through interviews with key stakeholders in the biomass industry, including states, trade organizations, and nonprofits that promote use of biomass; manufacturers; and dealers. Materials reviewed include case studies and existing outreach and education materials; specifically a strategy review for a Canadian workshop on increasing efficiency of biomass stoves; a New Hampshire swap-out program, and the Vermont Fuels for Schools program; materials and an interview of a leader of a recent outreach effort to assist low income families in western Massachusetts with home heating needs using biomass units; the USEPA's Burn Wise program materials and an associated case study to promote cleaner, more efficient biomass units.

78 Hoppin, Polly and Molly Jacobs. Wood Biomass for Heat and Power: Addressing Public health Impacts: Summary of a 2011 Symposium. University of Massachusetts Lowell, Lowell Center for Sustainable Production. 2012.

79 Becker, Dennis R. Policy Design for Biomass Heating. Presentation of the Department of Forest Resources at the University of Minnesota http://heatingthemidwest.org/wp-content/uploads/Dennis-Becker-HTM-2012.pdf.

This section will review the most common outreach and education platforms, describe existing education and outreach programs, evaluate additional needs, and provide recommendations for NYS to deliver outreach and education to consumers. The remainder of this section discusses separate strategies for general outreach and education and for more targeted outreach and education associated with a particular biomass program.

6.2 Generalized Consumer Outreach and Education

Generalized consumer outreach and education on biomass heating options comes from a variety of sources in many forms. Manufacturers and dealers often provide information on blogs and websites, local radio and television stations, and in newspapers and magazines. Manufacturers serve an important role in informing users about biomass as an option for home heating with the goal of increasing consumer confidence in the industry, and not just as a mechanism to increase their own sales. Appendix B provides examples of manufacturers' print media campaigns and links and descriptions to radio and television spots.

Manufacturers can also engage with consumers in other ways. One manufacturer reported that the increased presence of pellet delivery trucks on local roads and the early adoption by local schools and hospitals also helped increase consumer familiarity and interest in biomass systems.[80] EvoWorld, which manufactures high-efficiency wood boilers in NYS, installs booths at home shows. Econoburn, another manufacturer of high-efficiency biomass units in NYS, hosts booths at fairs to demonstrate technology for the general public.

A presence at trade shows is another opportunity for consumer education by manufacturers. For example, in Littleton, NH, a heavily attended home show sponsored by two local chambers of commerce has now been refocused as an energy and financing show for consumer education on heating and cooling of biomass. This change in focus was driven by consumer interest in biomass as an option for heating homes and businesses.[81]

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80 Scott Nichols, President TARM, personal interview.

81 http://www.unionleader.com/article/20130313/NEWS02/130319687

Nonprofits dedicated to the promotion of biomass have also engaged with the public at trade shows. The Northeast Biomass Thermal Energy Council sponsors biomass heating pavilions at oil heat tradeshows, such as the Northeast Sustainable Energy Association (NESIA) building expo and the New England Fuel Institute expo.[82] Interaction at trade shows of this nature will not be with consumers for the most part, but the trade shows provide a forum for contractors to learn about biomass heating options that they then might present to their customers.

Nonprofits might also provide general community outreach geared toward residential users of cordwood and pellet stove technologies, with the purpose of helping consumers use their existing stoves more safely and efficiently and introducing newer biomass systems. By design, these educational events are marketed toward current users of older technologies that attend to learn how to improve their current practices, with the understanding that they might feel inspired to upgrade to a more efficient unit. For this reason, educational events often feature demonstration trailers to showcase new technologies in use. See Section 6.2.1 for this type of community outreach.

In the past, trade organizations have also participated in outreach and consumer education. Trade organizations are limited to more generic messages because they represent a diverse group of members with a variety of units that have different specifications, costs, efficiencies, and emissions. Today, trade associations are spending less time on consumer outreach and education in order to focus their resources on regulatory issues.[83]

6.2.1 Example of Generalized Consumer Outreach and Education

In 2004, the Wood Heat Organization, Inc. provided a series of 11 evening workshops that included burn trailer demonstrations in Ontario, Canada. The goals of the workshop series were to help cordwood and pellet stove users heat their homes safely and efficiently. There was also an interest in educating attendees on the more efficient units available at the time, but the workshop series was not tied to any regulatory or incentive program.[84]

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82 Joe Seymour, Biomass Thermal Energy Council (BTEC) Interview.

83 John Crouch, HPBA, personal interview.

84 Wood Heat Organization, Inc. *Burn it Smart in Eastern Ontario, February 10-29, 2004: Final Report.* May, 2004.

The project organizers recorded their experiences and lessons learned, which provide valuable information for generalized and more targeted consumer outreach. Some overarching lessons learned include:[85]

- Utilize local partners to recruit, manage, and build trust surrounding the workshop.
- Hold workshops in the evenings.
- Hold workshops during the heating season.
- Recruit a presenter that is considered a credible source, but who can also speak about wood heating on a personal level.
- Show respect for the effort and skills that people already apply to their wood-burning practices.
- Establish rapport with the audience before discussing health impacts.
- Focus the workshops on efficiency.

An attendee survey following each of the workshops indicated that attendees were most interested in the workshops to learn about increasing efficiency in their home heating practices, both through improved practices with their older stoves or through stove swap-outs. Thirty-seven percent (37%) of attendees owned USEPA certified stoves; of those that did not, 70% said increased efficiency would motivate them to upgrade. The workshop providers felt that the marketing materials should have, therefore, focused on efficiency. See Appendix B, Sections B.1 and B.2, for the workshop series poster and press release.[86]

6.2.2 Targeted Consumer Outreach and Education

This section is divided into three parts, and each section provides an example and describes best practices and lessons learned.

6.2.2.1 Cordwood and Pellet Stove Outreach and Education

The chances that current biomass users will switch to a more efficient unit increase when the education and outreach campaign also educates the consumer about a financial incentive or mandate. In many cases, education and outreach will be the first step in rolling out a new program. Therefore, information about the program and a well-thought out process for participation should be developed in advance and presented at the outreach and education meeting. The NYS Department of Health has developed

85 Wood Heat Organization, Inc., 2004.

86 Wood Heat Organization, Inc., 2004.

information to inform consumers about safe pellet storage and requirements for smoke and CO detectors. Other states have also developed information materials for state-based campaigns. New Hampshire provides an example of a state-based campaign associated with a state/local partnership to change out residential biomass stoves.

Example for Cordwood and Pellet Stoves. The New Hampshire Department of Environmental Services (NHDES) collaborated with the city of Keene, NH, with support from the USEPA, the Hearth, Patio & Barbecue Association (HPBA), and other organizations, to improve air quality by conducting a woodstove change-out campaign in 2009 and 2010. NHDES first held a stakeholder meeting and designated a steering committee with representatives from local government and industry. They held a media event to kick-off the campaign at an outdoor location in the city. Participating dealers brought demonstration trailers to showcase the more-efficient, cleaner-burning stoves. As a result of these efforts, the rebate and outreach were targeted to low-income households that burned wood as a primary source of heat and qualified for low-income fuel assistance. (Section 6.2.2.3 has more information on designing programs for low-income households.)

Lessons learned from the Keene Woodstove Changeout Campaign, include:[87]

- Use local radio stations for announcements and interviews with questions answered live.
- Place posters in the library, medical center, and other public buildings to promote the program.
- Create state/local partnerships and involve industry.
- Plan an educational campaign on the proper use of a woodstove, with opportunities for education before, during, and after the campaign.
- Consider using the Burn Wise promotional and education material. See Section 6.2.2.3 for more information on Burn Wise, and Appendix B for the press release that NHDES adapted from Burn Wise materials.

87 New Hampshire Department of Environmental Services. Keene Woodstove Changeout Campaign, 2009-2012: Final Report. September, 2010.

6.2.2.2 Biomass Boiler Outreach and Education

When promoting biomass boiler systems for larger buildings, particularly hospitals, schools, and other municipal buildings that require additional scrutiny and buy-in, it is important to educate decision-makers as well as the local community. Beyond public meetings and informational sessions, it may be necessary to assist consumers and public officials throughout the process of scoping the project and performing a cost analysis. Several manufacturers and biomass nonprofits organizations provide calculators for determining capital costs, annual costs, and payback periods for biomass systems, which can be useful as a screening step before a site-specific engineering assessment is undertaken.[88] Site-specific assessments can include an air impact analysis (with planned stack configurations) and comparison to the displaced fuels, and a thermal efficiency analysis, which considers the efficiencies of different units and identifies the proper size of the replacement unit needed. The Vermont Fuels for Schools program is a good example.

Example for Biomass Boilers. The Vermont Fuels for Schools program, which helped many Vermont schools switch to biomass systems, was successful in part because the program provided school decision-makers with the information and tools needed to make the case for biomass heating.

The program was a joint effort of the Biomass Energy Resource Center, the Vermont Superintendent Associations, the Vermont School Energy Management Program, the Vermont Department of Education, the Vermont Public Service Department, and the Vermont Department of Forests, Parks, and Recreation. The goal of the program was to reduce costs for schools by replacing fossil fuel systems with wood chip and other biomass heating systems. The partners designed a multi-step outreach program for schools and a toolkit to help with a cost assessment, work with architects and engineers, and develop a project budget. The first step of the process was a school visit to evaluate the options for the school and educate school decision-makers. The second step was the delivery of the toolkit and assistance preparing for the bond vote necessary to proceed with the project.[89] This program focused on fuel cost savings and did not analyze environmental or public health impacts.

Best practices from the Vermont Fuels for Schools outreach and education plan include:

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88 See: http://forgreenheat.blogspot.com/2014/06/a-review-of-heating-fuel-calculators.html for a review of available calculators by John Ackerly, Alliance for Green Heat. Note that calculators should be used for screening only, and are not a substitute for a site-specific engineering study.

89 Biomass Energy Resource Center. *Vermont Fuels for Schools: A Renewable Energy-Use Initiative - An Overview.* Available at: http://www.biomasscenter.org/images/issues/pdfs/VFFS_brochure.pdf.

- Work with other state organizations to maximize resources and garner support.
- Provide training and educational materials, but also tools, to help consumers and decision-makers.

6.2.2.3 Targeted Consumer Outreach Programs for Low-Income Households

Many biomass heating programs target low-income households because these households may rely on older, less efficient, and dirtier stoves. Low-income households are also good candidates because they are often already working with community assistance organizations on their home heating needs. Challenges to working with low income households include a lack of capital to install units (even units with short payback periods) and a higher percentage of renters who do not have control over the type of heating unit in their home. Numerous program designs can help overcome these obstacles, however. Community outreach and education will be necessary, not just for general education, but also to explain clean burning options that are unique for low income households. A key component to working with low-income households is to partner with local organizations that already administer funding. Massachusetts is one example of using this kind of partnership.

Example for Low-Income Households. The New England Forestry Foundation (NEFF) and Innovative Natural Resource Solutions (INRS) have worked with several departments in the Commonwealth of Massachusetts and the U.S. Forest Service Wood Education and Resource Center to promote the use of efficient thermal wood energy as an option for heating low-income homes in western Massachusetts. They highlight affordability, stable pricing, and support for the local economy in their outreach and education messages and materials. See Section 6.2.3 for more information and Appendix B for examples of the fliers used for public outreach in this effort.[90]

[90] Innovative Natural Resource Solutions. *Working Forests for Home Heating: Using Local Cordwood and Wood Pellet Industry to Supply Low-income Fuel Assistance Programs.* Draft presentation version 9/3/2013 provided by J. Hushaw.

INRS worked with four local community fuel assistance programs in western Massachusetts to help with public outreach on thermal biomass heating and to serve as conduits to local low-income households. The four agencies provided access to the different sets of rules for administering utility and state funding, which influence the technology, hardware, and weatherization that they are able to provide to their constituents. The local assistance programs also helped strategize around a major obstacle: households receiving federal funding for heating assistance must declare a primary fuel for the heating season, which in effect, dissuades low-income households from fuel switching or supplementation during the heating season.[91]

Lessons learned about outreach and education to low income households include:

- Work with local assistance programs.
- Focus the message on the economic benefits of heating with wood and mechanisms to promote sustainable harvesting of wood.
- Stress that wood heating supports local jobs and the local economy.

6.2.3 USEPA Burn Wise Platform

In an effort to protect public health by reducing residential wood smoke, the USEPA, in partnership with HPBA, the Chimney Sweeps Institute of America, and other organizations, established the Burn Wise program. Burnwise is an educational program that developed outreach and education plans to encourage the wood burning community to burn only dry, seasoned wood or wood pellets. Another key message in this campaign focuses on the need to address energy efficiency improvements. This program is designed to accompany ordinance or replacement programs. The Burn Wise message is, “If you choose to burn wood, burn the right wood, the right way, in the right appliance.” In addition to general information about cordwood and pellet stoves and associated policies and programs, Burn Wise offers general outreach tools and information, including pre-recorded video and radio public service announcements (PSAs), press releases, training materials, posters, flyers, and Twitter information, which can be adapted and used by program planners for their own campaigns.[92] See Appendix B for scripts for PSAs, website banners, and sample tweets developed by Burn Wise.

91 Hushaw, J. at Innovative Natural Resource Solutions, LLC. Personal Interview. 26 August, 2013.

92 USEPA. *Strategies for Reducing Residential Wood Smoke.* Publication no. EPA-456/B-13-001 March, 2013.

Burn Wise provides an "Example Wood Smoke Program," which includes implementation of a Burn Wise education and outreach campaign. The example program suggests the following four steps for the campaign:

1. Establish a baseline of residents' wood burning habits, including frequency with which stoves are cleaned and upgraded.
2. Enlist local spokespeople. Consider working with local physicians, especially pediatricians, fire departments, retailers, chimney sweeps, and health officials. Consider hosting an educational event showcasing these spokespeople and, if possible, ask local retailers to provide older and newer stoves to demonstrate the difference in efficiencies.
3. Tap into the media. Consider placing tailored PSAs with local radio stations, adding a Burn Wise banner to municipal and other websites, invite press to events, and work with local newspapers to run stories about residential wood smoke.
4. Revisit the baseline to measure success.[93]

The USEPA also provides case studies of programs that have utilized Burn Wise materials, including the programs' outreach and education materials. The Wood Stove Changeout Program in Libby, Montana, provides a particularly useful look into the outreach and education platform prescribed by Burn Wise.

Example Use of USEPA Burn Wise Materials. The program in Libby was an effort of HPBA, in partnership with the USEPA, the Montana Department of Environmental Quality, Lincoln County, the University of Montana, and the National Fireplace Institute (NFI). Much of the material developed for this program has been adapted for use in the Burn Wise program and for training programs offered by NFI. The goal of the changeout program was to replace every old stove in Libby, a valley location that was classified as non-attainment for $PM_{2.5}$ due to emissions from residential wood burning.

The program hired a dedicated program coordinator to answer customer questions. HPBA designed programs through NFI to train technicians on installing stoves and developed an outreach plan to communicate the program to residents. The program used the local organization in charge of low-income weatherization to coordinate with low-income residents and verify low-income status.

[93] USEPA, 2013.

The program held a media event to launch the effort, followed by a stove fair for residents and an education session to advise on efficient use. The program also used advertisements in local newspapers, radio and television outlets, posters, and flyers. Program staff spoke at local civic and service organizations and wood stoves were on display in town offices.

The first phase of the program provided free replacement stoves for low-income residents. Some residents reported that they initially did not consider participating in the program because it was characterized as for low-income residents. These residents reported that the increased efficiency of the new units, along with less smoke and maintenance, eventually persuaded them to take advantage of the program. It was also helpful that the changeout program was voluntary, but, at the same time, the town also made it illegal to operate an older unit.[94] One of the most important lessons learned from the Libby Wood Stove Changeout program was to design outreach and education with an understanding of the local factors influencing wood stove use, including housing types, the local economy, population age characteristics, heating alternatives, fuel costs and availability, local traditions, and climate.[95]

See Appendix B. for flyers and educational materials from the Libby Wood Stove Changeout program.

6.3 Education and Outreach Findings and Recommendations

These recommendations come out of the lessons learned and best practices in the case studies and interviews summarized in this section. Additionally, broader weatherization and fuel minimization strategies should be addressed to reduce overall heating and cooling needs to minimize emission impacts and costs to consumer.

1. **Develop outreach and education partnerships.** Partner with other departments in the state and with local municipal governments during the design and execution of an education and outreach strategy and plan. Include local groups, such as low-income assistance organizations, that have an understanding of local consumers' needs, constraints, and market entry barriers. These organizations may also have established outreach and education platforms that are trusted by constituents. It is also beneficial to involve consumers in the planning process of developing an outreach and education strategy and plan; an interested group of consumers could help determine what will resonate with a larger audience.

94 Clearing the Smoke: The Wood Stove Changeout in Libby, Montana, HPBA in partnership with USEPA, Montana DEQ, Lincoln County, University of Montana, National Fireplace Institute.

95 Clearing the Smoke: The Wood Stove Changeout in Libby, Montana, HPBA in partnership with USEPA, Montana DEQ, Lincoln County, University of Montana, National Fireplace Institute.

2. **Consider both general and targeted outreach and education.** General outreach and education is beneficial, and can itself be a strategy for increasing the use of efficient biomass stoves and boiler. However, an outreach and education strategy and plan tied to a specific policy or incentive program may see greater results. The education and outreach plan should be developed early in the planning process for any policy or incentive program, and should be adopted before the policy or program is rolled out to the general public. This will help maximize program benefits by combining the dissemination of information with clear actions for consumers to take.
3. **Provide tools and materials to help consumers and decision-makers.** In addition to educational opportunities, education, and outreach plans should include materials and tools that help consumers and decision-makers weigh their options and make an informed choice. This is particularly relevant for larger biomass boiler systems.
4. **Measure against a baseline.** Conduct a baseline analysis, which might establish the high efficiency biomass unit prevalence, number of public buildings or private businesses with biomass systems, the number of attendees at local heating fairs, website hits, and media coverage statistics relevant to the biomass field. Set goals against this baseline and revisit after an established timeframe. Review the results, reevaluate the outreach and education plan, and adjust accordingly.
5. **Establish a local presence.** Work with local organizations and individuals, including low-income assistance groups, health officials, hospitals, and firefighters to bring outreach and education to local communities. Work with these organizations and individuals to speak at local events and provide information on websites and other media outlets.
6. **Understand the consumer.** Make sure messages are clear, instructions are simple, and administrative processes are streamlined. Increase education and outreach efforts during the heating season when consumers are thinking about heating options. Make any events accessible to all consumers by holding them in the evenings or on weekends. Enlist experts, but make sure that they have personal experience with biomass heating. Focus the message on what consumers can do to increase efficiency of their current practices, and encourage upgrades to more efficient units by providing demonstrations

7 Wood Fuels

Selection of wood fuel is critically important to maximize efficiency and clean combustion. Unlike liquid fuels, wood fuels are not always homogenous. The type and characteristics of the fuel selected affects the capacity of any technology to burn cleanly and efficiently. To inform the research, U.S. Forest Service (USFS), EIA, U.S. Department of Agriculture (USDA), European, and NYS-specific data were reviewed to develop information for this chapter. Section 7.1 provides an overview of the different fuel types. Section 7.2 provides details on the feedstock for these fuels. Appendix C contains information on non-woody biomass feedstocks.

7.1 Fuels Overview

Wood fuel typically comes in three forms: cordwood, pellets, or chips. T are other forms, such as biobricks and wood char, but their use is not common. Wood fuels are categorized as derived from hardwood or softwood trees, which refers to the expected density of the wood. Hardwood tree species include oak, beech, hickory, and maple; while softwoods include firs, pine, spruce, and aspen. All wood, regardless of species, has roughly the same energy content per pound, but the volume of wood required to make up a pound of wood will vary dramatically. Table 7-1 provides information on the Btu and weight of various wood species based on a common volume of wood (cord) and highlights the variation due to density.

Table 7-1. Weight and Btu Content per Cord of Wood by Species

Tree Species	Cord Weight (lb)	Btu per Cord (MBtu)	Type of Wood
Ash, Black	2,992	19.1	hardwood
Beech	3,757	24	hardwood
Birch, white	3,179	20.3	hardwood
Birch, yellow	3,689	23.6	hardwood
Cedar, white	1,913	12.2	softwood
Fir, balsam	2,236	14.3	softwood
Fir, Douglas	2,805	17.4	softwood
Hickory	4,327	27.7	hardwood
Maple, red or soft	2,924	18.7	hardwood
Maple, sugar	3,757	24	hardwood
Oak, red	3,757	24	hardwood
Pine, Eastern White	2,236	14.3	softwood
Spruce	2,100	14.5	softwood

7.1.1 Cordwood

Cordwood, or firewood, generally refers to wood logs that have been split and cut to lengths for direct use in wood stoves or hydronic heaters. A typical unit of measure for this fuel is a cord. The term cordwood is derived from the unit of measure "cord," which refers to a stack of wood equal to 128 ft^3, typically a stack 4 feet × 4 feet × 8 feet. A general rule for estimating the displacement of liquid fuels when burning wood is that one cord of well-seasoned hardwood (weighing approximately two tons) burned in an airtight, draft-controlled wood stove (55-65% efficiency) is the equivalent of using 175 gallons of No. 2 fuel oil or consuming 225 therms of natural gas.

The price for a cord of wood varies significantly in NYS. Factors that affect cost include wood type (hardwood or softwood), transportation distance, and demand for wood. Traditionally, hardwood species, such as oak and maple, are the preferred cordwood; however, these species are high value trees, and in many areas, may not be available.

Another important characteristic of cordwood is the moisture content of the wood, which is highly variable. Cordwood with moisture content higher than 20% will burn, but it will be hard to light and keep burning, and will produce more smoke. In addition, higher moisture content fuel burns less efficiently because it uses most of its energy to evaporate the moisture in the wood rather than producing heat energy. Typically, freshly harvested wood, referred to as "green wood," will have moisture content levels of approximately 50%, while split wood that has been allowed to sit untouched for a period of time, referred to as seasoning, has a much lower moisture content of approximately 15-25%.[96] The length of time necessary to season cordwood properly depends on the density of the wood, the size of the pieces, storage conditions, and whether or not the wood was split. Softwoods can reach appropriate moisture content levels in six months, while oak and other dense hardwoods may require two years of seasoning to reach appropriate moisture content levels.

96 Curkeet, Rick, presentation on Fuel Moisture Content, http://www.epa.gov/burnwise/workshop2011/WoodCombustion-Curkeet.pdf

7.1.2 Wood Pellets

Pellet fuel can be made from a variety of materials including compressed sawdust, paper products, forest residue, wood chips and other waste biomass, ground nut-hulls and fruit pits, corn, and cotton seed. For purposes of this report, the project team focused on wood pellets, however, additional information on other pellet feedstock materials can be found in Appendix C.

The advantages of pellets include higher heating value, more uniformity, automated delivery, and the ability to feed in a controllable manner. Pellet-fired stoves and boilers can modulate more easily than cordwood-fired systems. In the United States, there are no regulatory standards for pellet fuels; however, the Pellet Fuel Institute (PFI) has developed voluntary standards. Information on these standards can be found in Chapter 3.

Typical sources of biomass for wood pellets include waste from lumber operations (sawdust), forest waste (tops and branches), and other low value wood product streams. Other feedstock sources can include wood waste, such as scrap materials from the building sector and wood pallets. When using wood waste, precautions need to be taken to avoid contamination, especially from treated woods such as pressure treated wood that contains chromium, copper and arsenic or painted wood, which can also contain heavy metals.

To make a wood pellet, feedstock material is compressed to form a standardized fuel in terms of its physical properties (e.g., size and hardness) and moisture content, which is typically between 5% and 7%. The PFI voluntary standards require pellet dimensions to be typically no longer than 1 ½ inches with a diameter of ¼-inch or $^{5}/_{16}$-inch. The density of a pellet must be a minimum of 40 lbs/ft^3 to provide consistent hardness and energy content. The amount of pellet fines, or sawdust, which can pass through a $^{1}/_{8}$-inch screen, should be no more than 0.5% by weight to minimize dust levels during loading and problems with pellet flow during operation. The salt content of wood pellets should be less than 300 parts per million to avoid stove and vent rusting. Wood with high salt content can cause problems such as equipment damage and increased dioxins and furans in the smoke. Ash content determines how frequently ash removal will be required from a pellet stove. Premium grade wood pellets have an ash content of less than 1%, while standard grade pellets have an ash content of up to 3%. Pellets derived from other biomass feedstock typically have greater ash content (and thus higher emissions).

Seven pellet manufacturers were identified as operating in New York State while this report was being researched. At that time, one additional manufacturer indicated interest in moving to the Adirondacks. Table 7-2 lists the manufacturers, and their locations and maximum production levels (if known).

Table 7-2. Wood Pellet Manufacturers in New York State

Company	Location	Estimated Maximum Production Levels
Biomaxx	Arcade, NY	100,000 tons per year
Curran Renewable Energy	Massena, NY	100,000 tons per year
Essex Pallet and Pellet	Keeseville, NY	Not available
Hearthside Wood Pellets	Stamford, NY	Not available
InstantHeat Wood Pellets	Addison, NY	Not available
New England Wood Pellet	Schuyler, NY	100,000 tons per year
New England Wood Pellet	Deposit, NY	100,000 tons per year
VT Wood Pellet	Seeking to build in the Adirondacks	Not available

7.1.3 Wood Chips

Lower in cost, but much higher in moisture content (MC) than processed wood pellet fuels (5% MC), wood chips (≥40% MC) are most commonly used in larger scale boilers, including gasification systems. There are no existing US specifications that govern wood chip quality or performance, although draft quality categories have been proposed (Biomass Energy Research Center, 2011).[97]

Wood chip fuels can be broadly described in the following categories, ordered according to the quality of the chips:

- Mill chips.
- Bole chips.
- Whole tree chips.
- Waste wood chips.

[97] BERC, 2011. Woodchip Heating Fuel Oil Specification in Northeastern US. Available at: http://www.biomasscenter.org/images/stories/Woodchip_Heating_Fuel_Specs_electronic.pdf

Clean, mill, or paper-grade woodchips are produced from wood production by-products or from slab materials that are by-products of sawmill operations or from debarking of virgin roundwood. These chips are the highest quality for heating systems due to their low ash content, fairly consistent moisture content, and uniform shape and size.

Bole woodchips are produced by chipping the main stem or bole of a harvested tree. These chips are not debarked. Burning bark results in higher ash content and air emissions. Typically, the wood used for bole chips is of lower quality than mill chips. The quality of the bole chip can be improved by screening the fuel to remove pieces that are smaller or larger than the requested size.

Whole-tree woodchips are produced by chipping tree tops and limbs from pruning operations or other landscaping activities. Whole tree wood chips are lower quality chips than bole chips due to the larger bark content and variability in chip size.

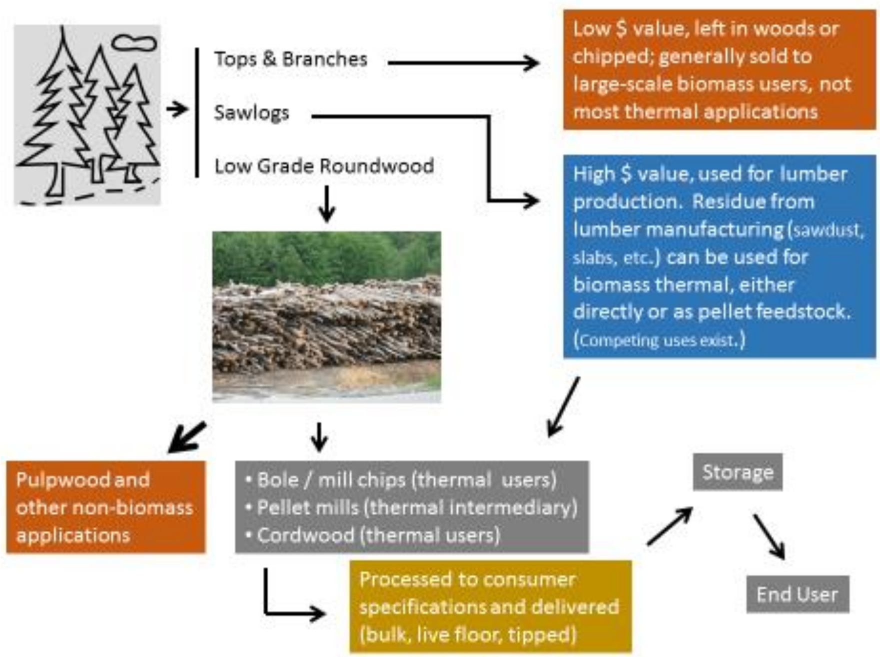
Wood waste chips are produced from clean wood waste materials such as urban tree trimmings, recycled wood, and Christmas trees. These chips are the lowest in quality and size, and management of contaminants such as treated and painted wood is difficult.

7.2 Woody Feedstock

Most fuel for wood-heating applications in NYS (and the Northeast region) comes from forest-based harvesting. Harvesting may be done directly, as in the case where wood is harvested and processed specifically for heating uses as part of a timber harvest involving sawtimber (for lumber manufacturing) or other higher value products. Biomass fuel may also be produced as a by-product of forest product manufacturing. Examples include sawdust and slabs that are generated at sawmills.

In a typical timber harvesting operation, a range of species are harvested. The biomass quality of the harvest varies, depending upon the forest's age and condition, the type of harvest being conducted, local markets, and other factors. A typical harvest includes sawlogs, which are sections of a tree trunk of the appropriate size and quality to become lumber, and lower grade roundwood, which is often used in pulp mills. Depending upon local markets and the logging equipment, tops and branches may be chipped and blown directly into a truck at the point of harvest. The chips are generally used in biomass electric generation applications. Figure 7-1 shows the range of products generated during a typical timber harvest and the potential opportunities for wood heat feedstock. When harvested, low-grade roundwood typically has a moisture content of between 40% and 50%, and a lower heating value of ±4,625 Btu per pound (or 9.25 MMBtu per ton).

Figure 7-1. Multiple Products from a Timber Harvest



7.2.1 Feedstock for Wood Fuels in New York State

7.2.1.1 Timberland Supply

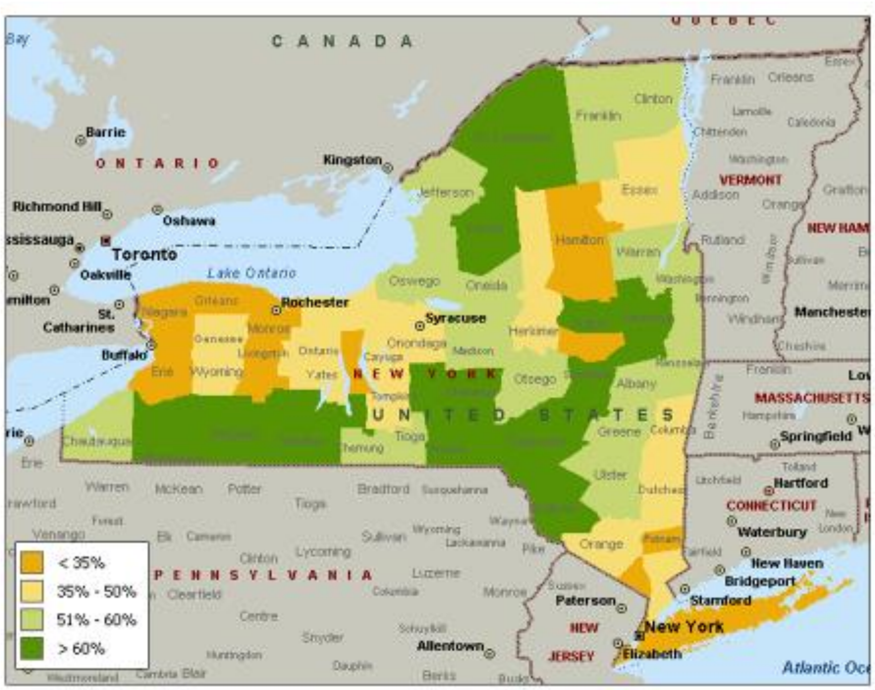
NYS is a heavily forested state, with an estimated 63% of its area covered in forest. Of the State's 19 million acres of forest land, nearly 16 million acres, or 53% of the State's land base, are classified as "timberland" – land legally and biologically capable of producing a commercial timber crop. [98] Timberland is defined as "forest land producing or capable of producing crops of industrial wood

98 Same as USDA Forest Service, Forest Inventory and Analysis webpage, http://www.fia.fs.fed.us/; via The Economic Importance of New York's Forest-Based Economy – 2013, North East *State* Foresters Association, http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf

(more than 20 cubic feet per acre per year) and not withdrawn from timber utilization."[99] As a result, well-forested areas with significant timber-harvesting restrictions or prohibitions (e.g., portions of Adirondack and Catskill Parks) are not classified as timberland. Figure 7-2 highlights timberland as a percentage of all land by county in NYS.

Figure 7-2. Percent Timberland by County in New York State

Source: USDA Forest Service



The total acreage of timberland in NYS has grown over the past 60 years, and has been relatively stable for the past three decades, as shown in Figure 7-3.

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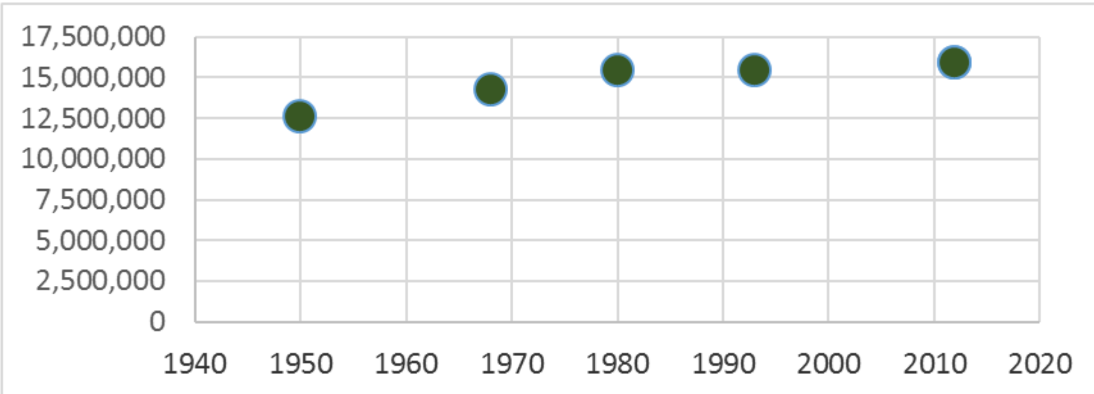
99 USDA Forest Service. "Common Definitions Used by the FIA," http://www.fs.fed.us/ne/fia/methodology/def_qz.htm.

Figure 7-3. Acreage of Timberland in New York State, 1950 to Present

Source: USDA Forest Service, Forest Inventory and Analysis webpage, http://fia.fs.fed.us; USDA Forest Resource Bulletin NE-20. The Timber Resources of New York. USDA Forest Resource Bulletin NE-20. 1970; Considine, Thomas J. and Thomas S. Frieswyk. Forest Statistics of New York, 1980. USDA Forest Service, Northeastern Station and NYS Department of Environmental Conservation Resource Bulletin NE-71. 1982.

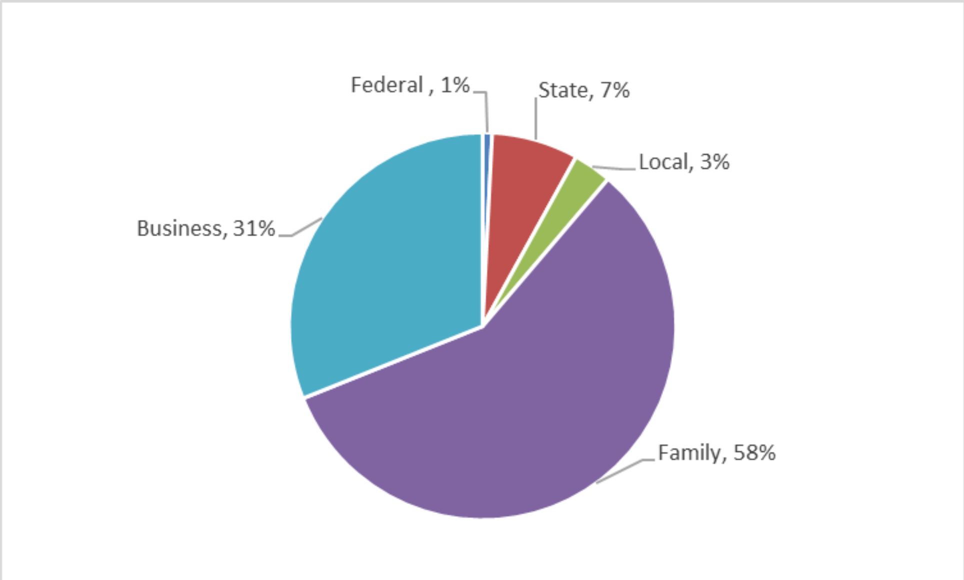


The vast majority of NYS timberland – 89% – is in private hands (Figure 7-4). The USDA estimates that there are roughly 686,000 private non-industrial (family) forest landowners in the State.[100] From a wood supply perspective, private lands (both non-industrial and industrial land) are often viewed as a more secure source of supply. Private landowners are often able to react to new markets and market forces quickly, and can make decisions on conducting timber harvests based upon their unique landowner objectives. However, the large number of non-industrial private landowners in the State making individual decisions on harvesting (or not harvesting) can prove a challenge for wood supply planning.

[100] Butler, Brett J. 2008. Family Forest Owners of the United States, 2006. Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 72 p.

Figure 7-4. Timberland Ownership in New York State, 2012

Source: USDA Forest Service, Forest Inventory and Analysis webpage, http://fia.fs.fed.us; via The Economic Importance of New York's Forest-Based Economy – 2013, North East State Foresters Association,http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf.



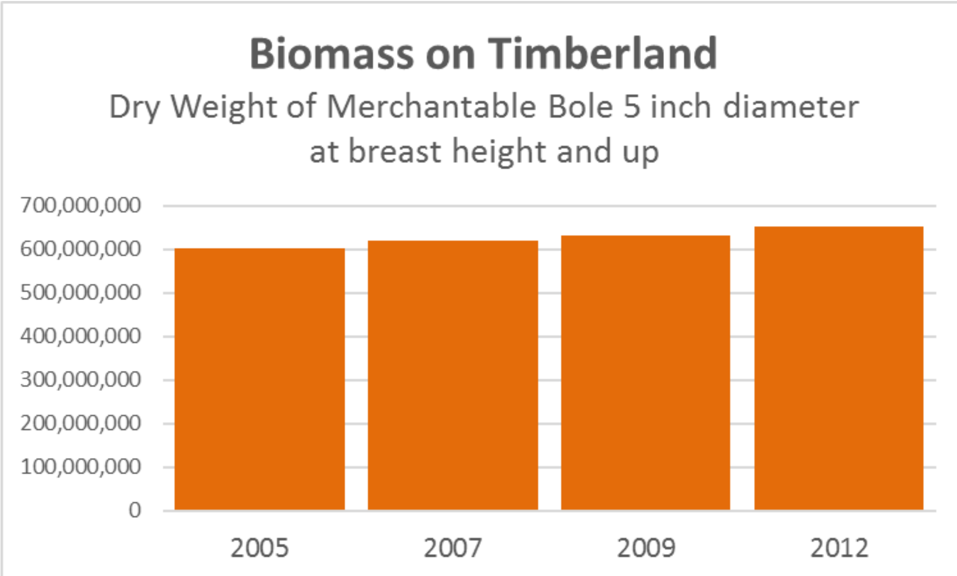
Data collected by the USDA Forest Service, Forest Inventory & Analysis (USDA Forest Service 2013b)[101] indicates that – with all existing markets for wood in place – the total volume of wood on timberland in NYS is increasing – and is now estimated at more than 652 million dry tons[102] of woody material on trees considered "merchantable," or large enough to meet or exceed a pulpwood specification (5 inches or greater diameter at breast height [DBH]), as shown in Figure 7-5.

101 Data derived using USDA Forest Service Forest Inventory and Analysis Tool, EVALIDator 1.5.1.05, using data years 2007 – 2011, http://apps.fs.fed.us/Evalidator/evalidator.jsp

102 The USDA Forest Inventory & Analysis reports biomass on timberland in dry weight; 652 million dry tons is approximately 1,185 million green tons (45% moisture content).

Figure 7-5. Biomass on New York State Timberland, 2005-2012 (tons)

Source: USDA Forest Service, Forest Inventory and Analysis webpage, http://fia.fa.fed.us; via The Economic Importance of New York's Forest-Based Economy – 2013, North East State Foresters Association, http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf



Using the Northeast Forest Biomass Project Evaluator, a tool available through the North East State Foresters Association,[103] a "steady-state model" was run for the State's timberlands[104] with the following assumptions:

- Timber harvest levels for all products stay constant.
- Acreage of timberland is reduced slightly over time (to account for development, conversion to other uses, or new lands set aside from harvesting).
- A forest growth rate that decreases slightly over time (to account for a maturing forest resource in the State).

This model run with these assumptions suggests that in year one there could be approximately 13.4 million green tons of accessible growth[105] in excess of timber harvest. The model also suggests that this volume increases annually as shown in Figure 7-6.

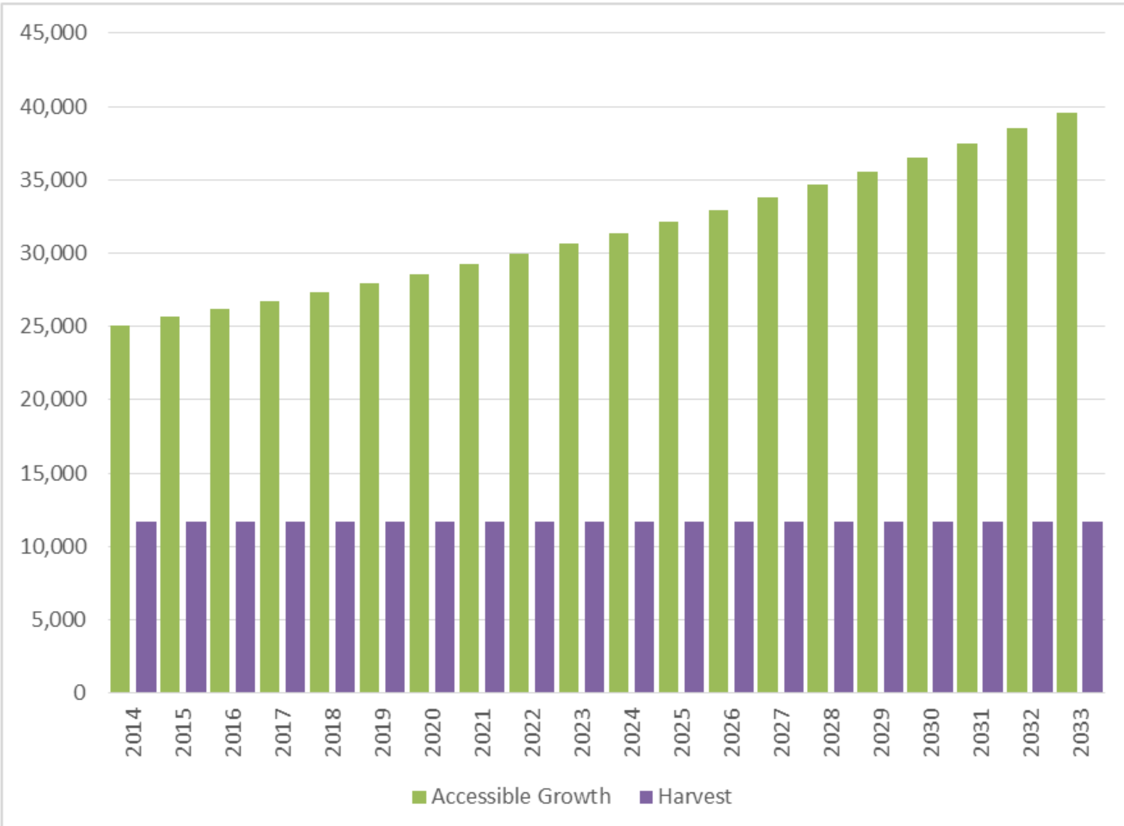
[103] Northern Forest Biomass Project Evaluator (BPE) Model. http://www.nefainfo.org/uploads/2/7/4/5/27453461/nefa_website_.pdf

[104] The Northeast Forest Biomass Project Evaluator Model was run using default settings for percent of standing volume that is low-grade (65%), percent of total sawtimber harvest that is high-value (50%), percent of tops and limbs inventory that is suitable / sustainable to extract for chipping (60%). Additionally, defaults were used for physical factors limiting access (slope, elevation, wetlands, distance to roads, deer yards, stream buffers, and easements total to 5%). Timber harvesting was further restricted by ownership type, again using the default settings (federal 15%, state 30%, municipal 10%, farmer 50%, corporate 90%, private <50 acres 50%, private >= 50 acres 70%).

[105] "Accessible" is limited by both the physical factors and landowner types described above.

Figure 7-6. Modelled Growth and Harvest – Steady State Run 2014 – 2033 (Thousands Green Tons)

Source: The Economic Importance of New York's Forest-Based Economy – 2013, North East State Foresters Association,http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf; using Northern Forest Biomass Project Evaluator, North East State Foresters Association, 2013, http://www.nefainfo.org/uploads/2/7/4/5/27453461/nefa_website_.pdf

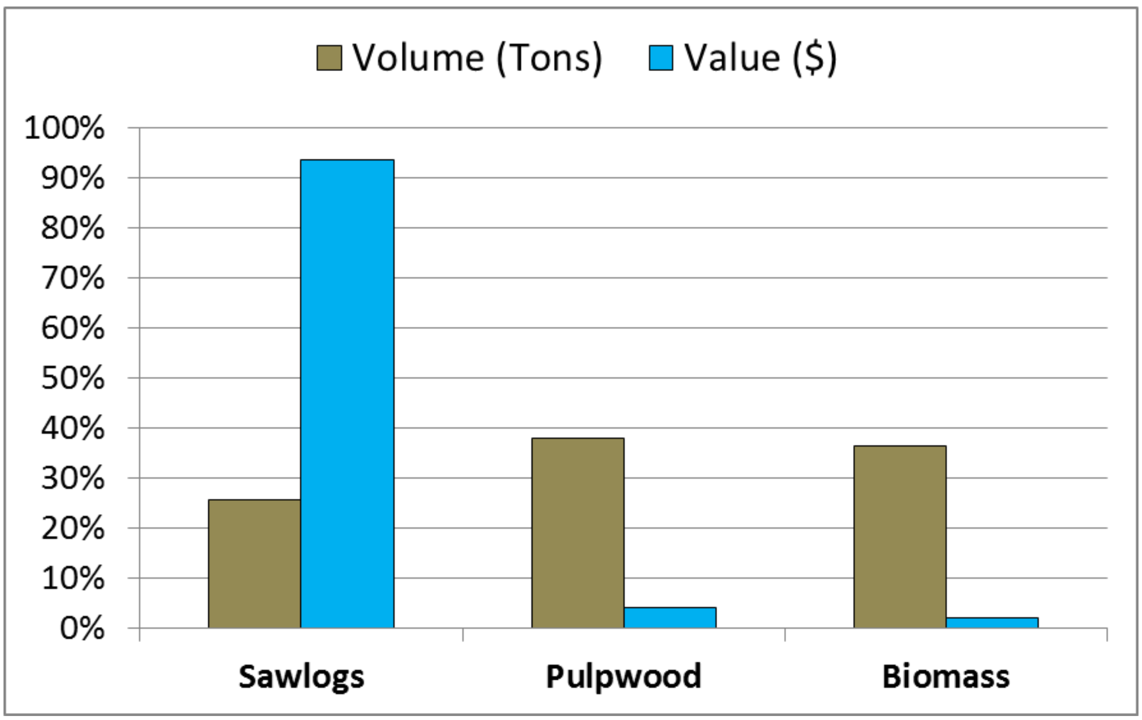


Experience suggests that not all of the 13.4 million tons of wood is of a quality appropriate for use in wood heating. Some will be trees with defects that render them unsuitable for processing. Some portion will consist of tops and branches that may fail to meet the specifications for wood heating units (or processors), and some portion is certainly sawlog grade material.

Timber harvests typically produce a range of products of unequal value. The most valuable products are sawlogs, which are used in the manufacturing of lumber. For example, 26% by volume of the total wood harvested during a 2011 period in New Hampshire was sold as sawlogs, but this 26% harvest volume represented 94% of all stumpage payments to landowners [106] (NH 2011a, NH 2011b). [107] By contrast, low-grade roundwood that was sold as pulpwood or for wood heat applications accounted for 38% of the volume harvested, but only for 4% of payments to landowners. The remaining amount by volume (36%) was used for wood chips suitable for use in electricity production but not of sufficient quality to be used in most thermal applications, which represented 2% of the total harvest value. Given the significant price differential, landowners have an incentive to avoid selling sawlog material for lower-value uses, as shown in Figure 7-7.

Figure 7-7. Volume and Value of Timber Products Harvest, 2010

Source: North East State Foresters Association. The Economic Importance of New York's Forest-Based Economy. 2013. http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf



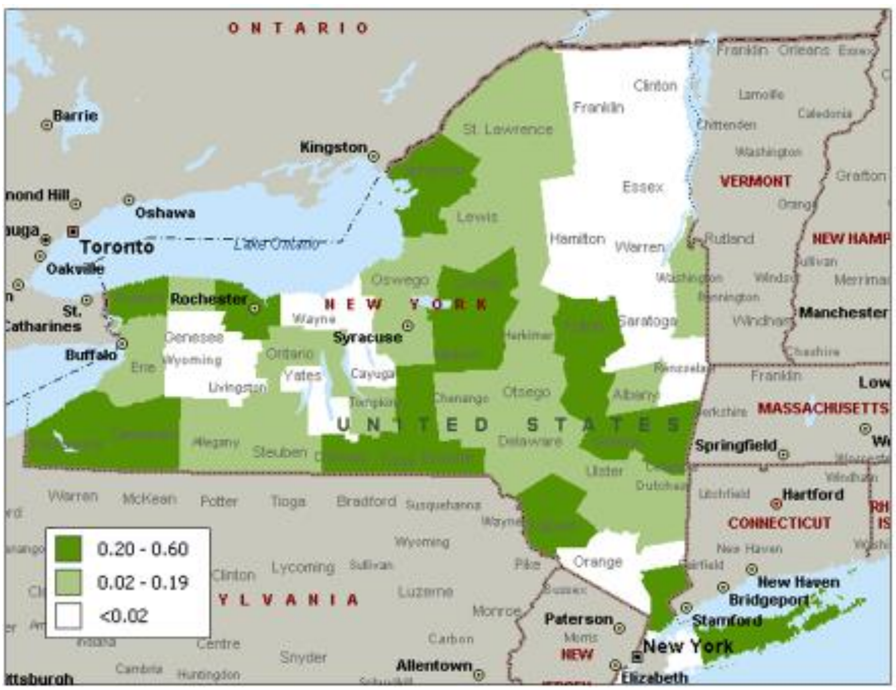
106 New Hampshire is used as the example because all wood harvested in the state is carefully tallied by state tax officials as part of its statutory process. As a result, this data set is more detailed and robust than found elsewhere in the region.

107 Data derived from NH Report of Cut summary, NH Division of Forests and Lands, 2011 and NH Timberland Owners Association Market Pulse, 3Q 2011. New Hampshire is used because of the data collection systems associated with its timber tax, where all wood harvested is carefully tallied by state tax officials as part of their statutory process; tis data set is far more detailed and robust than anything else in the region.

These data suggest that the availability of strong markets for sawlog material is a prerequisite to incentivize forest landowners to manage land and conduct timber harvests. Given this fact, feedstock for wood heat (as well as other uses for low-grade wood) should not be viewed as a competitor to the State's sawmill industry, but rather as a market that relies upon and needs a healthy sawlog market. One key driver for the sawlog market is U.S. housing starts, which have been recovering from recent lows. Using the most recent data available from the USDA Forest Service Forest Inventory & Analysis (USDA Forest Service 2013b),[108] in the period 2008-2012 there was an estimated roughly 10.5 million green tons[109] of unharvested low-grade[110] (non-sawlog) material grown on forest land in NYS produced annually.[111] Figure 7-8 shows this data by county.

Figure 7-8. Density of Annual Unharvested Low-Grade Material on Timberland, Green Tons per Acre (all lands)

Source: USDA Forest Service 2013b.



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108 Data derived using USDA Forest Service Forest Inventory and Analysis Tool, EVALIDator 1.5.1.05, using data years 2007 – 2011, http://apps.fs.fed.us/Evalidator/evalidator.jsp

109 The Forest Service's Forest Inventory & Analysis provides information in cubic feet. All data were converted to green tons, assuming 85 cubic feet of solid wood in a cord, with a cord of softwood weighing 2.3 tons and a cord of hardwood weighing 2.6 tons.

110 "Unharvested low-grade" is annual net growth less annual removals, as determined through the USDA Forest Service Forest Inventory and Analysis.

111 The FIA data is an estimate based upon field sampling of data, while the Northern Forest Biomass Project Evaluator uses FIA data to project future conditions.

An estimated 10.5 million green tons available in the State represents a theoretical maximum level of low-grade wood available from in-State sources. This amount is comparable to that identified in NYSERDA's Renewable Fuels Roadmap 2012 update, which estimates that NYS has 8.1 to 12.3 million tons of woody biomass potentially available.[112] A combination of landowner attitude, sensitive sites, distance to roads, proximity to water bodies, and other factors will significantly reduce this number.

While a detailed assessment is beyond the scope of this effort, Innovative Natural Resource Solutions, LLC. estimated that roughly 50% of the low-grade volume is typically unavailable, due to physical restrictions, landowner attitudes, and other factors. This assumption was used for this analysis, which suggests that 5.25 million green tons of low-grade wood from forest harvesting may be available for new uses such as wood heating, if markets were to be established. The 50% assumption compares favorably with the default model assumptions used in the Northern Forest Biomass Project Evaluator Model. Using the default assumptions for harvest accessibility by landowner type and physical factors limiting access, the model predicts that 53% of land area will be available for harvest.

7.2.1.2 Sawmill Residues

When sawmills cut cylindrical logs into rectangular boards, residue is produced, including bark, sawdust, and mill chips (Figure 7-9). While residue generation varies by tree species and mill equipment, a log in a sawmill generally produces 60% to 70% of useful timber as boards, 20% to 30% as wood chips, and 10% as sawdust(Wakefield 2007).[113] Due to high concentrations of wood residue originating from the outer part of the tree, which carries water from the roots to the leaves, sawmill residue is generally high in moisture, often as high as 50%. Unless dried, the residue typically has a lower heating value of ±4,500 Btu/lb, or 9 MMBtu per ton.

[112] Wojnar, Z (et al). Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply: Annual Update #2. NYSERDA, 2013.

[113] Wakefield, Emily. "PyNe Workshop Report." *ThermalNet.* Issue 04. June 2007.

Figure 7-9. Residue Production at Sawmill

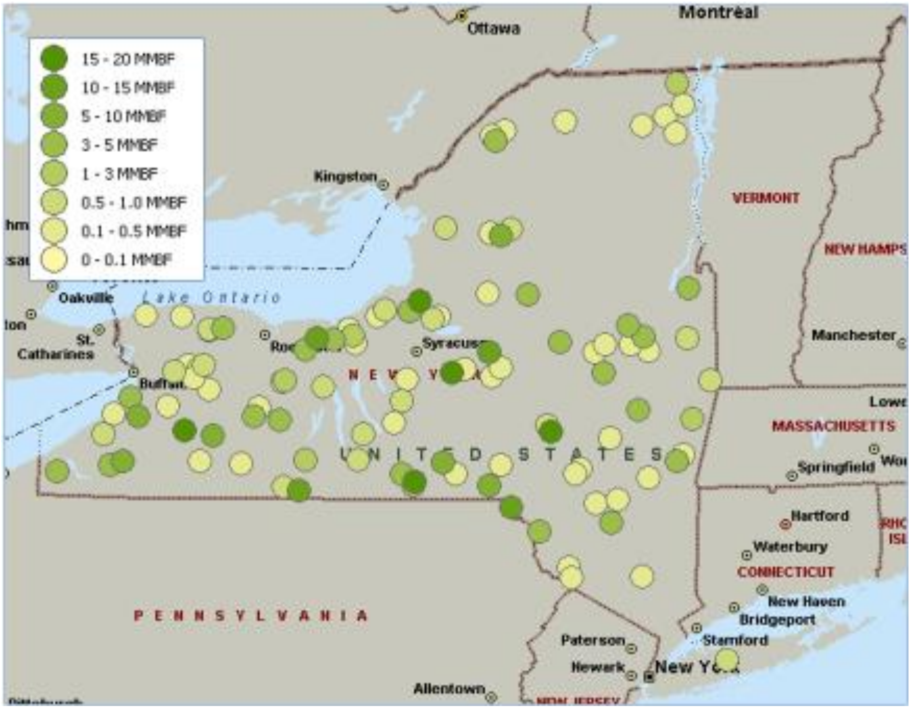
Source: Innovative Natural Resource Solutions LLC.

Sawmill residue, while a possible biomass fuel, has other potential uses as well. Bark is often sold for landscaping, sawdust is sold for animal bedding, and sawmill chips and sawdust are often sold to pulp mills. With these multiple uses, it is highly unusual for sawmills to have an excess of residual material. This analysis assumed that any mill residue used for heating would displace another use.

NYS has a sawmill industry dominated by mid- and small-sized firms. The sawmills typically specialize in either hardwood or softwood, with some capable of processing all wood species. Figure 7-10 and Figure 7-11 present NYS sawmills by hardwood and softwood production capacity (in million board feet [MMBF]).

Figure 7-10. Hardwood Sawmills by Production Capacity (in million board feet)

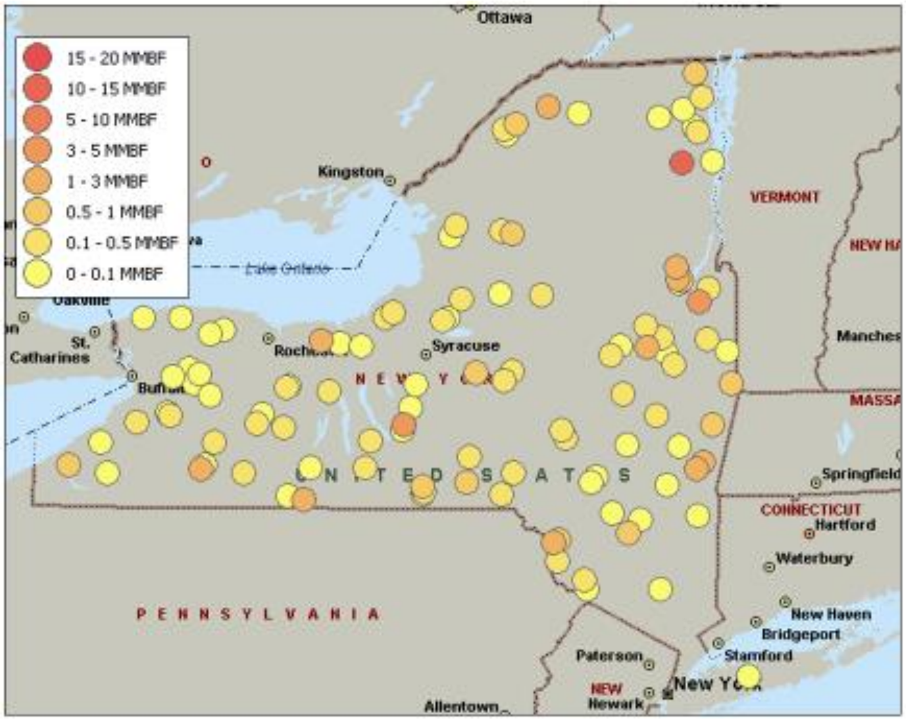
Source: NYSDEC 2013 [114]



[114] Produced using data from: New York State Department of Environmental Conservation, Division of Lands and Forests - Forest Utilization Program. Directory of Primary Wood Using Industry in New York State. 2013. http://www.dec.ny.gov/docs/lands_forests_pdf/primary.pdf

Figure 7-11. Softwood Sawmills by Production Capacity (in **million board feet)**

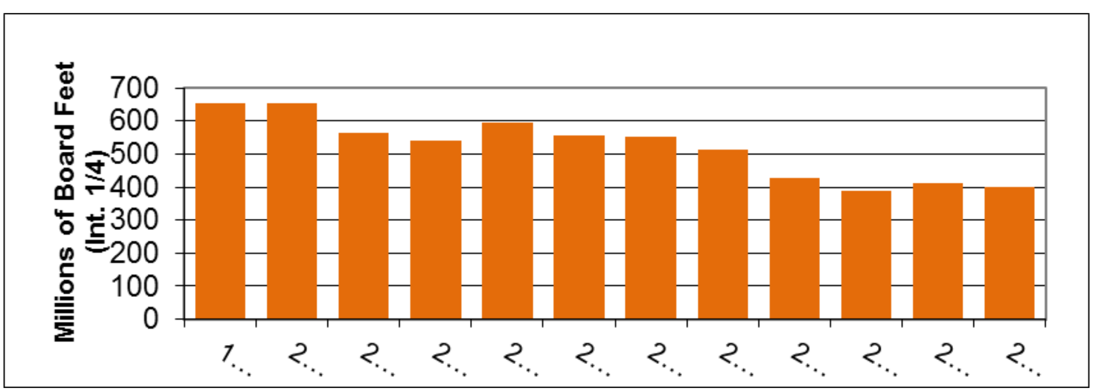
Source: NYSDEC 2013



Sawmill residue relies on the production of lumber at a mill. Therefore, sawmill residue availability closely tied to overall lumber production. In the United States, this is often a function of housing starts. From 1999 to 2011, NYS lumber mills experienced a significant reduction in processed volume, dropping from over 600 million board feet in 1999 to roughly 400 million board feet in 2011.

Figure 7-12. New York State Sawmill Consumption of Logs, 1999-2011

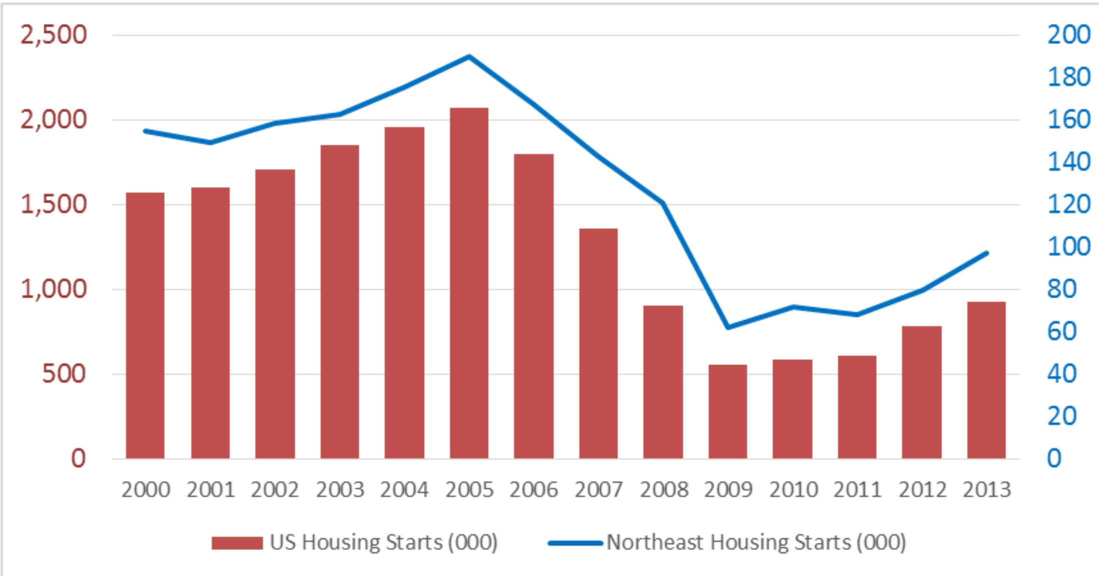
Source: NYSDEC 2011



Lumber production should rebound with housing starts, which have been growing slowly and steadily since hitting a low in 2009 (Figure 7-13). Any increase in lumber production will result in increased sawmill residue, which is then potentially available for wood heating uses.

Figure 7-13. Annual US and Northeastern Housing Starts, 2000 – 2013 (in thousands)

Source: US Census Bureau 2014



The 700,000 green tons of sawlogs processed by NYS sawmills in 2011 produced roughly 175,000 green tons of slabs and 70,000 green tons of sawdust.

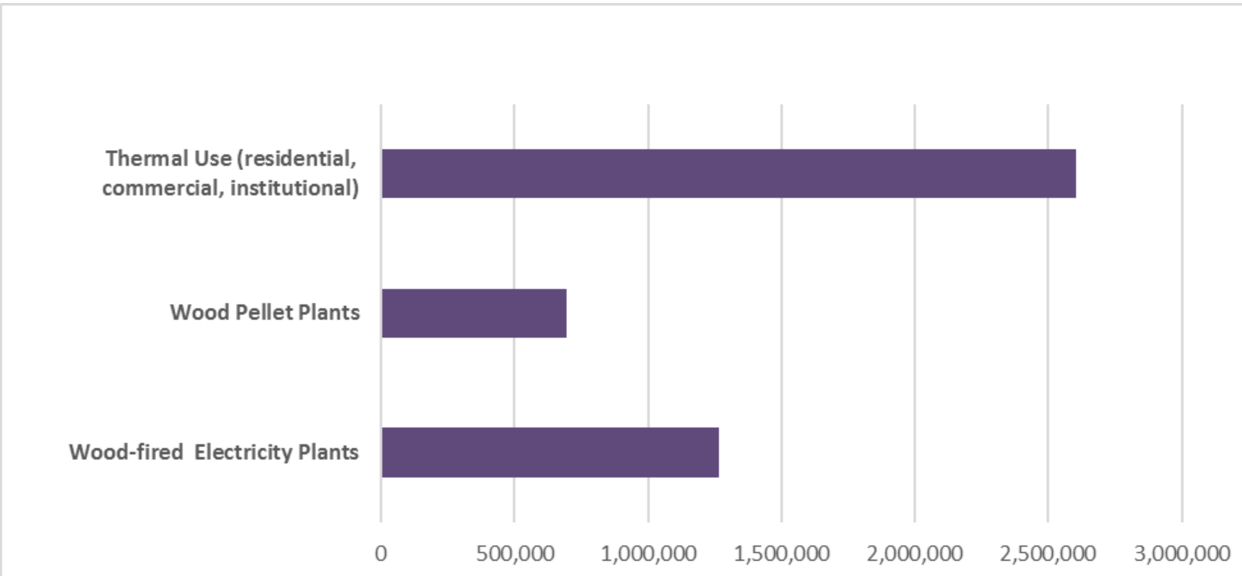
7.2.2 Current Use of Woody Feedstocks in New York State

NYS currently uses an estimated 4.6 million green tons of wood for energy, mostly in thermal applications. An estimated 2.6 million green tons of material are used directly in heating applications (including firewood use), and another 700,000 green tons are used to manufacture wood pellets, which will eventually be used in heating applications.

Wood use at electric generation facilities is also a major portion of the State's wood energy sector, with an estimated 1.3 million green tons of biomass use annually.[115] Since these data were collected, a new 60- MW wood-fired facility has come on-line near Watertown, NY,[116] and recently received a 20-year contract for electricity sales to a nearby U.S. Army base.[117] Assuming that a biomass electricity plant uses ±13,400 green tons of biomass per MW of capacity,[118] this facility will use another 670,000 green tons of biomass fuel annually. If all other existing facilities continue operations, this suggests roughly 2 million green tons of wood fuel will be used annually for electricity production.

Figure 7-14. Annual Wood Use for Energy, by Sector (in Green Tons)

Source: The Economic Importance of New York's Forest-Based Economy – 2013, North East State Foresters Association, http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf



115 The Economic Importance of New York's Forest-Based Economy – 2013, North East State Foresters Association, http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf.

116 ReEnergy Black Riverhttp://www.reenergyholdings.com/our-facilities/energy-generation-facilities/owned-and-operated-by-reenergy/reenergy-black-river/.

117 Watertown (NY) Daily Times, 19 February 2013 ,http://www.watertowndailytimes.com/article/20140220/NEWS03/702199779.

118 Appendix O: Biofuels Markets in New York State and Integration in the Northeast Region. Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply for New York. NYSERDA Report 10-05, March 2010.

Importantly, the data do not account for cordwood use, which is the most common wood fuel used for home heating. Cordwood has a local and diffused market, and lacks good data. Estimates on cordwood use in NYS (as well as almost every other state in the Northeast) vary widely, and the decentralized cash nature of the firewood business has not lent itself to a strong reporting structure. The Energy Information Administration estimated that NYS used 864,000 cords (2,246,400 green tons) of wood in 2011,[119] while the USEPA Residential Wood Combustion Estimation Tool estimated the State's cordwood use at 1,623,121 cords (4,220,114 green tons) in that same time period. The NYS Department of Environmental Conservation estimates firewood consumption at 1 million cords (2.6 million green tons).[120] An additional complication is determining how much wood is moved and used across state and international boundaries, as wood regularly travels across jurisdictional boundaries. New York does regulate movement of firewood,[121] but these rules do not apply to wood transported to sawmills or other manufacturing facilities for use in their operations.

7.3 Fuel Supply Findings

Wood dominates the solid biomass market in NYS. NYS is not unlike other states in that significant uncertainties exist about the amount of wood being used, especially for residential and cordwood operations. This effort also found that non-woody biomass fuels, such as pelletized fuels made from grass, corn, or other agricultural residue, are not ready for the market. Because the technologies to burn these non-woody biomass fuels are not developed and emissions from these alternative fuels are poorly understood, the fuel focus for this report was on wood. The analysis projected that approximately 10 million tons of green wood is available in NYS. Of that amount, 5.25 million tons of green wood could be used for thermal applications. By way of comparative examples, if a 5.25 million-ton harvest level could be achieved, the volume would be capable of providing feedstock for any one of the following three heating scenarios:

[119] EIA, http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/res/use_res_NY.html&sid=New%20York.

[120] Personal Communications. Sloane Crawford, NYS Department of Environmental Conservation – Forest Products Utilization. September 18, 2014.

[121] No untreated firewood may be imported into NYS and within NYS firewood may not be moved more than 50 miles from the harvesting location. These requirements do not apply to firewood that has been treated (heated to at 160 ºF for 75 minutes) and labeled as "New York Approved Treated Firewood/Pest-Free" by the producer.

1. 437,500 homes using wood pellets (assuming 2 green tons of feedstock per 1 ton of wood pellets, and 6 tons of wood pellet use per home per year), representing 3.8% of NYS' residential thermal heating needs. A similar number of homes could be heated using cordwood instead of pellets; or
2. 10,500 schools or similarly sized community-scale facilities (assuming 500 green tons of fuel used annually); or
3. 262 college campuses or similarly sized district energy facilities (assuming 20,000 green tons of fuel used annually).

These scenarios also assume that there is little to no growth in other sectors that might use this feedstock, such as production of cellulosic ethanol. It is unlikely, however, that wood heat markets alone can provide a sufficient financial incentive for harvesting. To be cost-effective, harvests must include both low-quality and high quality wood, and wood intended for a variety of uses. The most critical of these uses is sawmill logs, as they represent the highest value product. Concerns about fragmented forest ownership, competing uses for wood, and long-term availability of fuel exist. Much of this wood supply may not be accessible for use, as it is in small-scale private ownership where owners may have goals that do not include wood harvests. Compounding the supply issues is the lack of reliable estimates for current or future harvests of cordwood, which might reduce the industry growth estimates.

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8 Technology Overview

This chapter provides information on the types of wood heating technology currently available in the U.S. and Europe. Section 8.1 is a brief overview of the biomass combustion process to provide an understanding of the differences between various biomass heat technologies. Sections 8.2 through 8.5 provide an overview of the various heating technologies available for wood combustion and potential emission control options. k

Technologies have been divided into the following three groups, based on maximum heat output: (1) residential small-scale applications up to 250,000 Btu/hr; (2) small-scale and medium-sized ICI applications between 250,000 Btu/hr and 10 million (MM) Btu/hr; and (3) large-scale applications greater than 10 MMBtu/hr. These data were used to inform technology selections for three key categories, which are discussed further in Chapter 10 and Appendix G:

- Business As Usual (BAU) technologies - typically installed when there are no incentive programs to promote a technology.
- Best Available Technologies (BATs) - represent the best available devices, from an emissions and efficiency standpoint, in North America, and are also widely in use in European markets.
- Next Best Available Technologies (nBATs) - are not yet available in the US market but should be commercially viable within the next 10 years. Some of these units are beginning to or will shortly enter the European market but are not yet widely adopted.

When examining European technology for use in the United States, it is important to recognize housing stock differences in the two areas. Houses in Northern Europe tend to be smaller and better insulated. Additionally, their heating systems tend to be low temperature radiant systems with many heat zones, which differs significantly from the high temperature heating systems typically found in NYS.

8.1 Biomass Combustion Concepts

The conversion of solid biomass to heat through combustion for residential and ICI applications shares several core processes including drying of the fuel by evaporating water content, volatilization of organic molecules from the solid biomass fuel without combustion (also referred to as gasification), char combustion of the remaining solid fuel, and combustion of the volatilized gases from the previous steps (gas oxidation). Optimal conditions for complete combustion are dependent on temperature, time, and turbulence (known as the 3-Ts Rule). Appropriate burn temperatures (approximately 1,600 °F) to keep volatilized gases from condensing into liquids or particles, sufficient residence time for volatilized gasses to mix with oxygen in the combustion air (approximately 0.5 - 1 seconds), and turbulence to provide mixing for complete oxidation of gases prior to exiting the combustion chamber must exist to ensure clean and efficient operation. The most limiting of these three factors is turbulence, because the mixing of combustion gases and available air is quite challenging, especially in fixed-bed combustion systems.[122]

Achieving high-efficiency performance with low emissions requires staged combustion zones and controls on fuel feeding and air supply. Additional controls may be employed to improve performance over long burn periods and to optimize conditions at different stages of the combustion process.[123] The following section describes critical parameters to consider when evaluating biomass combustion technologies for different applications, including air supply, fuel feeding, draft direction, and staged combustion.

The basic principles of heat load[124] and combustion control do not generally differ with the size of the combustion technology. However, in small-scale applications, fewer variables tend to be controlled than in medium- to large-scale systems. Comprehensive load and control systems that regulate many parameters are more expensive than simple ones, so size constraints may impact what can be incorporated in small devices. Consequently, in small-scale applications, the control systems are usually kept as simple as possible in order to minimize costs. The simpler the control system, however, the more likely the unit will be adversely affected by poor fuel quality and/or improper operator conditions.

[122] Nussbaumer 2003, p. 1513.

[123] FNR 2007, p. 90.

[124] Heat load is defined as the percentage of load when compared to maximum capacity for a device.

8.1.1 Fuel Feeding

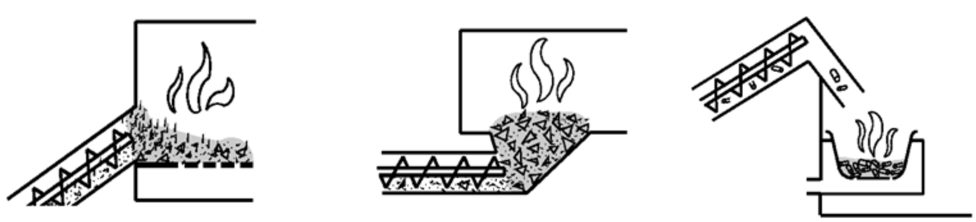
Fuel choice is a major determinant of fuel feeding methods. Biomass fuels such as cordwood, biobricks, or briquettes with a length of 10-40 inches are often stoked manually,[125] while smaller fuels such as wood chips and pellets are automatically transported into the combustion chamber.[126] Fuel feeding methods and rates also depend on the size and demand on the unit. Units larger than 500,000 Btu tend to be fed automatically due to the significant level of effort that would be required for manual stoking.

Manually stoked boilers or stoves are normally built with fixed-bed combustion, which means that the fuel is placed in a fixed area and in a fixed manner in the combustion chamber. In some units, the fuel is placed on a grate above the previous fuel load, while on other units there is no grate and new fuel is placed directly on top of the coals of the previous load.

In automatically stoked boilers or stoves, fuel is fed to the fire by an auger. The motor running the auger controls the amount of fuel. In manually fed stoves or boilers, controlling the heat output with the quantity of fuel is quite challenging and therefore inexact. Automatically fed systems can deliver new fuel to the fire in a variety of ways, including horizontally (known as “horizontal feed”), from the bottom (underfeed), or from above (top feed) (Figure 8-1). This flexibility means that automatically fed units can employ a broader range of technologies such as grates, bubbling or circulating fluid beds, or pulverized fuel combustion. Small- to medium-scale applications are predominately grate systems.

Figure 8-1. Possibilities for Automated Stoking: Horizontal Feed, Underfeed, Top Feed

Source: FNR 2007 p. 96



[125] Musil-Schlaeffer 2010, p. 9.

[126] Marutzky 1999, p. 99.

An advantage of automatic-feed systems over manual-feed systems is that the fuel input can be more easily modulated and adapted to fluctuating heat demand, however, today's units still do not have the turn-down performance nor efficiency at low loads of oil- and gas-fired units. In automatically fed units, air supply can also be more easily adjusted to match the fuel input, resulting in lower emissions.[127] Typically, the turn down capacity on automatically-stoked boilers ranges between 30% and 100 % of the maximum heat load.[128]

In contrast, thermal output in manually stoked systems cannot be easily and efficiently managed because fuel is loaded in hand-fed batches, rather than based on demand for heat. In manually fed, cordwood-fired systems, output can only be effectively modulated between 50-100% of maximum heat demand. Unit operation at heating loads below the effective modulation rates results in poor combustion and increases in air emissions (smoldering). In addition, automatically fed systems use a fuel with more consistent properties throughout, while cordwood, the typical fuel for manually fed systems, is more heterogeneous in its properties and has strong moisture content gradients from the core to outer shell and along its length. Due to fuel consistency and superior modulation capacity, automatically fed systems tend to have better and more consistent operational characteristics than manually stoked systems.[129]

For a typical home in Upstate New York, a heating system sized for the demand-day load will respond to calls for heat at or below 30% load for approximately 30% of its operational hours during the heating season. Sixty-seven percent of the time the load is at or below 50% of the boiler output capacity. These significant low-load demands make optimization of combustion challenging. If a boiler is oversized, the proportion of low-load operational hours increases even further.

127 Lot 15 Task 4 2009, p. 46.

128 FNR 2007, p. 73-74.

129 Marutzky 1999, p. 100.

8.1.2 Air Supply

When and how much air is supplied to a fire is a key factor in ensuring optimum performance. In residential heating systems, which typically use natural draft rather than forced draft, the amount of air supply is controlled by the position of the damper. Depending on the type of system, the air supply adjustment can be made manually or automatically. In automatic systems, air supply and fuel feed can be used to control heat output (Figure 8-2).

Integrating air supply control with load controls, such as fuel feeding rates or boiler supply water temperature, or thermal storage (discussed later) enhances the emissions and efficiency performance of wood-burning devices under a variety of conditions by optimizing the ratio between fuel and air supply. In some technologies, combustion conditions are continuously checked with a lambda probe that measures the excess air and/or with a flue gas probe to determine carbon monoxide levels. These values are compared to the desired ones and air supply is adjusted as necessary [130] (Figure 8-2). If a fan is

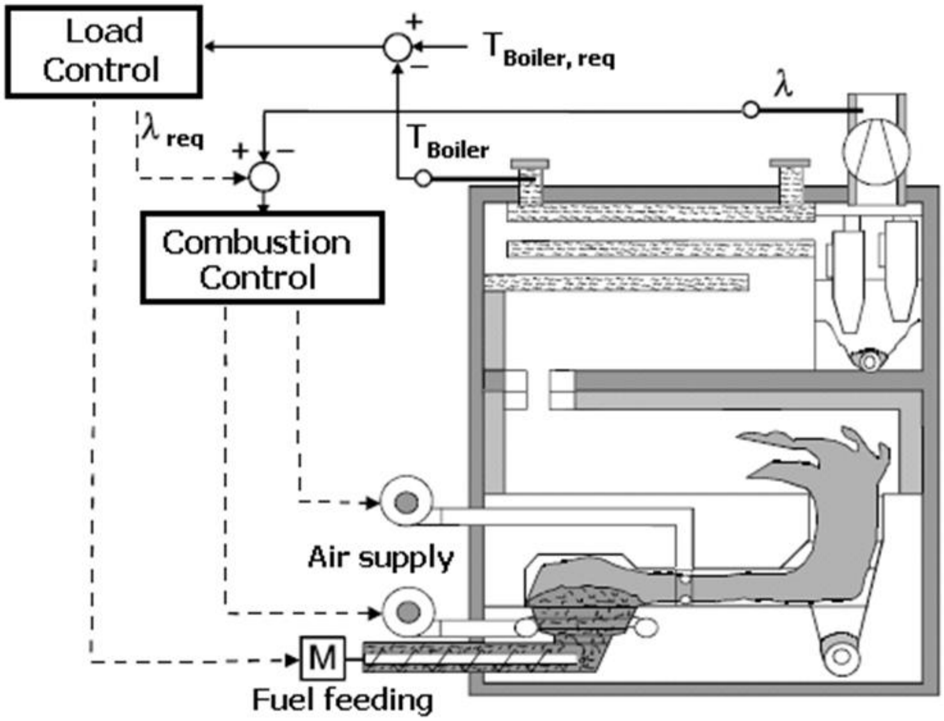
included, the volume of air is controlled with the fan's rotational speed. Figure 8-2 shows two fans, one for primary air and the other for a secondary air supply. [131] Without automatic control of air to fuel ratios, it is very difficult to obtain high levels of performance due to the highly dynamic nature of combustion in these systems.

130 FNR 2007, p. 102.

131 FNR 2007, p. 90, 102.

Figure 8-2. Load and Combustion Control Concept

Source: FNR 2007, p. 103



8.1.3 Staged Combustion

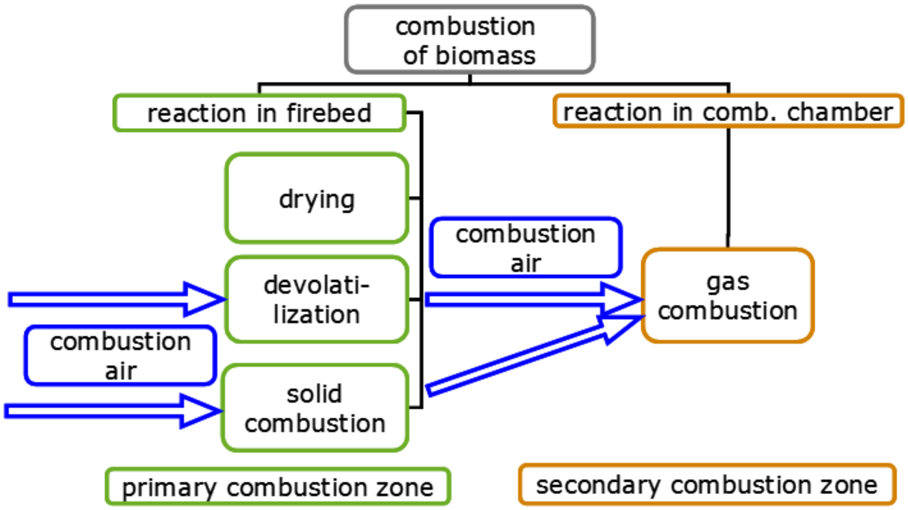
Staged combustion is an effective method to improve biomass combustion performance that greatly improves combustion control and efficiency and as a result, greatly reduces emissions. Staged combustion can only be achieved with a unit designed to ensure good air mixing, high temperatures, and sufficient residence time in the secondary combustion chamber. Staged combustion has been shown to significantly reduce PM, CO, and NO_x emissions, especially when air-to-fuel ratios are optimized automatically.

As shown in Figure 8-3, these reactions occur in a primary combustion zone on the fire-bed and in a secondary combustion zone above. To ensure clean and efficient combustion, air supply must be adjusted for ideal conditions in each zone. [132]

[132] Musil-Schlaeffer 2010, p. 9.

Figure 8-3. Overview of Reactions and Zones During Biomass Combustion

Source: Musil-Schlaeffer 2010, p. 9



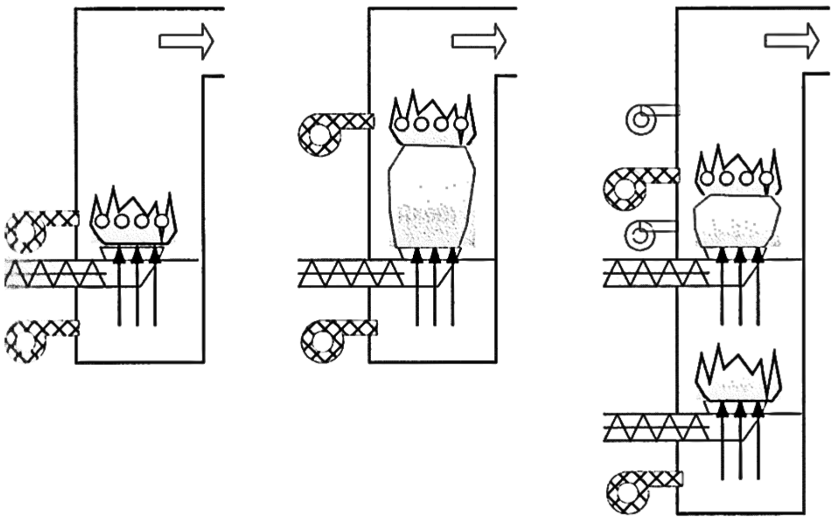
Staged combustion separates the combustion process into several processes that occur in different zones, as shown in Figure 8-4. In the primary combustion zone, the wood fuel is dried by the heat of the combustion chamber via primary air.[133] In this zone, temperatures and oxygen concentrations are relatively low, and results in the release of volatile gases from the solid fuel without complete combustion. Upon release of the volatile gases, a charred wood product remains, which is also burned in the primary combustion zone. The gases and heated air from the primary combustion zone flow to the secondary combustion zone.[134]

133 The term "primary air" refers to the air needed for volatilization and solid combustion in the primary zone.

134 Musil-Schlaeffer 2010, p. 9.

Figure 8-4. Staged Combustion Principles

Source: Loo, Koppejan 2002, p. 241; Obernberger et al., 1999



In the secondary combustion zone, the volatile gases from the volatilization and solid combustion processes in the primary combustion chamber are mixed with oxygen-rich, superheated secondary air. The residence time in the chamber, temperature, and turbulence (3Ts) are optimized to result in as complete combustion as possible and achieve high-efficiency and low-emission performance.[135]

In both primary and secondary burn chambers, ensuring clean and efficient combustion requires optimizing the air-to-fuel ratio. Typically, in manually fed stoves, the air supply is controlled by an operator pushing handles that control dampers. In advanced designs, combustion air is injected in two or more phases, allowing for staged combustion. Both the fuel feed rates and air supply are automatically controlled to ensure optimum air-to-fuel ratios at all times. Staged combustion can include two types of staging: (1) staged air combustion; and (2) staged fuel combustion.

[135] Musil-Schlaeffer 2010, p. 9.

8.1.3.1 Staged Air Supply Combustion

Staged air supply means that the air is injected at two or more positions. For example, primary air can be injected into the fuel bed, forcing combustion, and secondary air can be injected into the combustion chamber, facilitating appropriate burn rates in the gas phase. Separating the different reactions leads to better mixing of the combustion gases and air, thus improving burn conditions. Furthermore, the improved mixing allows a lower air-to-fuel ratio at higher combustion temperatures, which results in more complete combustion of the fuel. Staged air supply is used in small, medium, and large-scale applications. Use of this method is commonplace due to the simplicity of implementation.[136]

8.1.3.2 Staged Fuel Supply Combustion

Wood fuel can be fed into the system at two different positions. In such systems, the primary fuel is burned on a grate and secondary fuel is injected above into the flue gas phase (see Figure 8-4). Hence, the primary fuel often is solid biomass and the secondary fuel is pulverized biomass such as sawdust. Staged fuel combustion is therefore typically used when both types of biomass are available, for example in sawmills. This technology is used to reduce nitrogen oxides (NO_x) emissions.[137] Because of the significant level of effort needed to introduce fuel at more than one stage, this technique is not common in small-scale systems.

8.1.4 Draft Controls

Gasification is another term commonly used for the staged combustion technique that contributes to more complete and cleaner combustion. There are two gasification design approaches, which are defined by the flow of air: updraft and downdraft (or under burning). In downdraft systems, the air flow travels from the top downward and exits at the bottom, while in updraft systems, the air flow is reversed. The designs of updraft and downdraft systems each have differing combustion characteristics and challenges.

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136 Loo, Koppejan 2002, p. 238.

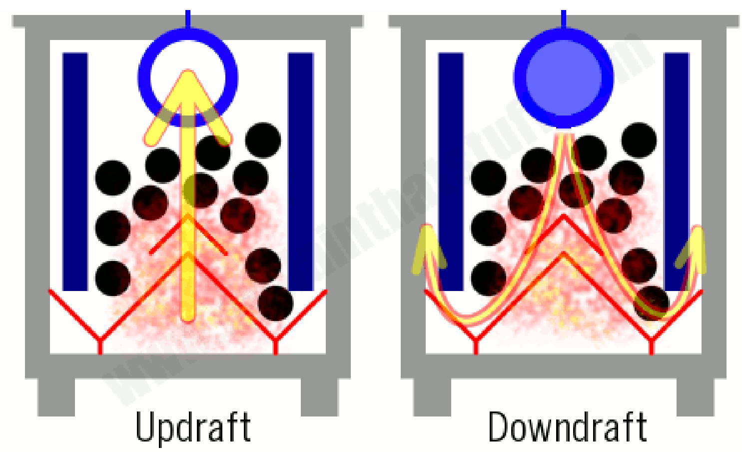
137 Kaltschmitt et al., 2009, p. 424-426.

8.1.4.1 Updraft Systems

In updraft systems, the primary air enters the combustion chamber through a grate at the bottom where the ignition starts.[138] The existing coal bed sparks the batch of fuel, which then in turn reacts. In this design, it is difficult to adjust the air supply to the different combustion zones because air naturally flows up.[139] "Top burning" is another form of an updraft system. In this design, the primary air enters the combustion zone sideways, and the fuel is ignited from the top or the middle of the fuel charge. Top burning units tend to have slower burns than through burning updraft systems. Both types of updraft systems are commonly used in single-staged cordwood stoves.[140] Because the draft is in updraft, a fan is not necessary and air flow is often controlled with manual dampers only.

Figure 8-5. Cordwood Combustion Principles

Source: http://www.explainthatstuff.com/how-biomass-boilers-work.htmlhtl.



138 Musil-Schlaeffer 2010 p. 9-10.

139 FNR 2007 p. 76.

140 Musil-Schlaeffer 2010, p. 9-10.

8.1.4.2 Downdraft Systems

In contrast to updraft systems, the combustion flame in downdraft devices burns from the top to the bottom of the fuel. Like updraft systems, the airflow can travel vertically or horizontally. Because travel in this direction is counter to its natural tendency, a fan is needed to force the flow direction. The fan allows tighter controls on the air supply, which increases combustion performance [141] and results in a relatively continuous burning process. Downdraft technology is considered state-of-the-art technology for cordwood boilers and woodstoves. [142]

8.1.5 Thermal Storage

Thermal energy storage uses a tank, filled with water or water plus glycol, to hold excess heat generated from a boiler or furnace. The hot water is held in the thermal storage tank until the next call for heat, when it is circulated through the heat distribution system. Figure 8-6 is a schematic of a pressurized tank: the supply (red pipe) comes into the tank at the top and return (blue pipe) comes out of the bottom. A thermal gradient or stratification of the heat is maintained in the tank. Depending on whether the system is drawing heat from the tank or the boiler is sending heat to the tank, the thermocline between hot and cold water will move to higher or lower levels in the tank. Care is given to designing the piping so that stratification can be maintained. Note that in this example, the supply from the boiler is 10 gallons per minute (gpm) but that it enters at 2 gpm -- the supply pipe is widened to slow the flow velocity and prevent turbulence in the tank. Sometimes a diffuser or deflector is used as well to prevent turbulent mixing. A more thorough discussion of thermal storage can be found in Chapter 11.

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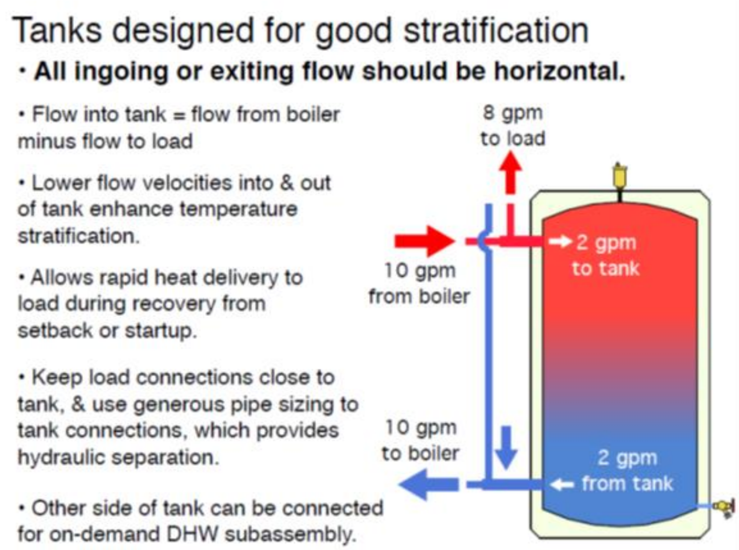
141 FNR 2007, p. 77-78.

142 Musil-Schlaeffer 2010, p. 11.

Figure 8-6.Thermal Storage Schematic (NYSERDA RHNY Training Materials)

Source: http://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/Biomass/biomass-hydronics-training.pdf



Thermal storage may come as a pressurized or “closed” tank, or it may come as an unpressurized or “open” tank. The pressurized tanks may be required to be ASME rated if they are 120 gallons or larger in a commercial application. Open tanks contain an internal heat exchanger and although covered, they are open to the atmosphere. Because of this, water in the open systems must be treated to prevent dissolved oxygen entering the heating system and causing corrosion. These unpressurized tanks also have a temperature limit that prevents their use with supply water that is more than180 degrees, so more heat emitters may be needed in the heating distribution system to make up for the cooler water being circulated in order to maintain comfort.

8.2 Residential Space Heating

A space heater is designed to directly heat the surrounding area rather than an entire building.[143] Typical devices include cordwood stoves and pellet stoves. Space heaters are often used only as supplementary heating units, but in some cases these devices provide primary heat.[144]

143 FNR 2007 p. 70-71.

144 Lot 15 Task 4 2009, p. 24.

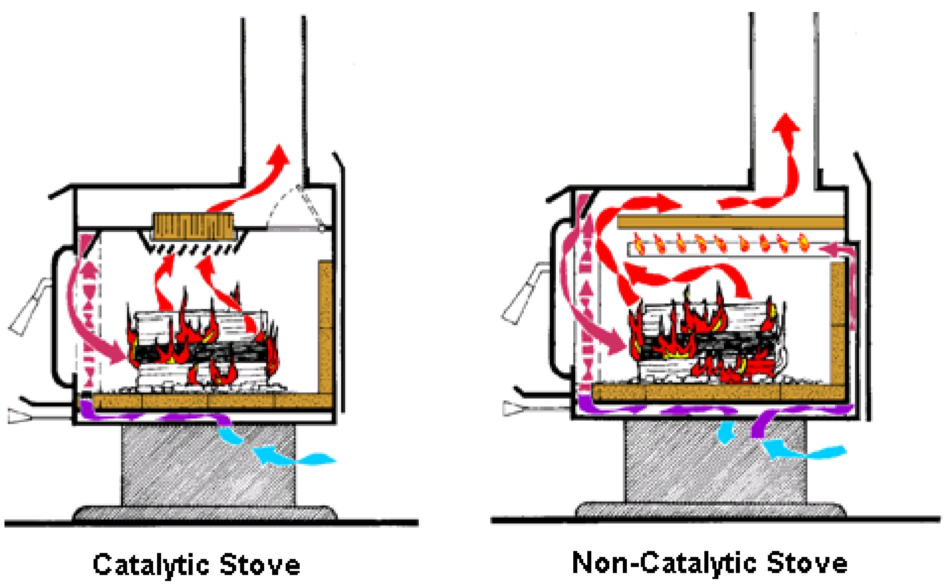
8.2.1 Cordwood Stoves

Cordwood stoves are free-standing, enclosed stoves. They are generally built of cast iron and designed for logs with a length between 10 and 18 inches. Wide variations in design are available, such as doors with or without a viewing glass, or casings of tile or soapstone.[145] Usually, this type of stove is based on the “updraft through-burning” principle. The combustion air supply is regulated manually with dampers. In simple designs, there is no separation of primary and secondary combustion air.[146] Cordwood stoves are typically operated in batch mode, which means that a batch of cordwood is manually placed into the combustion chamber to burn completely. When the entire batch is burned, the next batch of cordwood is loaded. In the United States, cordwood stoves are available with or without a catalytic system in the flue gas path. The construction and the air supply differ slightly between these two technologies.

Figure 8-7 shows the cross section of both technologies with the air flow (shown in blue) and flue gas flow (shown in red).[147]

Figure 8-7. Schematic Cross Section of a Catalytic and Non-catalytic Cordwood Stove

Source: SED online 2012



145 Musil-Schlaeffer 2010 p. 16.

146 FNR 2007 p. 72.

147 EPA online 2012.

The centerpiece of a catalytic stove is a ceramic honeycomb coated with a rare earth-metal catalyst that is located in the flue gas path. Similar to how a catalytic converter controls smog on motor vehicles, this catalytic unit enables combustion of the volatile gases at lower temperatures. As shown in Figure 8-7, the flue gases are guided through the unit, where volatile particles and smoke are combusted at 500-700 °F.[148] The lever-operated bypass damper (shown on the upper right) is only opened for starting and reloading when the temperatures are too low for the catalytic unit to operate. The catalytic honeycomb may degrade over time, depending on the quality of the catalyst and the quality of fuel used in the stove. Low emissions over long periods of time and at low heat load are the major advantages of catalytic cordwood stoves.[149]

The vast majority of stoves in the U.S. market are non-catalytic units. Good combustion in a noncatalytic stove requires three features: (1) the combustion chamber must be insulated to allow high combustion temperatures to be reached; (2) a baffle must be installed to extend the path of the flue gases (see Figure 8-7); and (3) pre-heated secondary air must be injected above the fuel batch, allowing staged combustion. In this type of stove, the baffle and other internal parts need to be replaced after several years of operation due to deterioration caused by high temperatures.[150] Unlike the catalytic stove, these units perform best at maximum load and tend to have high emissions at lower loads.

Control units are not commonly found in cordwood stoves, but there are some automatic control units available in Europe. Figure 8-8 depicts a cordwood stove with an automatic air control that continuously regulates the air supply. This unit can alert the operator to the maximal time for stoking to optimize combustion. As a result, the efficiency of the stove increases, and fuel is saved.[151] Downdraft units and hybrid units[152] are available on the market today and represent state-of-the-art technology.

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[148] CARB 2005.

[149] EPA online 2012.

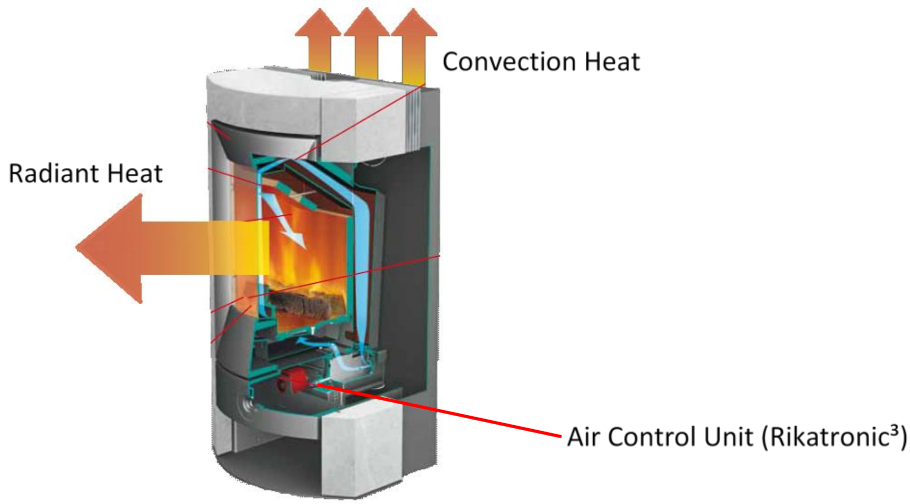
[150] EPA online 2012.

[151] Rika online 2012.

[152] Hybrid units use both catalytic and non-catalytic control technologies to reduce emissions.

Figure 8-8. Schematic of a Cordwood Stove with Air Control Unit

Source: Rika online 2012



8.2.2 Pellet Stoves

As with cordwood stoves, pellet stoves are also free-standing devices with or without a viewing window in the door. Conditions during pellet combustion are much more constant than while burning cordwood.[153] Moreover, unlike cordwood stoves, pellet stoves allow continuous operation through automated fuel feeding. The pellets are transported by a fuel screw into the combustion chamber (top feed), and usually ignite automatically with a glow-plug.[154] Another advantage of pellet stoves over cordwood stoves is that pellets allow easier control of the fuel feed rate because pellets are smaller in size than cordwood. It is, therefore, possible to operate a pellet stove at partial load when less heat is needed. An integrated storage hopper for pellets may be included that enables automatic, unattended operation for multiple days, further enhancing its usability.[155] Best practices for pellet storage should be integrated into this system. Chapter 11 has more information.Pellet stoves can be operated with no fans,[156] however, a large number of commercially available pellet stoves are equipped with a fan to control the air supply and ensure good combustion conditions.[157] Pellet stoves need electricity to operate

153 FNR 2007, p. 83.

154 Musil-Schlaeffer 2010, p. 14-15.

155 Lot 15 Task 4 2009, p. 41.

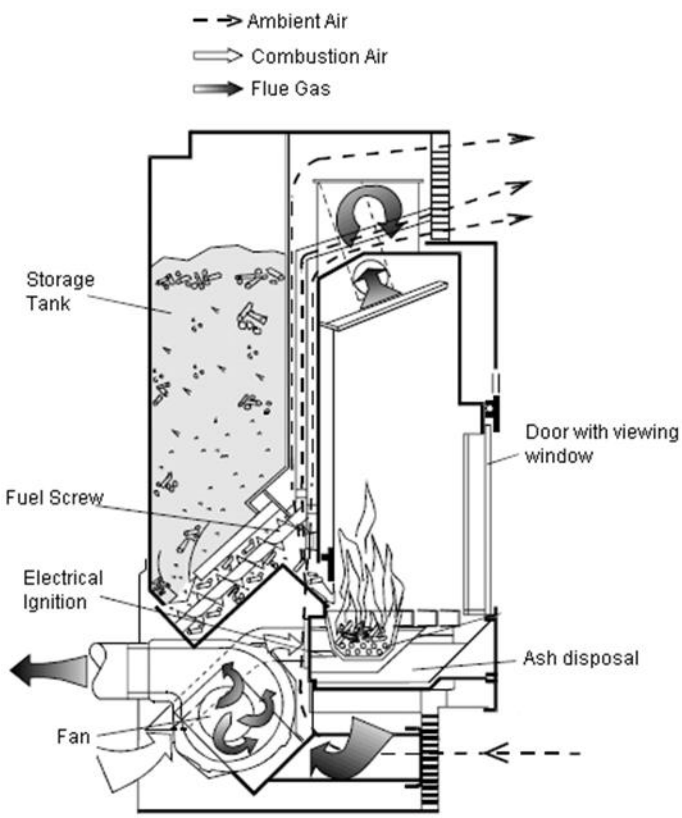
156 Lot 15 Task 4 2009, p. 41.

157 Musil-Schlaeffer 2010, p. 14-15.

the fan (if included), the fuel screw, and the glow-plug. Figure 8-9 presents a schematic cross section of a typical pellet stove. The path of the heated ambient air is marked with a dotted line, and the air is shown entering the stove at the bottom and exiting at the top. The combustion air (white arrow) is drawn in by the fan and moved into the bottom of the combustion chamber. The flue gases (grey arrow) exit the combustion chamber at the top and leave the building through the chimney.

Figure 8-9. Schematic of a Pellet Stove

Source: FNR 2007, p. 84



8.3 Residential Central Heating and Small-scale ICI

This section discusses biomass combustion technologies used to heat a detached house or small ICI installation (<1 MMBtu/hr). Based on NYS regulation, a unit is considered an ICI unit when the maximum heat rating is greater than 250,000 Btu/hr. For residential purposes, there is a distinction between space and central heating facilities. Unlike a central heating system, a typical space heater warms only the ambient area where it is installed and is not controlled by a thermostat responding to heating demand. Central heating systems typically consist of a boiler and a hydronic heat distribution system that involves a pump and water-filled pipes that are installed throughout the building. In a boiler, the water is warmed as it flows through pipes. The hot water is used to heat rooms, and may also be used for producing domestic hot water. The boiler is insulated to minimize heat losses to maximize the delivered efficiency of the heating system. The following sections describe cordwood and pellet boiler technologies used in central heating settings.

8.3.1 Cordwood Boilers

In the 1970s, cordwood boilers based on the through-burning combustion principle with natural draft were introduced. During the late 1990s, in the US, outdoor hydronic heaters, also known as outdoor wood boilers (OWBs), emerged as the cost of home heating oil increased. The OWB moniker is a misnomer because these hydronic heaters are unpressurized vessels and must operate below the boiling point. Over the past three decades, advances in cordwood boiler design have taken place to optimize combustion and delivered efficiency but have been slow to reach US market with the exceptions of a very small number European imports and just a few US manufacturers. A conventional OWB is a single-stage, natural updraft, wood-fired furnace that is usually housed in a garage or within a small insulated shed located some distance from a house. OWBs vary in size ranging from 115,000 Btu/hr up to 3.2 MMBtu/hr, although most tend to be smaller than 500,000 Btu/hr and heat buildings ranging in size from 1,800 square feet to 20,000 square feet. The OWB typically has an oversized firebox surrounded by a very large volume water jacket (200-450 gallons). Firebox sizes will vary with each unit but tend to range in size from 20 cubic feet up to 150 cubic feet. These large fireboxes can hold a very large charge of fuel - hundreds of pounds of wood - to minimize fueling frequency. Hot water is circulated from the OWB to the building though underground pipes to deliver hot water for both space heating and domestic use. The OWB cycles between on and idle depending on the call for heat from the building and the temperature of the water jacket. Combustion is regulated by the opening and closing of a damper controlled by an aquastat.

While OWBs are still available for sale in the NYS, new designs advanced cordwood boiler technologies have made significant improvements in combustion and heat transfer design. In contrast to the OWB, these technologies are designed with two or three stages of combustion and low-volume water jackets (30-50 gallons). Two stage combustion units typically have gasification (primary) and combustion (secondary) zones. The primary chamber is the firebox where wood fuel is loaded. This chamber typically holds no more than 50 pounds of cordwood. These technologies require the use of an auxiliary thermal energy storage tank.

Air is added to the firebox continuously while the damper is open and is blown downward through the wood logs. The gases are forced into a combustion chamber where additional super-heated air is added, resulting in a final combustion of the gases at temperatures higher than 980 °C (1800 °F). The three-stage combustion process gasifies wood in the primary combustion firebox. The hot gases are forced downward and mixed with superheated air, which triggers the secondary combustion. Final combustion occurs in a third, high-temperature reaction chamber. Single-, two-, and three-stage units control heat load through the opening and closing of an air damper to regulate heat load.[158]

Today, state-of-the-art cordwood boilers are based on the downdraft combustion principle with forced draft, which allows for better combustion. An induced draft pulls the flame beneath the grate and adds primary, as well as secondary, air in the correct combustion zones (see Figure 8-10). Downdraft boilers also allow fuel to be added without the risk of combustion gases leaving the boiler.[159] As a result, these gases do not exit the boiler at the door when it is opened for stoking. This feature is particularly important for indoor installations to prevent high levels of CO in the building. Other important parts of a cordwood boiler are shown in Figure 8-10. Because manual stoking is labor-intensive, new cordwood boilers have large fuel loading chambers and/or cordwood reservoirs. These features lessen the amount of stoking otherwise required to operate these units.

158 Gullett 2012.

159 Musil-Schlaeffer 2010, p. 21.

Figure 8-10. Schematic of a Cordwood Boiler

Source: (Guntamatic online 2012)

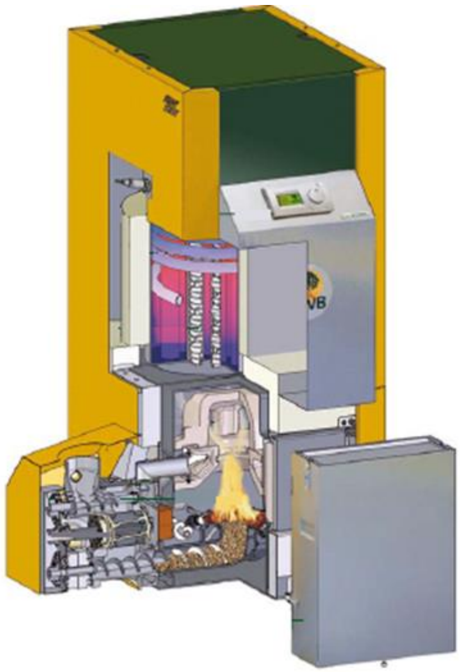
1 batch of cordwood (stoking area)
2 grate
3 ash disposal
4 pre-heated secondary air inlet
5 pre-heated primary air inlet
6 combustion chamber
7 heat exchanger
8 cleaning facility
9 fan
10 flue gas pipe
11 boiler control unit
12 air inlet
13 insulation
14 channel for ascending gases

8.3.2 Wood Pellet Boilers

Pellet boilers can be fully automatic with respect to fuel delivery into the combustion chamber. Fuel is transported by a screw, and a glow-plug ignites the fuel. The fuel can be delivered to the combustion chamber by top feeding, underfeeding, or horizontal feeding, depending on the manufacturing design (see Figure 8-11, Figure 8-12, and Figure 8-13). The use of smart technology such as flue gas sensors and variable speed mechanical draft optimizes combustion control as described previously, although the combustion mode is updraft from the grate. Residential pellet boilers in Europe are sized up to approximately 250,000 Btu/hr. If larger boilers are needed, wood chip boilers are commonly used with a low moisture content wood chip. In the United States, however pellet boiler installations may be as large as 8 MMBtu/hr. Periodically, the operator must refill the pellet reservoir and dispose of the ash. Otherwise, the boiler works automatically. Automated operation of the unit with a quality pellet fuel contributes to highly efficient and low-emission performance among biomass heating technologies. Pellet boilers are considered the state-of-the-art solution for biomass combustion, and are often equipped with automated combustion controls to optimize air-to-fuel ratios for optimal combustion performance.[160] Thermal storage is also used with pellet boilers to optimize thermal transfer to the heat distribution system by maintaining high-load operation of the boiler, reducing boiler cycling, and responding to intermittent calls for heat without the need to energize the boiler.

Figure 8-11. Pellet Boiler with Underfeed Stoker

Source: KWB online 2012



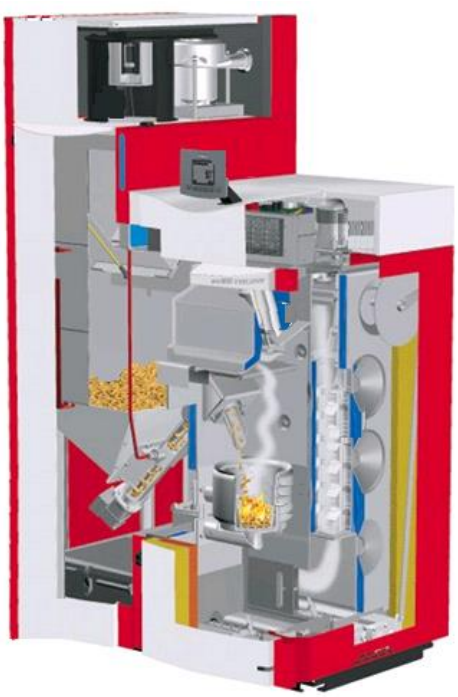
[160] Lot 15 Task 4 2009, p. 47.

Figure 8-12. Pellet Boiler with Horizontal Feed

Source: Hargassner 2012

Figure 8-13. Pellet Boiler with Top Feed

Source: Windhager online 2012



8.3.3 Multi-fuel Boilers

Multi-fuel boilers can burn more than one fuel, and so they sometimes have more than one combustion chamber. The ability to fuel switch allows the operator greater freedom in fuel choice. This section describes two models of multi-fuel boilers. The first model accommodates a combination of cordwood and oil, gas, or pellets. Figure 8-14 provides an illustration of this model. The boiler consists of a cordwood boiler on the left, where an additional burner can be installed. This boiler has only one combustion chamber, where either the gases from the cordwood or pellets burn, or where the additional oil or gas burns. If a cordwood batch is completely burned, but heat is still needed, the additional burner starts up to provide the necessary heat. As soon as new cordwood is added, the second burner stops.

Figure 8-14. Combined Boiler (Cordwood and Oil or Gas)

Source: Ligno online 2012

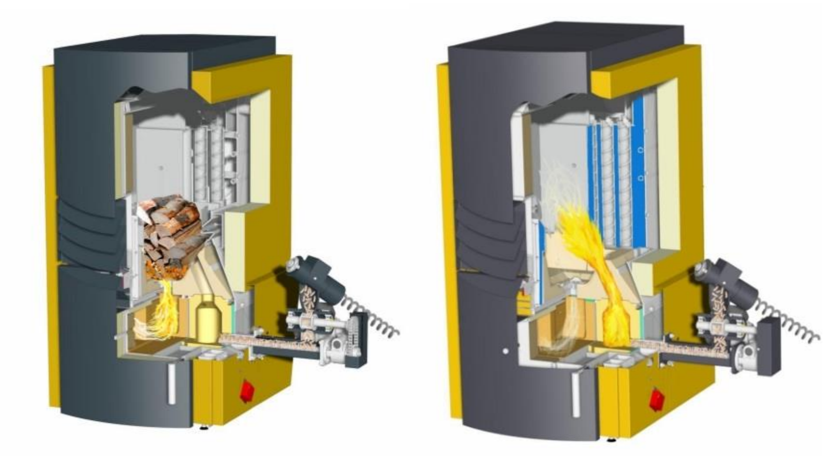
Description of special parts

1	control unit
2	channel for ascending gases
3	stoking door
4	stoking area
5	inlet primary air
6	grate
7 + 8	air control unit
9	ash disposal
10 + 11	cleaning unit
12	combustion chamber
13	lambda probe
14	flue gas exit
15	fan
16	oil or gas burner
17	automatic glow plug

The second type of multi-fuel boiler combusts a combination of cordwood and pellets. Unlike the cordwood oil/gas boiler, this boiler has two combustion chambers. In this system, the flue gases from the pellet burner must cross the cordwood combustion chamber (Figure 8-15). When heat is called for, the pellet burner begins operation. If cordwood is available, the batch is ignited by the pellet flame and the pellet burner stops when the cordwood system is engaged. When the cordwood is fully combusted, but heat is still needed, the pellet burner starts again. Units such as these are available in Europe, but not in the U.S.

Figure 8-15. Combined Boiler in Cordwood Mode (left) and in Pellet Mode (right)

Source: SHT online 2012



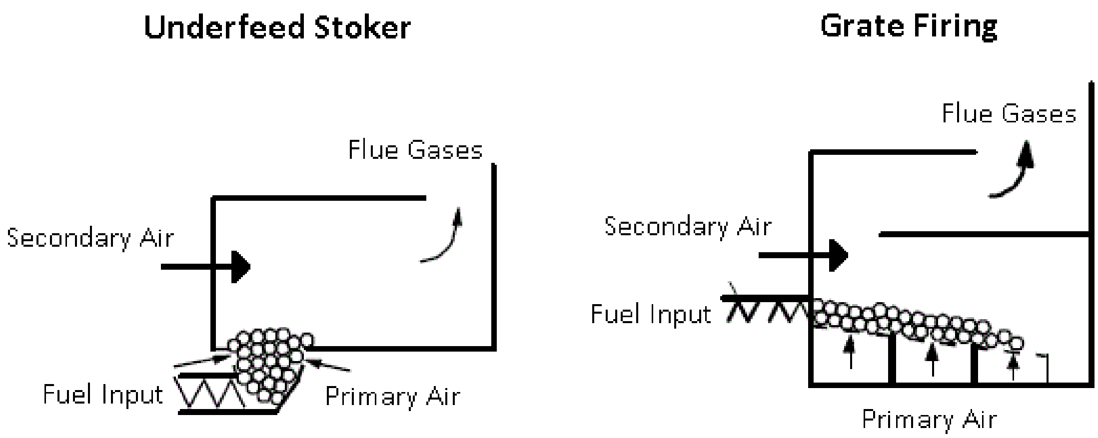
8.4 Medium-Scale ICI Wood Heating Technologies

For applications such as industrial steam production, district heating, or larger ICI applications, boilers with higher maximum load are needed. This section describes combustion technologies for medium-scale applications with nominal output capacity between 2 MMBtu/hr and 10 MMBtu/hr. Generally, these boilers are equipped with mechanical or pneumatic fuel-feeding systems. Automated stoking improves combustion control and thermal output flexibility, making the unit more adaptable to fluctuating heat demand. Moreover, manual stoking is no longer practical due to high labor costs (ABC 2006, p. 134). Typically, medium-scale applications employ fixed-bed combustion technology because more advanced technologies require sophisticated construction or need additional fuel treatment. As a result, they are typically not commercially viable below a nominal power of 10 MMBtu/hr.

Fixed-bed combustion systems include underfeed stokers and grate boilers, pictured in Figure 8-16. In both configurations, the fuel enters the combustion chamber onto a grate, where primary air passes through. The primary combustion zone is located on the fixed bed. Secondary air is typically added slightly above the grate.[161]

Figure 8-16. Fixed Bed Combustion Systems

Source: Kaltschmitt et al 2009, p. 493



8.4.1 Underfeed Stokers

Underfeed stokers are used for small- and medium-scale systems up to a nominal power of 9 MMBtu/hr (FNR I 2007, p. 118). In these boilers, the fuel is transported by a screw vertically from the bottom on an inner or outer grate (see Figure 8-16). Outer grates are the preference for modern combustion plants, as they allow for more flexible operations and an automatic ash-removal system.[162]

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[161] Loo, Koppejan 2002, p. 113.

[162] ABC 2006, p. 139.

Biomass fuels with low ash content (≤1%) and small particle sizes (up to 2 inches), such as wood chips, sawdust, and pellets, are suitable for underfeed stokers. Ash-rich fuels such as bark, straw, and grain are a poor fit for this combustion technology because the ash removal systems typically lack the needed capacity.[163] The moisture content of the fuel can vary between 5% and 40% (wet basis).[164]

In contrast to other combustion technologies, underfeed stokers allow for simple load controls and can, with proper tuning, adequately perform at partial-load operations provided fuel quality standards are maintained. In addition, underfeed stokers are economical and safe to operate.[165]

8.4.2 Grate Boilers

The main advantage of grate boilers is that they can accommodate a variety of fuels that can be mixed and burned together. Fuel with high moisture content can be burned in grate boilers due to long residence times in the combustion chamber and high combustion temperatures.[166] The moisture content of the fuel can vary from 5% to 60% (w. b.).[167] In addition, grate boilers allow a wide range of nominal output between 500,000 Btu/hr through 170 MMBtu/hr.[168] Many variations of grate boilers are available, including fixed, moving, travelling, and vibrating grates.[169]

8.4.2.1 Fixed Grate

Typical applications for fixed grate are cordwood stoves and boilers for residential heating. In medium-sized combustion systems, fixed grate technology is not used because fuel distribution across the grate is poorly controlled.[170]

8.4.2.2 Moving Grate

The essential element of a moving grate boiler is an inclined grate consisting of fixed and moveable rows of grate bars. Through alternating horizontal with forward and backward movements, the fuel is transported along the grate and across the combustion chamber. Unburned fuel is mixed with burned

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[163] ABC 2006, p. 139.

[164] FNR I 2007, p. 118.

[165] ABC 2006, p. 139.

[166] Marutzky 1999, p. 129.

[167] FNR I 2007, p. 118.

[168] FNR I 2007, p. 118.

[169] Loo, Koppejan 2002, p. 114.

[170] ABC 2006, p. 137.

fuel as a result of this movement. The primary air flows through grate bars, which are constructed of fire-resistant steel alloys. Sometimes the grate has multiple sections that can move differently, depending on the combustion stage. It is important to choose the ideal moving frequency of the grate bars to ensure maximum combustion.[171]

A wide variety of fuels can be burned in a moving grate boiler. Wet bark, sawdust, and wood chips can be used with air-cooled grate boilers, where the primary air cools the grate bars. If dry fuels with low ash sintering temperatures are predominantly burned, then a water-cooled moving grate is preferred.[172] The quality of the fuel will affect air emissions rates. Figure 8-17 displays the combustion chamber of a boiler with a moving grate. Note that the grate is inclined. Small spaces between the grate bars can be seen where the primary air flows into the combustion chamber. The fuel inlet is in the far back of the chamber.

Figure 8-17. Combustion Chamber in a Moving Grate Boiler

Source: Polytechnik online 2012

8.4.2.3 Travelling Grate

In a travelling grate boiler, the grate bars form an endless band moving across the combustion chamber, much like a band conveyor. At the end of the combustion chamber, only the ash remains on the band if the fuel is fully combusted. Because the fuel bed is not mixed, there are stable combustion conditions over the grate for burning wood chips and pellets. Moreover, particulate emissions are lower due to the elimination of entrained material that often occurs when air is made turbulent during air mixing stage.

171 Loo, Koppejan 2002, p. 118.

172 Loo, Koppejan 2002, p. 118.

Compared to moving grates, burn times are longer on travelling grates and require more primary air for complete combustion. In addition, the performance of this technology will be affected by nonhomogenous fuels. Spreader stokers can alleviate this problem by distributing and mixing the fuel over the grate. [173]

8.4.2.4 Vibrating Grate

Another type of grate boiler is the vibrating grate, which consists of an inclined, finned tube wall placed on springs. Spreaders or other hydraulic feeders carry the fuel into the combustion chamber. Vibrators stimulate the fuel bed and transport the fuel in one direction until it reaches the end of the combustion chamber where the ash is disposed. The primary air is distributed through holes in the grate. [174]

A vibrating grate system is constructed with only a few moving parts. The short, periodic motion of the grate prevents the formation of slag and clinker materials. As a result, vibrating grates often are used with fuels that have sintering and slagging tendencies, such as straw and waste woods. [175] The disadvantages of this system include increased carbon monoxide (CO) emissions and formation of fly ash. Incomplete combustion can also occur because controlling fuel and ash transport is difficult. [176]

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[173] Loo, Koppejan 2002, p. 116-117.

[174] Loo, Koppejan 2002, p. 120.

[175] Marutzky 1999, p. 136.

[176] Loo, Koppejan 2002, p. 120.

8.5 Technologies for Large-scale ICI Boilers

Conversion systems with a nominal thermal output of more than 10 MMBtu/hr are referred to as "large-scale" applications. At this scale, automatic fuel feeding is essential to maintain combustion. Depending on the technology and fuel, feeding can be done mechanically or pneumatically.[177] Large-scale applications were not analyzed as part of this analysis because these units represent a small fraction of total boiler installations in NYS. However, a technology review of these units is informative for determining what technologies might be scaled down to residential or small- to medium-sized ICI boilers.

This section discusses two technologies: 1) fluidized bed combustion and 2) pulverized fuel combustion. Unlike grate boilers, these technologies need small fuel sizes, between 3.6 and 0.2 inches in diameter. In large-scale applications, pretreatment of the biomass fuel is required for nearly every fuel type.

8.5.1 Fluidized Bed Combustion

Fluidized bed combustion is based on a cylindrical vessel with a perforated bottom plate filled with a bed of hot, inert, granular material. Silica sand and dolomite are the commonly used materials, representing 90% to 98% of the fuel and bed material mixture. The primary air is conducted through the perforated bottom where it fluidizes the bed material into a seething mass of particles and bubbles. The intense heat transfer and mixing create good combustion conditions.[178] This type of technology is well-suited for large-scale applications, as the amount of combustion air is low and the combustion is very efficient. Consequently, the flue gas flow volume is smaller than in other combustion technologies. The initial capital and operation costs for a fluidized bed are too high for use in medium-scale applications compared to other fixed-bed technologies.[179]

[177] ABC 2006, p. 134.

[178] Loo, Koppejan 2002, p. 125.

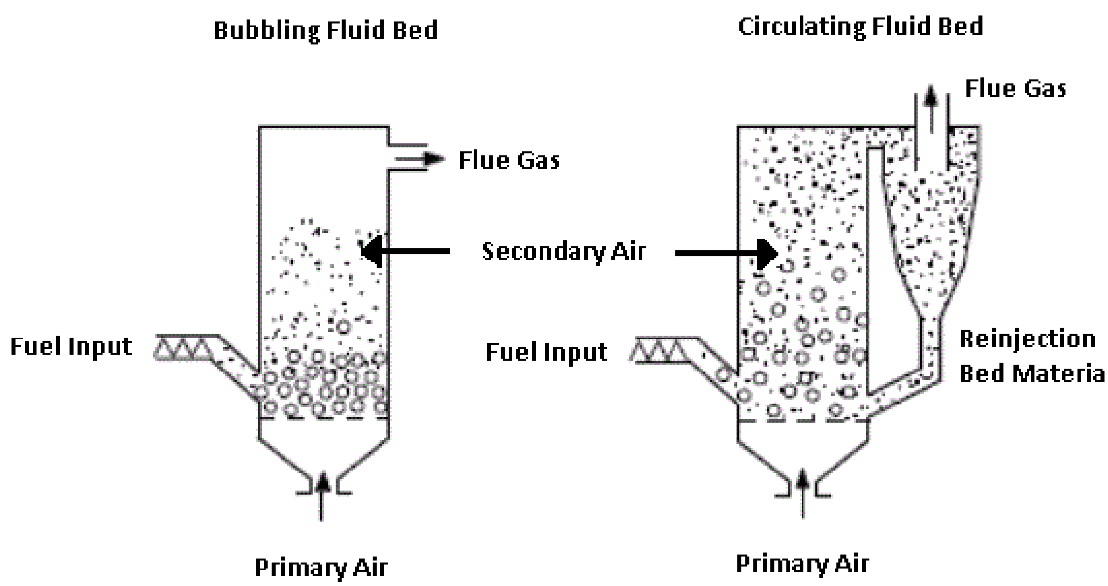
[179] Loo, Koppejan 2002, p. 125.

The fuel mixture used in fluidized bed combustion systems can vary over time (e.g., mixtures of wood and straw), but choices are limited due to fuel size and impurity requirements. Materials such as stones and metal pieces can be problematic if they contaminate or clog the air inlets at the bottom.[180] Pretreatment of the fuel burned in fluidized bed combustion is, therefore, required to control size and remove contaminated materials.[181]

In addition to the fuel requirements, long heating startup times of up to 8 to 15 hours are necessary before operation mode can begin.[182] This technology has comparatively low NO_x emissions due to low excess air and relatively low bed temperature. Two technologies are used in fluidized bed combustion: bubbling fluid bed (BFB) and circulating fluid bed (CFB). Figure 8-18 illustrates these two technologies.

Figure 8-18. Schematic Fluidized Bed Combustion Systems

Source: Kaltschmitt et al 2009, p. 493



180 Marutzky 1999, p. 143.

181 Loo, Koppejan 2002, p. 125.

182 Marutzky 1999, p. 136.

8.5.1.1 Bubbling Fluid Bed

The typical characteristic of a bubbling fluid bed boiler is that the bed material is floating in a bottom area and is not transported through the whole boiler.[183] For this combustion technology, a maximum fuel size of approximately 3.1 to 4 inches should not be exceeded.[184] Air velocity between 3ft/s and 8 ft/s is necessary to keep the fuel and the bed material bubbling.[185] As previously stated, fluidized bed combustion is suitable for large-scale applications, typically sized from 20 to 170 MMBtu/hr.[186]

8.5.1.2 Circulating Fluid Bed

Circulating fluid bed boilers use higher air velocities (16 to 33 ft/s) to transport bed material across the boiler. Before exiting the boiler, the bed material and the fuel components that are not fully burned are separated from the flue gases and reinjected into the combustion chamber, which increases the heating capacity of the unit.[187] Generally, fuel pieces must be smaller than those used for a bubbling fluid bed technology. Smaller pieces require more attention to fuel preparation.[188] Maximum fuel size ranges from 1.5 to 2.4 inches,[189] while moisture content requirements are similar (5% to 60% wet basis). Units utilizing circulating fluid bed technology are typically 50 to 850 MMBtu/hr in size (FNR I 2007, p. 118).

A positive attribute of this technology is that higher turbulence in the boiler leads to better heat transfer and homogenous temperature distribution across the combustion chamber. As a result, better and more consistent combustion conditions are achieved.[190]

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183 Marutzky 1999, p. 143.

184 Kaltschmitt et al., 2009, p. 494.

185 Loo, Koppejan 2002, p. 126.

186 FNR I 2007, p. 118.

187 Marutzky 1999, p. 143.

188 Loo, Koppejan 2002, p. 127.

189 Loo, Koppejan 2002, p. 127; Kaltschmitt et al., 2009, p. 494.

190 Loo, Koppejan 2002, p. 127.

The disadvantages of this technology include the significant effort required for flue gas cleaning, increased loss of bed material in the ash, and additional pretreatment needs for smaller fuels. As with bubbling fluid bed technology, circulating fluid beds have do not perform as efficiently when operating at partial load.[191]

8.5.2 Pulverized Fuel Combustion

Pulverized fuel combustion boilers burn sawdust, fine shavings, or other fuels that have an average diameter less than 0.08 inches. These fuels are injected pneumatically with the primary air into the combustion chamber. Auxiliary burners are used to start the combustion process and are then turned off when the temperature increases. Because the fuels are small, the combustion reaction steps (gasification, charcoal combustion) occur simultaneously, allowing quick load changes and efficient load control. In this application, the fuel quality should be as consistent as possible and humidity should be controlled such that moisture content does not exceed 20% (w. b.).[192]

Typically, pulverized fuel combustion boilers are built with nominal outputs of between 1.7 and 700 MMBtu/hr.[193] Figure 8-19 shows a schematic of a pulverized fuel (or powder) boiler. The air inlet, the fuel input, and the auxiliary heater are visible. These fuels present additional storage and handling challenges due to their fine particle size and low moisture content leading to their potential for a dust explosion.

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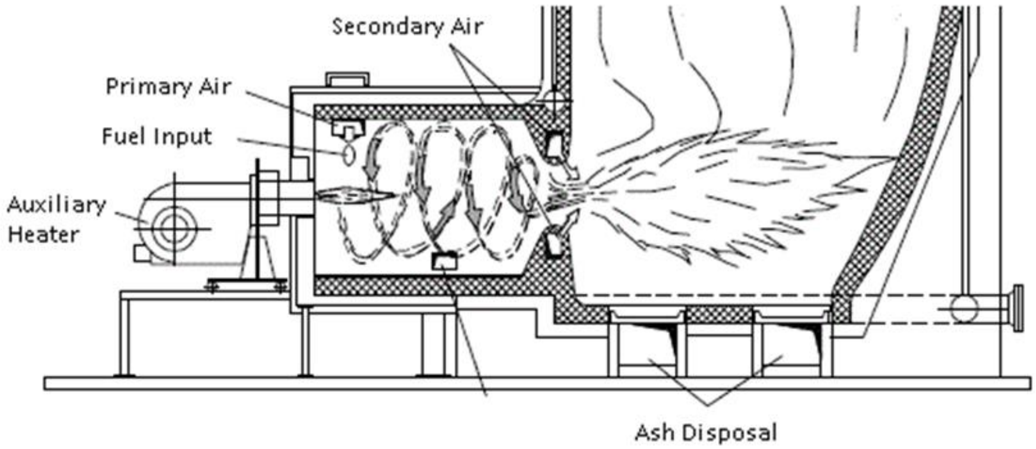
[191] Loo, Koppejan 2002, p. 127.

[192] Loo, Koppejan 2002, p. 128-129.

[193] FNR I 2007, p. 118.

Figure 8-19. Schematic of Pulverized Fuel Combustion

Source: Kaltschmitt et al 2009, p. 521

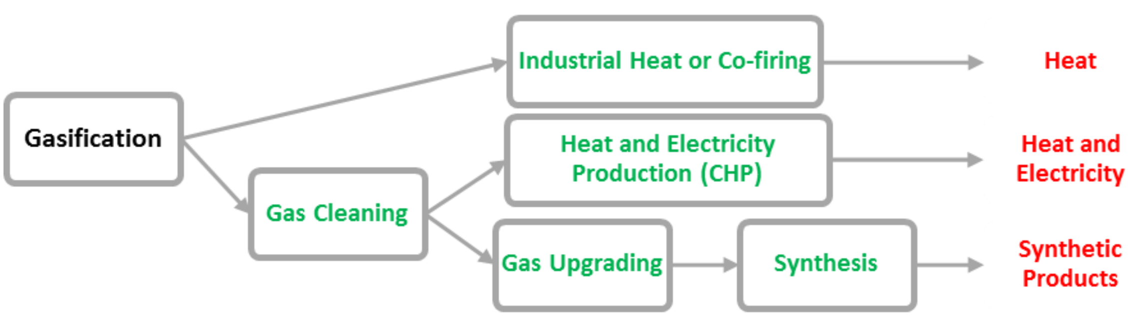


8.6 Thermal Biomass Gasification

Thermal biomass gasification allows the use of solid biomass to generate heat or electricity. Other synthetic products, including various gas and liquid fuels, can also be produced with this technology. During the gasification process, solid biomass is heated up until it changes to a gaseous phase. The biomass gas can be processed further through three primary options, as depicted in Figure 8-20.

Figure 8-20. Thermal Gasification Options

Source: Hofbauer 2009, p. 14



In the first option, the gas may be burned to produce heat. This application requires the least amount of effort; the raw gas can be used without further cleaning in applications such as industrial heat or co-firing. If the gas is cleaned, then it can be used to generate heat and electricity in a combined heat and power (CHP) process as the second option, or to produce synthetic products in the third option. Heat and electricity are generated with a gas engine or a steam process. Synthesis to other products is a very complex process, as a specific gas composition is needed.

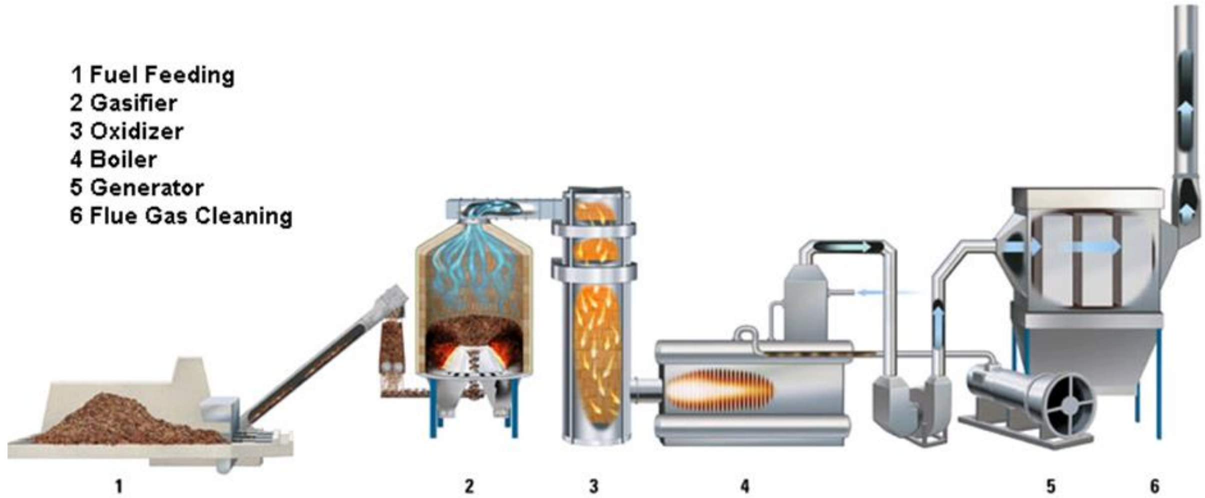
Thermal biomass gasification is done in either fluidized bed or grate combustion systems. Two examples – technologies from Nexterra System Corporation and an Austrian demonstration CHP plant biomass gasification application – are explained in more detail in this section.

Figure 8-21 displays the six typical system components of a Nexterra gasification plant: 1) fuel feeder, 2) gasifier, 3) oxidizer, 4) boiler, 5) generator, and 6) flue gas cleaner. The output of Nexterra's applications range from approximately 8 to 140 MMBtu/hr of thermal power and 6 to 50 MMBtu/hr of electrical power.

The biomass fuel must be pretreated before it can be fed into the gasifier. Here, the centerpiece is a fixed-bed updraft gasifier where the synthetic gas, or syngas, is produced. The gas is upgraded to clean flue gas in the oxidizer before it is either sent to energy recovery equipment or directly fired to provide hot gas, hot water, steam, and/or electricity. The boiler can also be used to burn the gas for hot water or steam. To generate electricity, a steam turbine may be added to the system. The flue gases pass through air pollution controls to reduce emissions before exiting the system.

Figure 8-21. Typical System Components of a Steam/Hot Water System

Source: Nexterra online 2012



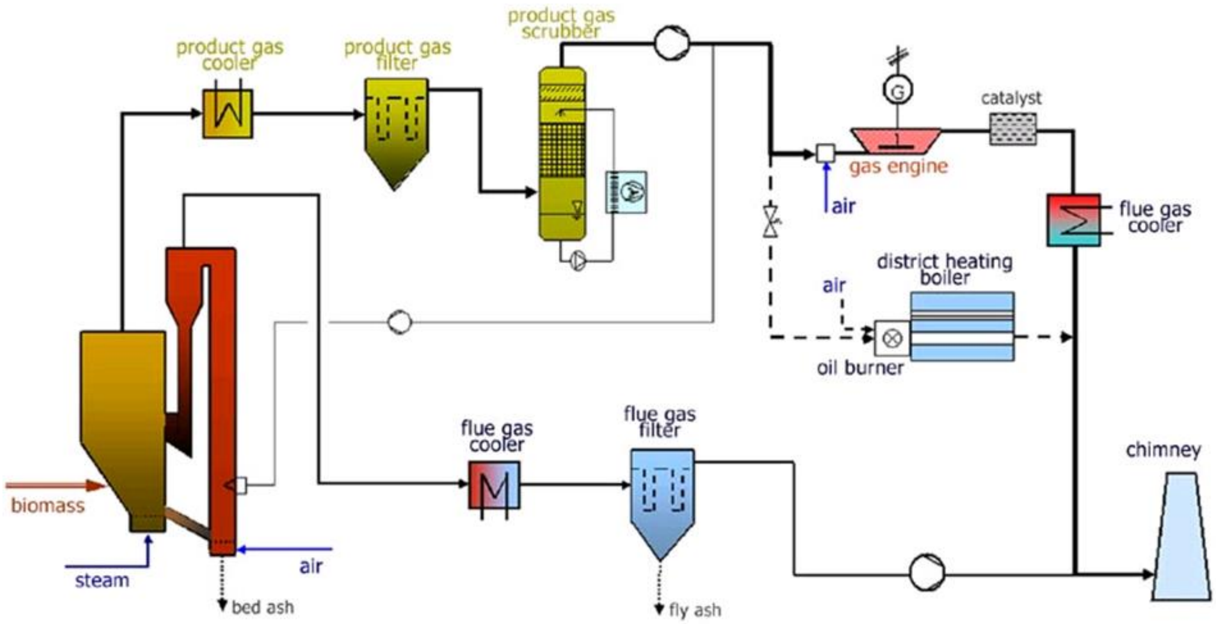
A CHP plant in Guessing, Austria is illustrative. It has a thermal power of 15.3 MMBtu/hr and electrical power of 6.8 MMBtu/hr. In this plant, roughly 1,000 lb/hr of wood chips are converted to gas in the fluidized bed gasifier.

Figure 8-22 displays the process flow diagram with the main components. It is a biomass-fueled, steam-blown gasifier producing heat and power with an internal combustion engine. The solid biomass is gasified with steam at a temperature of approximately 1560 °F. By using steam instead of air as the gasifying agent, a nitrogen-free gas with low tar content and high heating value is produced. The remaining charcoal is fed into the combustion zone with the circulating bed material, which serves as a heat carrier, and is burned. The heat from the flue gas is used both in the gasification process and for district heating. The product gas from the gasifier is cooled and cleaned. The separated particulate matter (PM) is recycled to the combustion chamber to burn any remaining carbon. The gas is further cooled in the scrubber, where concentrations of tar, ammonia, and acid gases are reduced. The gas cleaning process does not generate residues, wastewater, or condensates, as all residues are returned to the process.[194]

[194] Hofbauer et al 2006, p. 18.

Figure 8-22. Schematic of CHP Plant in Guessing, Austria

Source: Nexterra online 2012



8.7 Emission Control Technologies

Particulate emissions from biomass combustion consist of inorganic ash particles or unburned organic molecular components like soot. Generally, particulate emissions are defined by two properties: (1) the particle aerodynamic diameter; and (2) particle concentration in the flue gas (also called the PM load). These properties will influence the extent of potential emission reductions. Depending on the size of the device, PM loading, and particle size range, different emission controls may not always be appropriate. The following sections describe PM controls by device size.

8.7.1 Particulate Matter

Particulate emissions from biomass combustion consist of inorganic ash particles or unburned organic molecular components like soot. Generally, particulate emissions are defined by two properties: (1) the particle aerodynamic diameter; and (2) particle concentration in the flue gas (also called the PM load). These properties will influence the extent of potential emission reductions. Depending on the size of the device, PM loading, and particle size range, different emission controls may not always be appropriate. The following sections describe PM controls by device size.

8.7.1.1 Control Technologies for Residential and Small ICI Wood Burning Equipment

In small-scale combustion systems, high efficiency and low emissions are achieved most often through primary design features. Small-scale boilers and stoves should be designed to avoid the need for secondary or "add-on" control measures. Measurements taken on European equipment have found that the majority of dust particles emitted from cordwood stoves, pellet stoves, and wood chip boilers fell below 0.15 µm in diameter, as shown in Table 8-1. These observations have also been made in the U.S. by Clarkson University and US EPA.[195]

Table 8-1. PM Emission Rates & Particle Diameter for High Efficiency/Low Emissions Residential Technologies

Source: Kippel, Nussbaumer 2006, p. 23-30

	Cordwood stove	Pellet stove	Wood chip boiler
Average PM (mg/m³) at 13% oxygen	20-50	24-26	50-150
Average PM (lb/MMBtu)	0.0304-0.0759	0.0332-0.0360	0.0926-0.2768
Average particle diameter (µm)	0.02-0.1	0.02-0.1	0.07-0.11

While emission control technologies and energy storage measures may not be commonly applied in the United States, they are widely used in Europe. For example, in Austria central heating cordwood units are required to be sold with thermal storage. This facilitates good energy management of the heating system and better combustion conditions for the boiler, which in turn, reduces emissions. In the U.S., thermal energy storage is available but has not routinely applied. With the development of New Source Performance Standards (NSPS) by the USEPA in early 2015, thermal storage will now be required for certain cordwood boiler technologies. The minimum volume for thermal storage in the U.S. will be

determined for low-volume staged combustion boilers using a test method developed by Brookhaven National Laboratory and referenced at M28-PTS in the NSPS. In NYS, technology transformation efforts

[195] http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Wood-Fired-Hydronic-Heater-Tech.pdf
http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Evaluation-performance-emissions-wood-combustion.pdf

are underway as part of Renewable Heat NY which provides financial incentives for these technologies with thermal storage. More information on thermal storage can be found in Chapter 11.

Catalytic converters

Cordwood stoves equipped with catalytic converters are available in both Europe and the United States today. The catalytic unit is located in the flue gas path and reduces emissions caused by incomplete combustion. Catalysts can reduce volatile organic compounds/hydrocarbons and organic PM, but cannot reduce emissions of inorganic PM. In addition, use of catalysts will actually increase SO_2 emissions. [196]

Catalytic units used for emissions reduction in combustion appliances often use a solid substrate covered by a catalytic surface that reacts with a gaseous partner (the flue gas). In Figure 8-23, the principle of catalysis is shown and the main steps are numbered as follows:

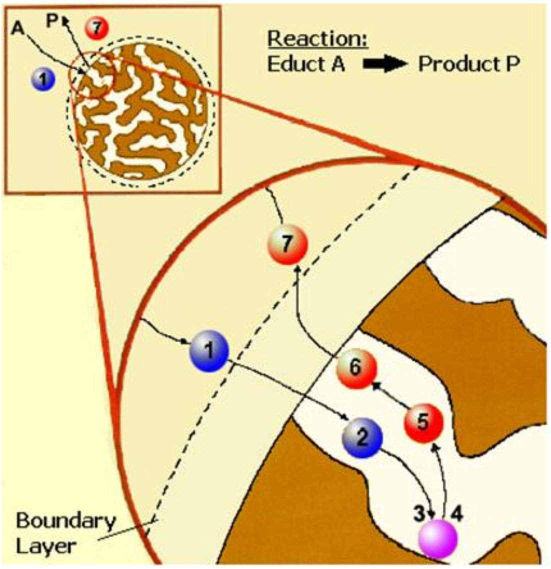
1. Mass transfer of the reactants (A) through the boundary layer of the catalyst.
2. Diffusion of the reactants into the pore of the catalyst surface.
3. Absorption of the reactants by the catalytically active surface.
4. Chemical reaction on the surface (catalysis).
5. Desorption of the products from the catalytic surface.
6. Diffusion of the product out of the pore.
7. Mass transfer of the product through the boundary layer of the catalyst.

Steps 1-3 and 5-7 are transport mechanisms of the gaseous reactants and products into and out of the surface and boundary layer of the catalyst. The catalysis takes place in step 4, and is a complex process.

[196] Tragsdorf 2005, p. 19.

Figure 8-23. Principle of Catalysis

Source: Kulik, Salinger 2006, p. 9



The performance of this type of solid catalytic unit is mainly influenced by two factors: 1) the structure of the catalytic material and 2) the operating conditions. The structure is characterized by the surface area and the type and amount of rare earth metals used as catalyst. For the reaction temperature, flue gas composition and gas flow conditions are the most important parameters. The catalytic unit is placed directly in the path of the flue gas and gas is forced to flow through it. The flue gas reacts with the catalytic surface, where emissions are absorbed and removed. Shortcomings of catalytic controls include their limited lifespan and the technology's inability to reduce emissions during start up periods because high temperatures are needed to start the catalytic reaction.[197]

Flue gas condensation

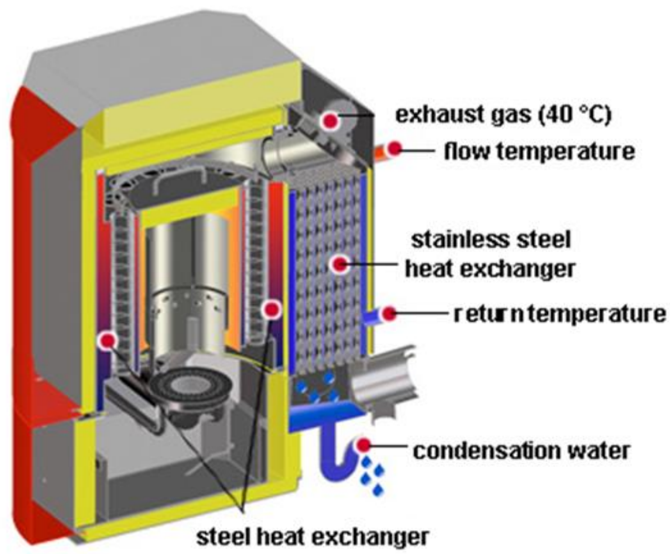
Both efficiency improvements and emission reductions can be attained with flue gas condensation technology. Figure 8-24 illustrates a condensing pellet boiler with a secondary heat exchanger cooling down the flue gases to increase efficiency and reduce particulate emissions. This technology uses a secondary heat exchanger in the flue gas path that cools down the flue gases below the dew point (100-160 °F). Due to the corrosion potential of substances in the flue gas, the secondary heat exchanger is normally constructed of stainless steel materials. As a result, the heat of the flue gases, as well as the latent heat due to condensation of water in the flue gas, can be recovered, thereby increasing the

[197] IEA Task 32 2011, p. 100.

efficiency. In addition, high water content in the flue gas augments the amount of heat recovered. Flue gas condensation technologies achieve the greatest gains when used with high moisture content fuels.[198] Homes using condensing boilers need to have a use for low temperature heat recovered by the second heat exchanger such as radiant heat systems, which are more common in Europe than in the US so the extent applicability here is more limited unless expensive modifications are made to turn high temperature systems.

Figure 8-24. Pellet Boiler with Flue Gas Condensation

Source: Oekofen online 2012



[198] Hartmann 2004, p. 11.

Different studies of flue gas condensation have found that efficiency improvements between 2% and 10% based on higher heating value (HHV) can be achieved. Variation in efficacy is dependent on the moisture content of the fuel and the temperature level of the cooling water.[199] Recent studies of small-scale boilers support the higher range of 10% efficiency improvement in boilers with a nominal power range of 17,000-658,000 Btu/hr.[200] Note that flue gas condensation will increase efficiency only if the recovered heat from the flue gases is used, typically for low-temperature heating purposes. Low temperature heat distribution systems are common in Europe but represent a small amount of the U.S. heating market.

Flue gas condensation also can be used to reduce particulate emissions by wet separation, where PM particles are precipitated from the flue gases through use of the condensing water.[201] Ellner-Schuberth et al. reached particle removal levels between 2% and 74%, depending on the fuels and boilers used in their study.[202] However, the IEA's study indicates that in residential units, efficiency improvements should be the primary driver for flue gas condensing because emission reduction efficacy is highly variable.[203] Flue gas condensation is state-of-the-art technology in residential and small commercial biomass applications in Europe. These technologies are not currently available in the U.S., but should be in the next five years.

Electrostatic precipitators (ESPs)

ESPs achieve reductions in particulate emissions by using the electrical charges of particles. Figure 8-25 illustrates a filter unit for small-scale applications. The filter unit is installed within the flue gas duct, through which the gases are channeled. The electrode (located in the middle of the unit) is electrically charged, thus starting the ionization process. The particulate matter in the flue gases is charged by the ions. Due to electrostatic forces, they are attracted to the flue pipe and deposit there. The flue gases then exit through the chimney.

199 Hartmann 2004, p. 29.

200 Ellner-Schuberth et al 2010, p. 115.

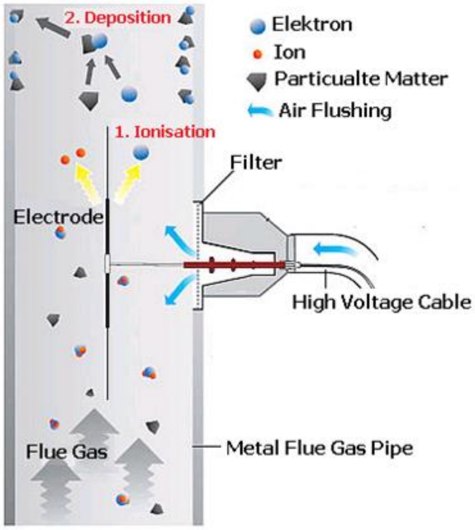
201 Good et al. 1998, p. 12.

202 Ellner-Schuberth et al 2010.

203 IEA Task 32 2011, p. 101.

Figure 8-25. Principle of Electrostatic Precipitation

Source: Kutzner + Weber online 2012



There are two modes of electrostatic precipitation: wet and dry. In wet electrostatic filtering, the flue gas is completely saturated before entering the unit. With a saturated flue gas, the power requirements for electrically charging the particles can be reduced, resulting in higher efficiencies. [204]

A variation includes condensation of the water vapor in the flue gases caused by the cooling of the precipitator by ambient air. As the condensed water flows down, it cools the flue gases and cleans the electrodes. [205]

An advantage of this cleaning technology is that even very small particles can be collected. However, the high electrical resistivity of some materials may render some particles uncollectable. [206] Measurements conducted by the IEA showed separation efficiencies of electrostatic precipitation devices between 50% and 85% for high efficiency wood burning equipment. [207]

Although these units are available on the market, the technology is still in the demonstration phase for devices smaller than 1 MMBtu/hr. IEA states that electrostatic separation is the most promising control technology for residential and small-scale ICI biomass combustion. It should be noted that ESPs must

204 Musil-Schlaeffer 2010, p. 40-41.

205 Musil-Schlaeffer 2010, p. 40-41.

206 Loo, Koppejan 2002, p. 248.

207 IEA Task 32 2011.

be optimized to ensure proper operation otherwise ESPs can increase emissions of dioxins and furans.[208] This control technology is most effective when used on high-efficiency, low-emission stoves and boilers.

8.7.1.2 PM Emission Control Technologies for Medium and Large-sized ICI Wood Boilers

In wood boilers sized 1 to 10 MMBtu/hr, fuel composition is typically less consistent than fuel used in small-scale appliances. Optimization of boiler design is not sufficient for keeping emissions low and efficiency high, therefore emission controls are necessary at this scale. In Europe, it is common to have advanced emission controls on boilers larger than 1 MMBtu/hr. In the U.S., use of these devices is only typical in large scale operations (greater than 10 MMBtu/hr).In the Northeastern U.S., three wood-fired boilers smaller than 10 MMBtu/hr and 3 units sized 1-30 MMBtu/hr that used ESPs were identified.

With medium-sized wood boilers, particulate matter is the primary pollutant of concern. Typical control technologies include cyclones, ESPs, fabric filters (also known as baghouses), and scrubbers. Table 8-2 provides an overview of typical particle sizes removed by the different systems and the removal efficiency. For example, fabric filters remove particles up to a size of 1 µm, with an overall efficiency of 99%.

Table 8-2. Properties and Costs for PM Emission Control Technologies

Sources: (Loo, Koppejan 2002, p. 244), (NESCAUM 2015)

Control	Particle Size (µ inch) (µm)	Removal Efficiency	Cost ($)	Comments
Cyclone - multicyclone	> 197 > 5	< 80%	Installation: *10K-20K* Maintenance: minimal yr	• Inexpensive • Ineffective at removing fine $PM_{2.5}$
Baghouse / fabric filter	< 39 < 1	> 99%	Installation: *100-150K* Maintenance: 10K per yr	• Increased cost • Highly effective at removing $PM_{2.5}$
Electrostatic Precipitator	< 39 < 1	> 99%	Installation: *100-175K* Maintenance:*1-2K per yr*	• Increased cost • Highly effective at removing $PM_{2.5}$
Scrubber	> 20 - 118 > 0.5 - 3	80- 99%	Installation: Maintenance: unknown	• High cost • Used only on large units

[208] http://www.epa.gov/ttnchie1/le/dioxin.pdf

Table 8-3 shows the particle size ranges that are appropriate for the given separation technologies. Achieving a separation rate of more than 95%, however, requires a minimum particle size, which is also shown in the table. Smaller particles can also be removed, but at lower efficiencies. Note that for electrostatic precipitation, there is a size window between 0.4 and 1.5 µm where separation efficiency is lower. For this technology, particle sizes above or below this window can be filtered out with an efficiency of more than 95%.[209]

Table 8-3. Particle Size vs. Emission Control Technology

Source: Nussbaumer 2009, pp. 536-539

Technology Property	Cyclone	Fabric filter	Electrostatic precipitation	Scrubber
Particle diameter for possible separation	from 2-5* to 55 µm	from 0.05 to 20 µm	From 0.1 to 20 µm	from 0.5 to 100 µm
Particle diameter for good separation efficiencies (>95%)	>25 µm	>0.05 µm	<0.4 µm and >1.5 µm	> 2-5 µm*

* Value depends on the design/construction.

Cyclones

Cyclones and multi-cyclones are the most commonly deployed control technology for wood boilers in the United States. Cyclone technology is based on gravity and centrifugal force, as depicted in Figure 8-26. Flue gas is injected into the cyclone, and due to the centrifugal forces the particles in the flue gas hit against the wall and fall down into a bunker. Cleaned flue gas exits the cyclone through a dip tube at the top.[210] A multicyclone uses the same concept as a cyclone but employs multiple, smaller diameter cyclones to improve its capturing capacity. Cyclones are a low cost control technology that is simple in construction and maintenance. While they may provide moderate to high overall control efficiency in capturing PM_{10}, their efficiencies for $PM_{2.5}$ are lower due to design constraints, therefore they are best suited to high PM loading and large particle PM applications. If centrifugal and gravity

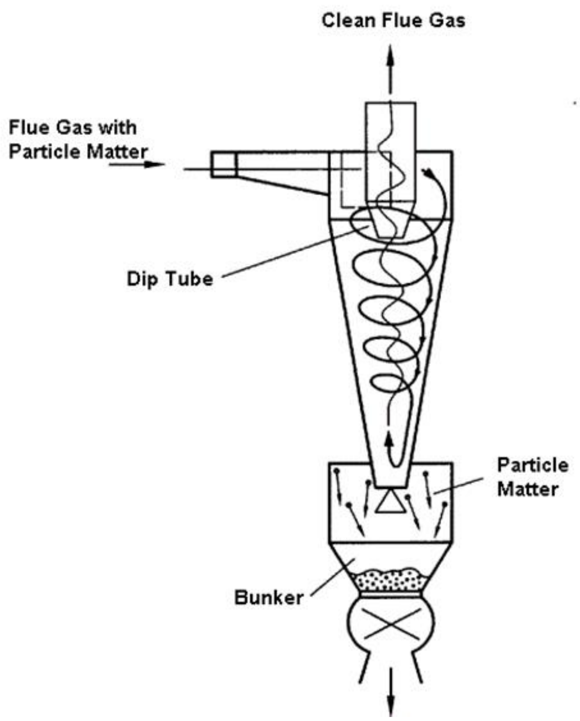
[209] Nussbaumer 2009, pp. 536-539.

[210] Loo, Koppejan 2002, p. 246.

forces are too slight, small particles may remain in the flue gases. Cyclones are sensitive to variable PM loadings and flow rates, but can operate in high flue gas temperatures up to 1,700 °F. [211] Since combustion particles are typically below 0.15 um, this emission control technology captures primarily bottom ash that has become entrained in the exhaust.

Figure 8-26. Schematic of Cyclone Technology

Source: SUVIS online 2012



Baghouse

A baghouse consists of a fabric filter, tightly woven from special fibers through which flue gases are directed. Figure 8-27 displays a schematic of a typical baghouse. The separation efficiency of fabric 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 ultrafine 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 multi-cyclone first to remove large particulates, and periodically injecting a drying agent/flame retardant into the fabric filter. Other options for addressing the fire risk include reducing the operating temperature to approximately

[211] Loo, Koppejan 2002, p. 246.

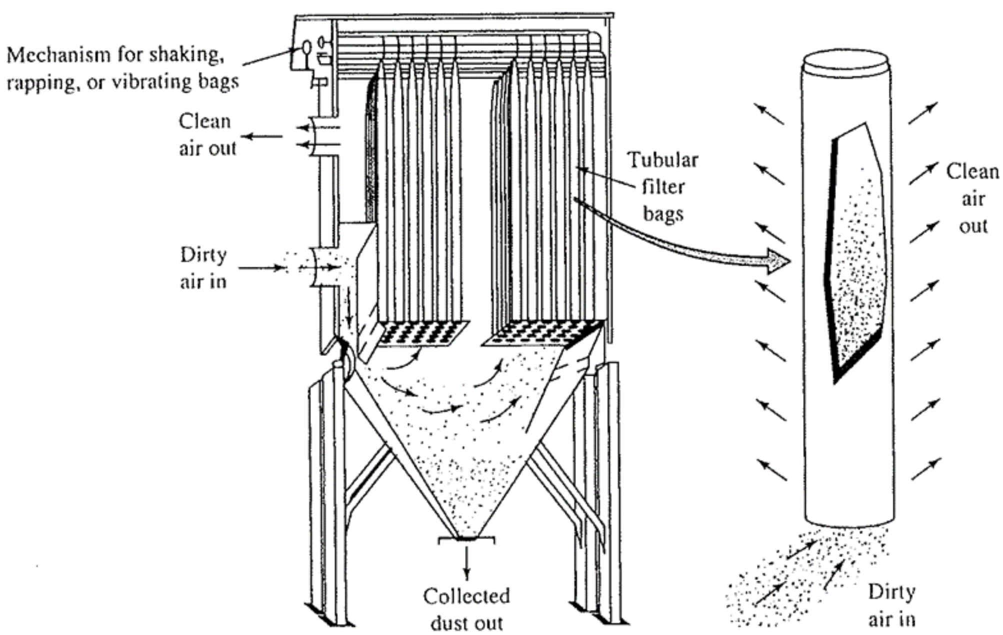
480 °F. If temperatures are too low, however, condensation of tars can take place, clogging the filter cloth. Baghouses also require the moisture content of the flue gas to remain below 20% to keep the filter dry.[212]

Even with the operational limitations, baghouse capture efficiency rates remain high even under conditions where flue gas flow rates and particle content is high. Efficiencies of over 99% have been obtained. Although a thin layer of particles on the filter cloth enhances filtration efficiency, as more particles settle on it the pressure drop increases. For this reason, the cloth must be cleaned from time to time by vibration or pressurized air.[213]

Five wood biomass boilers were identified in the northeastern United States that used a baghouse. Of these units, none were smaller than 10 MMBtu/hr.

Figure 8-27. Schematic of a Baghouse and the Cleaning of a Filter Bag (right side)

Source: Loo, Koppejan 2002, p. 251



[212] Musil-Schlaeffer 2010, p. 99.

[213] Loo, Koppejan 2002, p. 250.

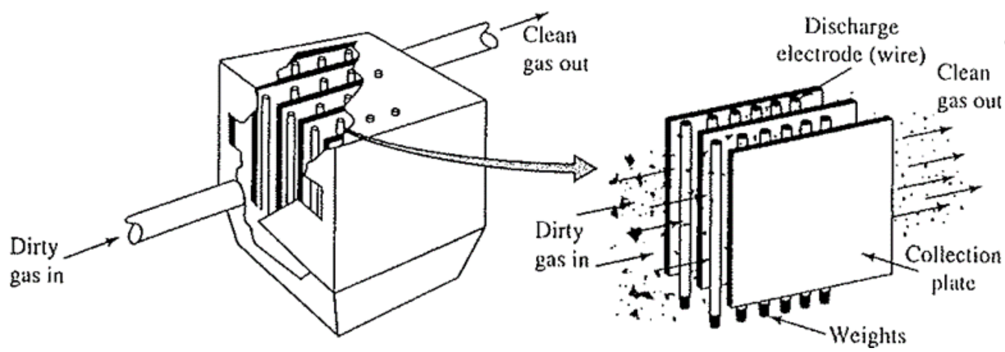
Electrostatic precipitators (ESP)

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 though vibration and the freed particles are directed into a collection unit.[214] This separation technology is sensitive to variable particle loadings or flow rates, but is robust in temperatures up to 900 °F. Although very small particles can be collected, the high electrical resistivity of some materials may make them uncollectable. Its efficiency is comparable to fabric filters, at over 99%. This technology tends to be costly due to its complex design and operation.[215]

In Europe, ESPs are used in small-, medium-, and large-scale applications. In the US, their use is more typical with units larger than 10 MMBtu/hr. Although more than 1,000 ESPs have been installed on wood boilers in Europe, the project team could only identify 23 wood boilers in the US using ESPs. Several of these units were installed on wood boilers smaller than 10 MMBtu/hr. One such example is an 8 MMBtu/h pellet boiler that is part of a steam CHP system at the State University of New York College of Environmental Science and Forestry in Syracuse, NY.

Figure 8-28. Principle of Electrostatic Separation for Medium- to Large-scale Applications

Source: Loo, Koppejan 2002, p. 248



214 Musil-Schlaeffer 2010, p. 40-41.

215 Loo, Koppejan 2002, p. 248.

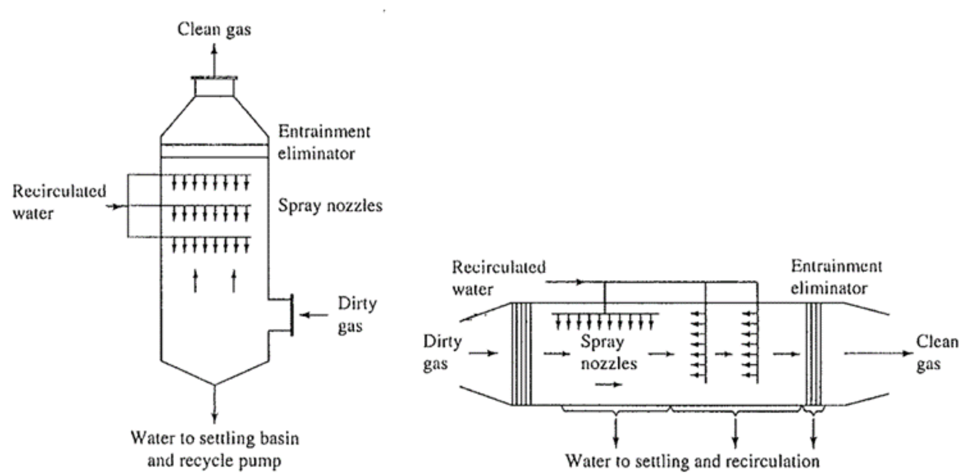
Scrubbers

In scrubber technology, water droplets "scrub" particles from the flue gas – the particles are removed through collision and interception with the droplets. The efficiency of removal increases with an increasing number of droplets and a higher relative velocity between the droplets and the flue gas. Smaller droplets and higher velocities can remove more PM particles, but more and smaller water droplets and a higher velocity create a higher pressure drop, which in turn causes higher energy demand.[216]

Some scrubbers are designed with a counter-current or a cross-flow spray chamber, while others use a cyclone spray chamber. Figure 8-29 depicts a counter-current and a cross-flow spray chamber. In both designs, flue gases are forced through the chamber in one direction, and the water droplets come from the opposite side or direction. A cyclone spray chamber is a combination of an ordinary spray and a cyclone, which enhances absorption efficiency.

Figure 8-29. Schematic of a Counter-current (left) and a Cross-flow Spray Chamber (right)

Source: Loo, Koppejan 2002, p. 253



[216] Loo, Koppejan 2002, p. 252.

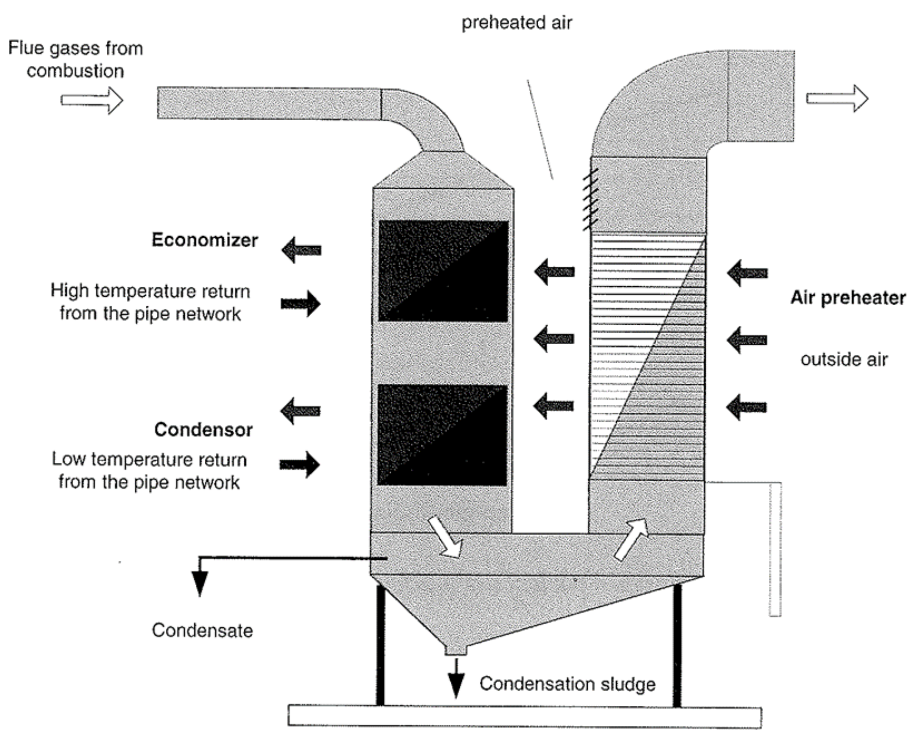
Flue gas condensation

In medium- to large-scale applications, flue gas condensation is often the most effective and economical way to improve device efficiency. Figure 8-30 presents a diagram of a flue gas condensation unit for biomass combustion plants. Heat recovery is conducted in two stages, at high and low temperatures. In the first step, flue gases are cooled in the economizer. The flue gases are then further cooled, forcing condensation into the condenser. Before the dry flue gases leave the unit, they are cooled once more. The recovered heat is used to preheat the combustion air.

The energy recovery potential of such systems is up to 20% of the energy input from the biomass fuel relative to the LHV. Precipitation efficiencies of flue condensation are about 40% to 75% of the PM mass, much lower than what can be reached with other technologies, but this is an ancillary benefit to the heat recovery. [217]

Figure 8-30. Flue Gas Condensation Unit for Industrial Applications

Source: Loo, Koppejan 2002, p. 138

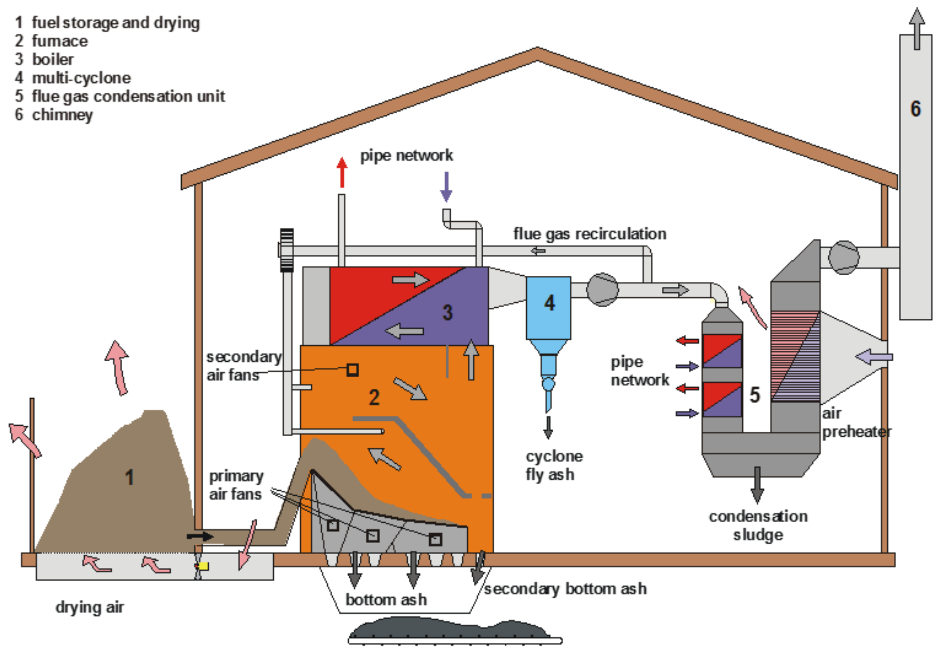


[217] Loo, Koppejan 2002, p. 136.

Figure 8-31 shows an example of a medium-scale biomass combustion plant. Note that different methods for flue gas cleaning can be combined (e.g., a cyclone with flue gas condensation) to meet emission limits or efficiency requirements.

Figure 8-31. Components of a Medium-scale Biomass Combustion Plant

Source: ABC 2006



8.7.2 Carbon Monoxide and Volatile Organic Compounds

Carbon monoxide (CO) and volatile organic compound (VOC) emissions in flue gases are best controlled through combustion optimization with smart sensors and variable speed fans. In this regard, the oxygen sensor is not only a combustion optimization tool, it is an important health and safety device because these devices are installed within the building envelope and depending on the fuel-technology combination, have CO emissions at much higher concentrations than allowed for natural gas or oil-fired heating systems. Carbon monoxide and VOCs can be reduced with catalytic converters. The catalytic converter is inserted in the flue gas flow and further oxidizes carbon emissions to form carbon dioxide (CO_2). In general, catalytic converters consist of a substrate material coated with a catalytic material, with attention paid toward limiting the amount of expensive catalytic material needed.[218]

[218] Jarzombek 2010, p. 17.

For small combustion systems like stoves, there is active research and development interest in catalytic converters to reduce CO, VOCs, and organic particulate emissions. Some companies already offer stoves with catalytic converters, such as the German company Caminos with “KlimaKAT.”

8.7.3 Nitrogen Oxides

Secondary measures for controlling nitrogen oxides (NO_x) are based on the addition of a reducing reagent (e.g., ammonia), which reacts with NO_x to form molecular nitrogen (N_2). The reaction requires either high temperatures or a catalytic material. The two main approaches for secondary control of NO_x are selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). Because reducing NO_x requires significant effort, it is most commonly used with large-scale applications. Small- to medium-sized combustion systems generally rely on primary measures to keep NO_x emissions low.

8.7.3.1 Selective Catalytic Reduction (SCR)

To reduce NO_x emissions by SCR, ammonia is added to the pre-cooled flue gas at about 750 °F (400°C). This flue gas and ammonia mixture is passed through a catalyst, where the NO_x is reduced to molecular nitrogen. The catalyst accelerates the reduction and allows lower reaction temperatures. In biomass combustion units, plate catalysts are typically used rather than honeycomb catalysts because they are more resistant to deactivation by heavy metals. The NO_x reduction rate of an SCR is higher than that of SNCR, reaching NO_x reduction efficiencies in the range of 80% to 95%. The most relevant factors influencing SCR performance are the ammonia molar quantity ratio, the temperature of the catalyst, and the flue gas velocity.[219]

[219] Nussbaumer 2009, p. 544-546.

8.7.3.2 Selective Non-Catalytic Reduction (SNCR)

With the non-catalytic reduction process of SNCR, higher temperatures are needed. Therefore, the reducing reagent is injected into the secondary combustion chamber where higher temperatures occur. The reducing reagent is either ammonia or urea. In both cases, the maximum reduction rate occurs at temperatures between 1,560 and 1,740 °F (850-950 °C). The ratio between the molar amount of NO_x and reducing reagent also has an optimal point for maximum reduction. Above this optimal point, the reduction rate remains constant, thus injected reagents in excess of the maximum point do not react with the NO_x. The removal rates achievable with SNCR are from 73% up to 92% under optimal conditions. [220]

8.7.4 Sulfur Oxides

Sulfur dioxide (SO_2) is the result of combustion of materials that contain sulfur. Because wood contains sulfur, albeit less than coal and No. 4 and 6 fuel oils, burning wood releases sulfur oxides at higher rates than No. 2 distillate oil, which in NYS, is ultra-low sulfur heating oil. The combustion of other biomass, like miscanthus, grass, or straw, can release higher amounts of sulfur oxides, mainly in the form of sulfur dioxide (SO_2). [221] Desulfurization measures have only been used in large-scale combustion systems such as wood-fired power plants.

8.7.4.1 Dry Method

The dry separation of sulfur oxides is achieved by the addition of alkaline adsorbents like limestone ($CaCO_3$), calcium oxide, or calcium hydroxide. At high temperatures, the adsorbents bond with sulfur oxides to form $CaSO_3$ or $CaSO_4$. Good mixing is essential for this reaction, which occurs with fluidized bed combustion systems. [222]

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[220] Nussbaumer 2009, p. 543-544.

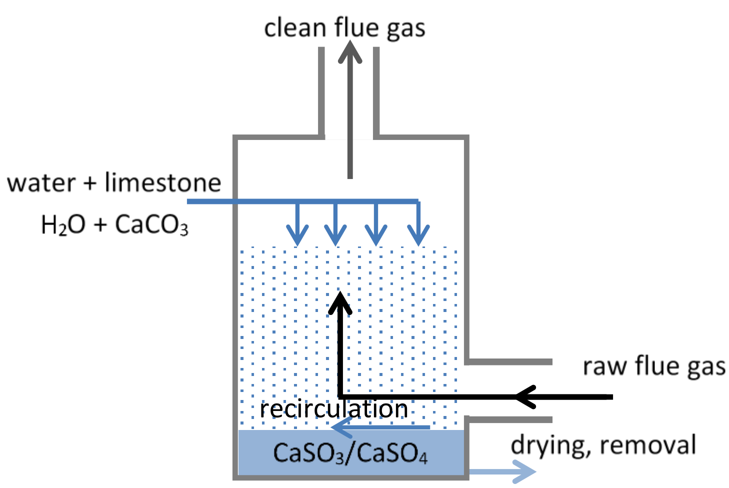
[221] Nussbaumer 2009, p. 259.

[222] Schultes 1996, p. 28; Van Loo, Koppejan 2002, p. 261.

8.7.4.2 Wet Method

The reduction of sulfur oxides from combustion flue gases can be achieved with a scrubber through use of a wet method. Figure 8-32 depicts a wet scrubber system. At the start of the process, flowing raw flue gas is sprayed with a water-limestone mixture. Sulfur dioxide dissolves and reacts with the limestone to form CO_2, which joins the flue gases, while $CaSO_3$ or $CaSO_4$ remain as a slurry in the vessel. The cleaned flue gas leaves the vessel through the stack. A part of the slurry is thickened and removed as a solid waste. The remaining part is enriched with limestone and recirculated back into the process. [223]

Figure 8-32. Schematic of Wet Sulfur Oxide Separation



8.8 Cogeneration Technology

The cogeneration of heat, power, and/or cooling is becoming of increasing interest, even in small-scale heating systems, as the heat demand of buildings declines due to improved sealing and insulation. With the decreases in building heat demand, using potential excess heat for generating electricity can become an attractive option. In NYS, there can be a number of siting, permitting, and codes-related approval processes that must be followed when undertaking a combined heat and power (CHP) or combined

[223] Van Loo, Koopejan 2002, pp. 259-260.

heat/cooling and power (CHCP) project. To assist project developers and planning/code officials in navigating these processes, NYSERDA has published a detailed guidebook for distributed generation and cogeneration siting requirements.[224] This section provides an overview of the technologies and possibilities of CHP and CHCP generating systems, along with best practices for their use.

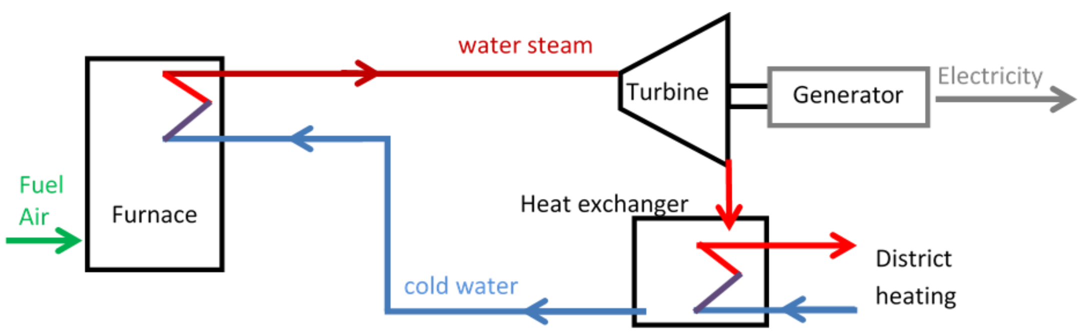
8.8.1 Combined Heat and Power Production

Combined heat and power (CHP) production can be used to enhance the efficiency of heating systems and their fuel use. As a result of increased heating efficiency, using excess heat to generate electricity is a potential additional benefit for the operator. In medium- to small-scale applications, the additional electricity generation can provide some level of grid independence.

8.8.1.1 Steam Process

Large-scale CHP applications are most commonly based on the use of steam. Figure 8-33 shows the schematic of a steam cycling process commonly used in district heating applications. The main parts of the system include a boiler, turbine, generator, heat exchanger, and the working fluid (e.g., water). In the boiler, the cold liquid working fluid (water in the example schematic) is heated until it vaporizes. The steam is sent to a steam turbine that generates electricity from a drop in the steam's pressure. The steam is then cooled across the heat exchanger where the condensation heat can be used for heating. The cold condensed water is subsequently returned to the boiler to be heated again.[225]

Figure 8-33. Schematic Steam Process for District Heating Systems



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[224] Clean Distributed Generation in New York State: State and Local Siting, Permitting and Code Issues, http://energy.pace.edu/sites/default/files/publications/Pace_CHP_Siting_Guidebook.pdf

[225] Kaltschmitt et al. 2009, pp. 552-553.

Similar to the water-based steam cycle is the Organic Rankine Cycle (ORC), which uses an organic fluid instead of water. The substantial advantages of ORC are the thermodynamic properties of the organic fluid compared to water. A lower boiling temperature and lower working pressure reduces the heat needed for electricity generation. While there currently are some installed commercial ORC CHP plants, the majority of CHP installations rely on the classic water-based steam cycle. [226]

The type of electric power generator technology used in a CHP system will depend upon the amount of planned electricity production. Options include steam turbines, steam piston engines, and steam screw engines. Table 8-4 gives a short overview of typical sizes for each technology option.

Table 8-4. Overview of Steam Circle Processes Used in Biomass CHP Plants

Source: BE2020+ 2011, p. 15

Working fluid	Engine type	Typical size	Status
water	steam turbine steam piston engine steam screw engine	> 1.7 MMBtu/hr 0.341 - 3.41 MMBtu/hr 0.341 - 3.41 MMBtu/hr	proven technology proven technology under development
organic medium	steam turbine steam engine	0.853 – 8.53 MMBtu/hr	some commercial plants available

8.8.1.2 Gas Engine

Another CHP approach is to burn a gas in an engine without using a working fluid for power generation. Similar to the steam process, the resulting combustion waste heat can be used for heating applications. Wood biomass can be a source of the gas, and the gasification process is already common in large-scale applications. It has also been used in smaller systems with nominal electrical power below 2 MMBtu/hr. The following paragraphs briefly describe a few examples of existing biomass gasification CHP systems.

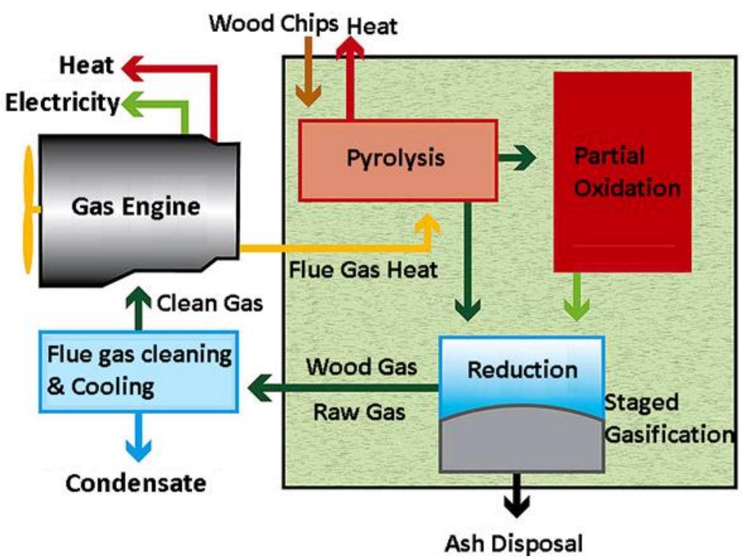
226 BE2020+ 2011, p. 16.

8.8.1.3 CLEANSTGAS® Process

The Austrian company Cleanstgas GmbH provides a special wood chip gasification plant for heat and power generation with a nominal electrical power below 1.706 MMBtu/hr (medium-scale). Figure 8-34 shows the schematic of the three stage gasification process: 1) pyrolysis; 2) partial oxidation; and 3) reduction. The wood chips are transported through these physically separated stages to produce nearly tar-free biomass gas. After cooling and cleaning, the gas is burned in an engine to generate electricity and usable waste heat.[227]

Figure 8-34. Schematic Gasification from Cleanstgas

Source: Cleanstgas 2013, p. 6



The physical separation of the three gasification stages potentially provides biomass gas nearly free of tar and particulate matter, which also reduces the amount of contamination in the condensate from the cooling process. As a result, the condensate can potentially be disposed of as common sewage without requiring additional cleaning. The chemical characteristics of this condensate should be further studied to determine appropriate disposal methods. Electrical efficiencies of over 27% are possible, with overall system efficiencies reaching values of more than 74%. Typical nominal thermal loads are about 3 MMBtu/hr.[228]

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227 Cleanstgas 2013, p. 6.

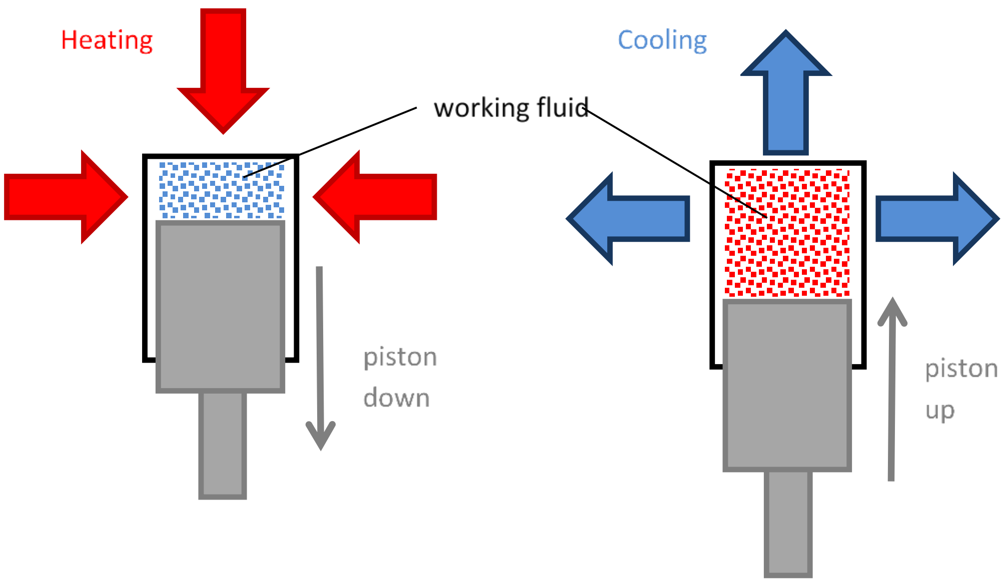
228 Cleanstgas 2013, p. 6.

8.8.1.4 Stirling Engine

In contrast to internal combustion engines, a Stirling engine is externally heated. The engine's working gas (e.g., helium or nitrogen) is moved between a hot and cold chamber by a displacer piston. Due to the temperature difference, the gas volume changes and moves the piston. This mechanical work can be used for power generation.[229]

Figure 8-35 shows a simple design of a Stirling engine with one cylinder and one piston. On the left side of the figure, the working fluid is heated from outside. The gas volume expands with increasing temperature, moving the piston downward. As the working fluid cools (right side of the figure), its volume shrinks, moving the piston back upward.[230] The design of a Stirling engine can vary with the number of pistons and cylinders (e.g., one cold and one hot cylinder). More detailed information on Stirling engines is in Beith et al. 2004 and Pehnt et al. 2006.

Figure 8-35. Schematic Stirling Engine Phases



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[229] Pehnt et al. 2006, p. 7.

[230] Beith et al. 2004, p. 105.

Theoretically, a Stirling engine can be driven by any kind of heat source. In solar thermal CHP plants, for example, Stirling engines are already common.[231] In the biomass sector, some institutions and companies are working on incorporating Stirling engines with biomass combustion for heat and power generation.

The limiting factor for the efficiency of a Stirling engine is the heat transfer to and from its working fluid. High temperatures at the heater and low temperatures at the cooler result in the greatest efficiencies. The temperature differentials needed for greater efficiency are the main challenges for a biomass-Stirling engine system. Achieving high combustion temperatures often is only possible through pre-heating the

combustion air. On the cooling side, corrosive and particulate components of the biomass flue gas tend to deposit on heat exchanger surfaces, reducing the amount of heat transfer. Under hot conditions, the corrosive components can harm engine materials, further diminishing heat transfer. In an effort to address this, current research is focusing on preventing surface deposition and cleaning surfaces to improve heat transfer conditions over long operating times.

Research is currently occurring on combining biomass combustion units with Stirling engines in small- to large-scale applications. For residential biomass, commercially available boilers using cordwood and pellet fuels have been combined with Stirling engines in research on electricity generation units. There are, however, no such combinations currently commercially available on the European market.

In terms of medium- to large-scale biomass applications, wood chip boilers have been coupled with Stirling engines as part of research projects. In order to minimize particles in the flue gas, the combustion technologies were either grate boilers with staged combustion or biomass gasification systems.

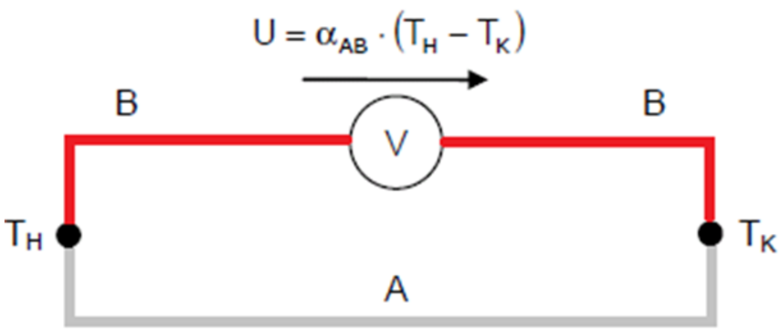
[231] Beith et al. 2004, p. 115.

8.8.1.5 Thermoelectric Generators

Thermoelectric power generation can be done through the direct conversion of temperature differences into electricity (Seebeck Effect). If an electrically conductive solid body is exposed to a temperature gradient, the electrical charges shift. Figure 8-36 is circuit diagram of this effect. When two conductors of different materials A (grey) and B (red) are joined in a loop and they are placed at different temperatures (T_H, T_K) in an open circuit, a thermal voltage U can be measured. The Seebeck coefficient (α_{AB}) is a parameter that describes the relationship between the thermo voltage U and the temperature difference, and depends on the composition of the material.

Figure 8-36. Circuit Diagram of Seebeck Effect

Source: Friedl et al. 2009, p. 3

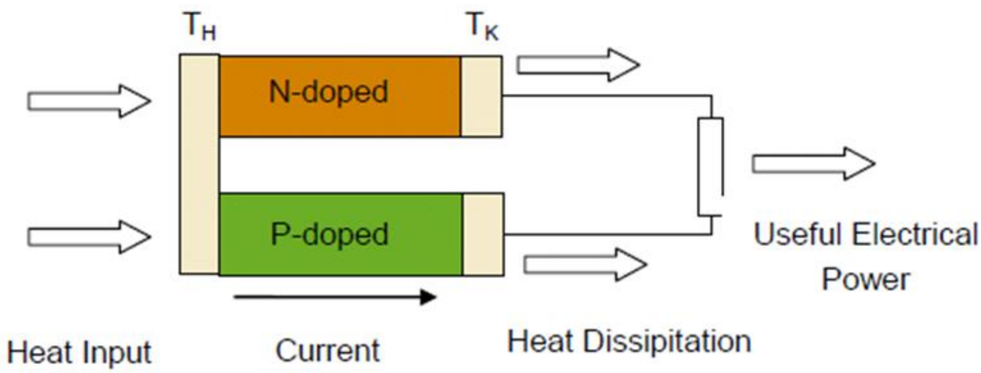


For electricity generation, the circuit between two semiconductors (N-, P-doped) is closed by an electrical load (see Figure 8-37). If heat flows parallel across the semiconductor pair from the hot to the cold side of the thermo-generator, a direct current occurs. The amount of useful electrical power is dependent on the material used, as well as the temperature difference.[232]

[232] Friedl et al. 2009, p. 2-4.

Figure 8-37. Principle of a Thermoelectric Power Generator

Source: Friedl et al. 2009, p. 3



This technology is only suitable for small-scale biomass combustion systems. In pellet stoves or boilers, the technology can lead to energy self-sufficiency and provide fully automatic operation for features requiring electricity demand, such as pellet feeding, ignition, and device controls.[233]

A recent project integrated a thermoelectric generator (TEG) with a nominal power of 200 W into a 10 kW pellet combustion unit to demonstrate that a pellet boiler can operate self-sufficiently when thermoelectric generators are included (Friedl et al. 2009). The maximal temperature difference was set by the maximum temperature of the TEG at 250 °C (428 °F) and the temperature of the water in the boiler at 60°C (140 °F). Based on these limits and the assumption that 50% of the fuel heat was conducted to the TEG, the calculated efficiency of the TEG was 4% and the maximum system efficiency could be 2%. After optimizing thermal insulation and operating parameters, the arrangement achieved a measured maximum TEG electrical efficiency of 3.6%, a maximum system efficiency of 1.7%, and a maximum power of 220 W. With further optimization to ensure a consistent temperature distribution on the TEG's surface, the calculated efficiency values can be achieved.

[233] Friedl et al. 2009, p. 2.

8.8.2 Combined Heat and Cooling Production

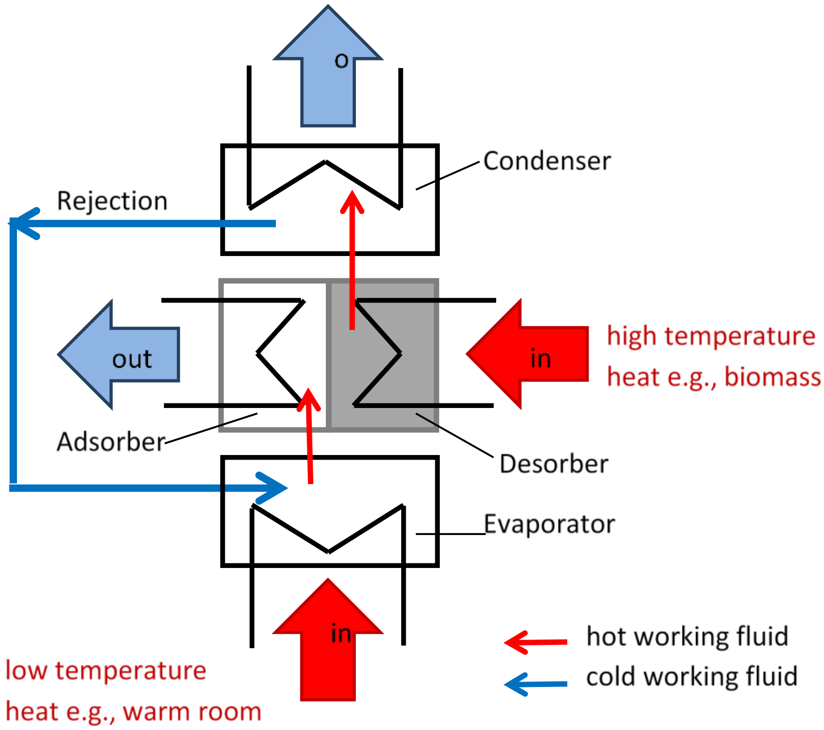
In addition to heat generation, there is interest in adding combined heat, (power) and cooling production to wood heating boilers. The primary focus of the research is on sorption chillers using heat with a small amount of electricity for cooling. An *absorption chiller* uses fluid for the sorption material. An *adsorption chiller* uses a solid for sorption at the material's surface.

Figure 8-38 depicts a schematic of an adsorption chiller. This chiller consists of a condenser, an evaporator, a solid adsorber and desorber, and a rejection pipe for the working fluid. The adsorber and desorber are heat exchangers equipped with an adsorbent (e.g., zeolite) that collects the working fluid (e.g., water).

During an adsorption chiller's working period, two processes happen in parallel. In the first process, the working fluid is heated to evaporation in the evaporator, then sent to the adsorber where it is adsorbed, releasing heat. In the second process, the desorber is heated from outside to separate the working fluid from the adsorbent. Afterward, the working fluid is sent to the condenser where it is cooled down again. When the working fluid condenses, it is rejected to the evaporator to be heated again. The sides reverse in the next working period, with the adsorber becoming the desorber and vice versa.[234]

[234] Schramek 2010, pp. 1535-1537.

Figure 8-38. Schematic of Adsorption Chiller



As seen in Figure 8-38, heat has to be provided for evaporation as well as for desorption. Condensation and adsorption are exothermic processes and give heat to the surroundings. For cooling applications, such as in buildings, warm room air is sufficient to use as a low-temperature heat source for evaporating the working fluid. For the desorption process, higher temperature heat is necessary. Hence, (waste) heat from a biomass boiler or solar thermal collectors can be used to drive the chiller. An important aspect of chillers is the re-cooling step, which has a large influence on the efficiency of the system.

In contrast to the solid used in adsorption chillers, absorption chillers use a fluid as the absorbent. Therefore, an absorber fluid cycle is used instead of an adsorber-coated heat exchanger. During heat emission, the evaporated working fluid is absorbed in the absorber. By heating the mixture in the desorber, the two fluids are separated again. In the condenser, the working fluid is re-cooled.[235]

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[235] Schramek 2010, p. 1532.

Sorption chillers are currently available and used in medium- to large-scale applications. Opportunities exist with district heating plants, for example, where heat demand in summer is reduced to providing hot water. The cooling side of sorption chillers raises interest as a way to keep a district heating boiler running at nominal load. Solar thermal cooling also provides opportunities, such as with office buildings where the demand for cooling is greater than the heating demand.

For small-scale applications, this technology remains in development. Between 2006 and 2010, combined heat, power, and cooling systems were examined within the European Project POLYSMART (www.polysmart.org). One field test took place in Austria where a Stirling engine and an absorption chiller were combined with a wood chip boiler. The chiller, having a nominal power of 34,000 Btu/hr, was added to cool the storage room of a vineyard. A 170,000-Btu/hr wood chip boiler drove the chiller and solar thermal collectors on the building's roof supported it. Because absorption chillers of this small size were not commercially available, a prototype was built for the field test. Measurements showed good results for this prototype with thermal efficiencies of 50-75%.[236]

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9 Air Quality Impacts Analysis

As illustrated in Chapter 8, wood can be used for heating in a variety of settings, from residential to large-scale institutional and industrial applications. In both residential and institutional settings, wood heating equipment in NYS ranges from high-polluting, inefficient technologies (lower than 20% annual fuel use efficiency) to cleaner-burning, highly efficient technologies (greater than 80% annual fuel use efficiency). As wood heating equipment becomes more widely adopted in homes and institutions, there are associated health implications for those exposed to air pollutants in wood smoke (e.g., fine particulate matter ($PM_{2.5}$) is defined as PM with an aerodynamic diameter of less than 2.5 micrometers). Population subgroups susceptible or most affected by $PM_{2.5}$ exposure include children, asthmatics, persons with pre-existing respiratory disease or cardiac problems, older adults, and healthy adults who work or exercise outdoors.[237, 238] Therefore, physical placement of wood combustion units in locations close to sensitive populations, such as at schools and hospitals, can present a public health concern.

While decisions about which wood burning technology to install are critical for local air quality, the answers to other questions will also have an air quality impact. Is thermal storage utilized? What is the quality and moisture content of the fuel? Is pollution control equipment installed? Is the installation physically configured to mitigate potential impacts? This chapter investigates how the selection of a wood heating technology, along with considerations of how and where it is operated, can affect local air quality in NYS.

The analysis described in this chapter addresses the impacts on areas immediately surrounding wood heating installations at institutions and homes. This analysis is complementary to the statewide emissions analysis of Chapter 10, which presents a comprehensive view of potential air quality impacts from a more widespread adoption of wood heating for residential, commercial, and institutional buildings under various potential scenarios.

The chapter provides information on study design and methodology, results from the individual sources analysis, results from the neighborhood sources analysis, conclusions, limitations, and research needs.

This study underlines the key importance of technology choice in controlling air impacts from residential and commercial wood heating installations. Natural gas and oil boilers are both cleaner than wood in

[237] Pope 2000

[238] Johnson and Graham 2005

terms of health-relevant combustion emissions. Air impacts from advanced, efficient, and highly controlled wood heat technologies produce pollutant levels much lower than those produced by conventional wood technologies, and much closer to levels produced from oil boilers. Unit sizing, use of thermal storage systems, fuel choice, terrain effects, stack characteristics, building design, neighborhood influence, and existing conditions were also flagged as important contributors to adverse air impacts near wood heat installations. Impacts of fine particulate matter close to large schools and residential installations were shown to be of potential concern for some higher emitting technologies, and represent an area for potential health impact assessment. Outdoor air impacts for carbon monoxide and sulfur dioxide appear to be considerably below levels of concern for ambient air quality.[239] Additional analysis is required to determine the extent to which impacts from nitrogen oxides, toxics including compound such as polyaromatic hydrocarbons (PAHs), formaldehyde, or benzene or other volatile organic compounds may be of concern. The analysis also pointed to the need for additional data to better characterize emission rates from studied technologies, among other further research needs.

9.1 Study Design and Methodology

This study utilized dispersion modeling to provide insight into how local air quality may be affected in various parts of NYS. The AERMOD air dispersion modeling system was used to evaluate the resulting air impacts of emissions from wood heating equipment in various terrains and under different meteorological conditions.

9.1.1 Dispersion Model

Dispersion modeling *is the use of mathematical simulations to represent the movement of gases or particles in the air.*

Local air quality impacts were evaluated through single- and multiple-source dispersion modeling exercises simulating current and reasonably anticipated future wood combustion technologies over a range of meteorological regimes, terrain types, and heating loads at residential and institutional building installations.

[239] Carbon monoxide may be a concern for indoor air if the combustion system is leaking into the living area. Pellet storage can also be a source of potentially dangerous levels of carbon monoxide, as discussed further in Chapter 11. This chapter, however, restricts discussion to ambient outdoor air.

The dispersion model AERMOD (version 14134) was used in this analysis. AERMOD is the USEPA's recommended model for a variety of source-specific assessments, including assessing near-source impacts in a permitting setting, and is capable of appropriately reproducing relevant concentrations from emission sources at multiple timescales.[240] It incorporates the latest state-of-the-science in atmospheric transport and dispersion concepts, including a revised approach to estimating building downwash effects. The meteorological processor AERMET is capable of calculating hourly meteorological parameters based on minute-resolution measurements with the AERMINUTE preprocessor. Because it uses measurements by the minute to calculate hourly parameters, this preprocessor significantly reduces the number of hours that are categorized as calm, when there is no or very little wind movement, and for which AERMOD does not calculate results. This improved time resolution thereby reduces the number of hours for which the model cannot calculate dispersion values, times when ambient concentrations may remain elevated due to the lack of dispersion or atmospheric buoyancy. AERMET (Version 12345) outputs were supplied to NESCAUM by NYSDEC for the three NYS locations simulated in this study. The AERMET data are described more fully in the meteorological data discussion later in this section.

AERMOD is a steady-state Gaussian dispersion model designed for short-range air pollution impacts that is USEPA's preferred model for near-source impacts in a wide range of applications involving terrain effects.

Model performance within a factor of two is typically regarded as reasonable model performance, and AERMOD is generally able to reproduce maximum observed concentrations, although it may not accurately predict the precise time and location of the peak levels.[241] The focus of this study is on air pollutant levels associated with adverse health impacts, and the precise time and location are not critical to assessing potential air quality impacts from the technologies. Based on the available literature, and feedback from discussions with the project advisory group, USEPA, and state modeling contacts, AERMOD (Version 14134) was selected for dispersion modeling to support this study.

[240] Visit http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod for more information on the AERMOD system, including links to model validation studies.

[241] Rood 2014

Procedures consistent with standards used for permit modeling were used to represent wood heating units in AERMOD. Because permitting is intended to cap emissions so that violations of relevant air quality standards do not occur, permit modeling is deliberately conservative; that is, permit modeling is designed such that the actual value will likely be no higher than the estimated value. In addition to assessing the maximum potential impacts, an attempt was made to quantify air quality impacts from typical operation. Therefore, this analysis is effectively an examination of the range of effects from typical to maximum air impacts from each technology category under various conditions. Typical and maximum emissions scenarios were modeled for residential and institutional[242] buildings with specific technologies using cordwood, wood chip, and wood pellet fuels. Emission scenarios are described in more detail in Section 9.2. In Sections 9.3 through 9.8, additional model inputs are addressed, including the building type, pollutants to be modeled, the technology specific type, topography, meteorology and installation-specific parameters, and the uncertainty they may introduce.

Because this analysis examines theoretical sources in a variety of terrains, meteorological conditions, and emission scenarios, the results are not necessarily directly comparable to direct observations at actual sources. Air quality model results from different technologies are compared to one another, and from location to location, and to health-based, enforceable air quality standards. These theoretical source comparisons do not necessarily reflect the air pollution levels measured near actual installations of these technologies. When examining these model results, caution should be observed against applying the results out of context; location-specific air quality modeling must be performed to assess the impact of a specific installation.

9.2 Emission Scenarios

Maximum emissions *are the highest emissions associated with a source.*

Typical emissions *are emissions most commonly occurring from the source, and are not necessarily average emissions.*

For each emission source, two distinct scenarios were modeled: (1) a maximum emissions scenario, representing the highest emissions associated with the source; and (2) a typical scenario, representing emissions most frequently occurring from the source. It was assumed that maximum emissions would

[242] This study focuses on residential and institutional installations of wood heat. Commercial units are installed in the institutional settings, so these units are often described in this chapter as institutional units rather than commercial units.

occur at the highest predicted load level.[243,244] These two scenarios generally represent the maximum and typical load levels of the unit—corresponding with the highest anticipated emission rate and the typical emission rate, respectively—based on a thermal demand analysis of the building. Note that the maximum load for a unit that is right-sized or undersized for the building, or that incorporates thermal storage, is 100% of the unit design load. In contrast, a maximum load for a unit that is oversized (and does not incorporate thermal storage) will never reach 100% of the unit's capacity. Also, note that a typical load is one that is most common, not an average of all loads demanded by the building.

Heat load *is the numerical thermal energy output by a heating device.*

As described further in the following sections, emissions and other model inputs were designed to be consistent with the "maximum" and "typical" scenarios. For the maximum scenario, the highest expected annual estimates for the load level (and associated emissions) were used so as not to underestimate potential impacts. For the maximum scenario, parameters associated with high load operations (i.e., higher emission rate, higher exit gas temperature and velocity) were generally used. The typical scenario is generally associated with lower load conditions at which the unit typically operates (i.e., lower exit gas temperature and velocity). Using maximum and typical rates provides a range of results expected to occur from operation of these technologies. Using the maximum and typical emission levels also correlates well with potential health outcomes, which are often associated with both highest-level and repeated exposures to air pollutants.

For estimation of annual impacts, only the typical emissions scenario was used because operation of heating devices is expected to average out over longer time periods.

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[243] The one exception to the rule that maximum emissions correlate with maximum load is for the EPA-certified, non-catalytic residential cordwood stove. For this unit type, a non-maximal load was used for the maximum emissions scenario because of technology-specific data that indicate maximum emissions occur at a lower load level.

[244] Lower load levels produce higher emissions per unit energy produced. That does not necessarily mean, however, that lower load levels produce higher net emissions. Based on data from tests, aside from the one exception (mentioned in the preceding footnote), the higher load conditions do produce higher emissions.

In determining model inputs, whenever appropriate, this study relied on testing data that best represent the scenarios for the units that were simulated, instead of data from average unit performance. For example, emission rates observed for stack tests under typical and maximum conditions were preferred over calculated emission rates using emission factors and assumed performance characteristics. In most cases, however, as described in the sections that follow, appropriate stack testing data were not available and average unit performance data were used.

The differences in the maximum emissions scenario between units reflects the expected benefits that may arise from maximum operation, whereas the differences in the typical emissions scenarios between units reflects the expected benefits that may arise from typical operation. Comparison between the maximum and typical scenarios for different units is not generally appropriate because they represent different operating scenarios.

9.3 Installation and Building Types

Sensitive populations *are groups of people at greatest risk to health effects, and include the very young, the very old, and those with pre-existing respiratory health conditions.*

Wood-burning equipment is experiencing significant growth in both institutional settings (e.g., schools and hospitals) and residences across NYS. Although units installed at these locations are not large in size compared to industrial units, rated for less than 10 million Btu per hour (MMBtu/hr), they have the potential to increase exposure of sensitive populations to air pollution. This section describes the buildings at which simulated wood burning technologies are installed and the modeling approach. The approach for placing receptors in the model around sources is also described.

Building downwash *is the effect that a structure has on the dispersion of a plume.*

According to the USEPA,[245] the building downwash processor used with AERMOD, which estimates the effect the size and shape of a building has on wind, may result in overpredicting pollutant concentrations near the building. The primary issue for the building downwash module occurs when modeling elongated buildings at an angle to the wind direction. The “projected building length” output from the module may be larger than the actual along-building fetch, which will tend to overestimate the downwash influence

[245] Brode 2012.

and displace the location of downwind recirculating winds that influence the vertical dispersion of plumes (called the "cavity region"). Therefore, including building downwash using this module may increase the conservatism of this analysis for elongated buildings. It should be noted that terrain and local weather conditions also influence pollutant dispersion. These factors are described in greater detail in Section 9.6.1 and 9.6.2.

9.3.1 Large School

A 130,000-square-foot school was selected for analysis based on the results of a review of typical school sizes across NYS (see Chapter 10). For this analysis of a large school, a single elongated school building with dimensions of 300 ft by 450 ft and a height of 20 ft is assumed. The building modeled has a flat roof and the stack is located on the short edge of the building facing north. In addition to the situation where a boiler was installed in the building with a stack at the building's edge, this study also included a scenario at the large school with a containerized pellet boiler. The 15 ft by 20 ft and 10 ft tall container unit was assumed to be located 20 ft from the north face of the school building. As stated previously, because the building is elongated, results for this building may be biased toward higher impacts than a square building.

9.3.2 Small School

The analysis based the school placement parameters on a school setting in Derby, Vermont, as reported by the consulting group RSG.[246] Derby is located in the far northern portion of Vermont, and has a climate analogous to northern NYS. The specifications for the Derby school coincide with the specifications that were independently selected for the small school analysis in this study based on results of thermal demand modeling for average small school sizes in central and northern NYS. There are two interconnected academic buildings on site with a total area of approximately 55,000 square ft.

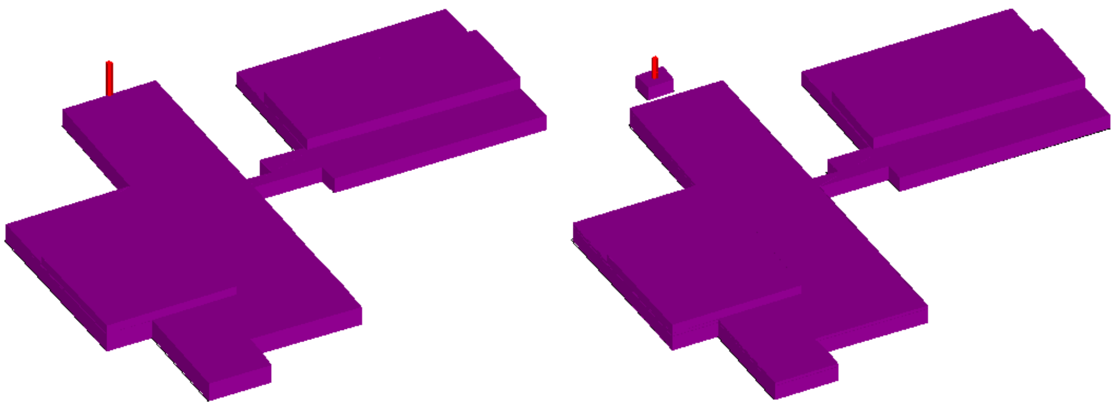
For the small school, similar to the large school, two situations were assumed: a situation where the boiler would be located inside the school building with the stack located at one of the building edges; and second, a situation in which a unit is installed in a container shed located 20 ft from the nearest face of the school building. The container was modeled as a 15 by 20 ft structure with a height of 10 ft and a flat roof. Stack height for the container shed was modeled at two heights above ground level: 14 ft for the short stack and 25 ft for the tall stack.

[246] RSG 2008.

This analysis assumes building dimensions identical to those of the Derby school, adjusted to the coordinates and elevation for the study locations. Figure 9-1 shows the two situations: the school without the container shed (left) and the school with the container shed (right).

Figure 9-1. Small School Building

Red line indicates boiler and stack. (Left) small school building with boiler and stack located in the building and (right) small school building with boiler and stack located in a container 20 ft from the building.



9.3.3 Hospital Building

A 100,000-square-foot hospital (based on a capacity of 50 beds and assuming 2,000 square feet of facility space per bed) was selected for the analysis. The analysis assumed an elongated building that is 450 ft by 250 ft that has a height of 20 ft and a flat roof, with the stack located on the short edge of the building facing north. As stated previously, because the building is elongated, results for this building may be biased toward a more conservative result.

The hospital has a maximum hourly heat demand of 2.0 MMBtu/hr, and a heat load profile conducive to using a wood-chip fired technology. Therefore, wood chip units are modeled in the hospital setting for all wood heat technologies (units and technology categories are listed in Section 9.5). The hospital setting was designed with the input of industry experts who advised that there is a great deal of variability in hospital building and heating system design, and that the summer load is often much higher than winter load because of the reheat demand. Industry standards exist that require a minimum safety distance (25 ft or more) between air intakes and combustion equipment stack exhaust at medical and health care facilities.[247] Though many hospitals have multiple boilers, this analysis assumes a single boiler designed to meet full building demand.

9.3.4 Residential Home

The simulated home was designed to be consistent with a previous wood boiler study by the NYS Department of Environmental Conservation.[248] The simulated home is a 2,500-square-foot ranch design, with dimensions 49 by 65 ft (15 meters by 20 meters) with a 16.4-ft flat roof. Units considered in this study for the home include an indoor wood stove for space heating, a wood boiler housed indoors, and an outdoor wood hydronic heater (outdoor wood boiler). For all indoor units, exhaust is vented through the chimney located in the center of the roof at a height of about 20 ft. In the case of the outdoor wood boiler, the unit has a weatherproof housing with insulation and is located 20 ft from the home with a stack height of about 10 ft.

9.3.5 Receptor Configuration

Receptors are simulated points where air concentrations are modeled. In this analysis, receptors are spaced to be consistent with the NYSDEC study.[249] In all cases, the source was placed in the center of the modeling domain, with receptors arrayed in a polar grid at ground-level spaced evenly around the source. Due to the short stack height and high influence from building downwash for the residential analysis, receptors were placed close together because the highest impact areas were anticipated to be very near the source. Receptors at home simulations were spaced in a circle at 10-degree increments around the source, with concentric rings of 10-meter spacing from 10 to 100 meters, and then 50 meter spacing from 100 to 500 meters. From end to end, the domain for residential sources spans one kilometer. Receptors that would be inside buildings were removed.

Around the institutional sources and in neighborhoods, all the receptors used in the residential grid were included and additional receptors were added beyond the 500-meter mark at intervals of 500 meters out to 5,000 meters (5 kilometers). From end to end, the domain for institutional sources spans 10 kilometers.

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247 American Institute of Architects 2006, Guidelines for design and construction of health care facilities, Washington DC.

248 NYSDEC 2007

249 NYSDEC 2007

9.4 Pollutants

Wood smoke is a complex mixture of many components, many of which have public health impacts.[250, 251, 252] The impacts of wood burning on local air quality were assessed for five pollutants, as described in the following subsections. In general, federal health-based national ambient air quality standards (NAAQS) for criteria air pollutants were used for assessing local air quality outcomes. Criteria air pollutants are regulated by the USEPA through the development of science-based guidelines or criteria for setting permissible levels. The analysis was restricted to the pollutants and metrics listed in this report; numerous other pollutants (e.g., benzene) were not explicitly modeled in this analysis. While this analysis does not represent any individual actual installation, comparing the results to a NAAQS, where applicable, provides a useful benchmark against which to compare the modeled impacts. Most installations using the boiler output ratings assessed in this study would not trigger a regulatory monitoring requirement because the USEPA has no requirements for emissions testing or monitoring of biomass boilers with a maximum rating of less than 10 MMBtu/hr.

Table 9-1 displays the metrics against which the modeled results were assessed. The USEPA offers guidance on the performance of air modeling for comparison against the federal standards. The USEPA guidance was followed in modeling pollutant levels against federal standards for all except the annual metric. For annual metrics, USEPA guidance suggests comparing the highest modeled annual average against the standard, whereas in this study, the average of five modeled years was used, so maximum annual impacts in specific years may be higher than impacts presented here. Unless otherwise noted, summary health effects information is based on data from the USEPA National Ambient Air Quality Standards website.[253] For ease of comparison, a consistent unit system of micrograms per cubic meter ($\mu g/m^3$) was used for evaluating pollutant levels, with the exception of CO, which is reported in parts per million (ppm) in this chapter.

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250 Naeher, L.P.; Brauer, M.; Lipsett, M.; Zelikoff, J.T.; Simpson, C.D.; Koenig, J.Q.; Smith, K.R. 2007. Woodsmoke Health Effects: A Review. *Inhalation Toxicology.* 19: 67-106.

251 Johnston FH, Hanigan IC, Henderson SB, Morgan GG. Evaluation of interventions to reduce air pollution from biomass smoke on mortality in Launceston, Australia: retrospective analysis of daily mortality, 1994-2007. BJM 2013; 346 :e8446.

252 Noonan CW, Navidi W, Sheppard L, Palmer CP, Bergauff M, Hooper K, Ward TJ. Residential indoor PM2.5 in wood stove homes: follow-up of the Libby changeout program. Indoor Air. 2012 Dec;22(6):492-500. doi: 10.1111/j.1600-0668.2012.00789.x. Epub 2012 Jun 18.

253 US EPA, National Ambient Air Quality Standards (NAAQS), http://www3.epa.gov/ttn/naaqs/criteria.html

Table 9-1. Health-Based Air Pollutant Metrics

Note: Information about the federal standards is available at www.epa.gov/oar/criteria.html. "Level" indicates the level of the standard. When there is no federal standard for a particular "Averaging Time," that is noted under "Level." "Form" indicates the value or values used to calculate the metric. For example, "2nd highest annual" for 1-hour CO means that the reported value is the second highest 1-hour average value for CO from each analysis year.

Pollutant	Averaging Time	Level ($\mu g/m^3$)	Form
$PM_{2.5}$	24-hour	35	98th percentile (8th high) annual
	Annual	12	Annual mean
	1-hour	No federal standard	2nd highest annual
CO	1-hour	40,000 (35 ppm)	2nd highest annual
	8-hour	10,000 (9 ppm)	2nd highest annual
NO_2	1-hour	188 (100 ppb)	98th percentile (8th high) daily maximum annual
SO_2	1-hour	196 (75 ppb)	99th percentile (4th high) daily maximum annual
VOC	Annual	No federal standard	Annual mean

9.4.1 Fine Particulate Matter

$PM_{2.5}$ typically makes up greater than 90% by mass of the inhalable fraction of combustion-sourced PM. $PM_{2.5}$ is of particular concern because it can travel and deposit deep in lung airways and cause a variety of potentially fatal and nonfatal cardiopulmonary effects. People with breathing and heart problems, children and the elderly may be particularly sensitive to particulate matter. No threshold, below which adverse health effects do not occur, has been identified. Short-term health indicators include increased risk of hospital admission and emergency room visits. Long-term exposure may lead to chronic bronchitis, reduced lung function, and increased mortality in those with existing lung or heart problems.[254] The USEPA has set the standards for $PM_{2.5}$ at 35 micrograms per cubic meter ($\mu g/m^3$) for the eighth highest

[254] Pope 2000; Johnson and Graham 2005.

(98th percentile) daily average value in a year, averaged over three years (that is, if monitored daily, the 3-year average of the annual eighth highest daily average value must be below 35 $\mu g/m^3$), and at 12 $\mu g/m^3$ for the annual mean concentration, also averaged over three years. The annual and daily standards are based on the link between exposure and premature death caused by heart and lung disease, and cardiovascular effects (e.g., heart attacks and strokes).

An increasing body of scientific literature also indicates that exposure to $PM_{2.5}$ over the course of several hours can have adverse health impacts, especially cardiovascular effects associated within short-term exposures.[255] This literature suggests that increased $PM_{2.5}$ exposures for periods of as little as 1 to 2 hours (or even at sub-hourly timescales) may lead to measurable adverse health outcomes. These data suggest that peak exposures at very short timescales may be significant, and in the context of impacts from wood heating devices, these short timescales are consistent with the startup and shutdown periods, during which wood heaters are least efficient and most polluting. The USEPA's policy assessment for setting the NAAQS in 2013 noted that adverse health effects are evident from exposures over a period of one to several hours, particularly for effects related to cardiac ischemia, vasomotor function, and other more subtle health effect markers.[256] The USEPA also found evidence for cardiovascular effects resulting from exposures as low as one to several hours.[257]

While there is no hourly $PM_{2.5}$ NAAQS, public health studies indicate that subdaily or levels below the NAAQS may have health effects. A longitudinal study of 110 children (59 boys and 51 girls, examined at age 10 and then again at age 25) looked at how changes in air quality caused by relocation were associated with changes in annual lung function growth rates.[258] The study found that as a group, subjects who had moved to areas of lower PM_{10} (PM with aerodynamic diameter less than 10 micrometers, which includes $PM_{2.5}$) levels showed increased growth in lung function and subjects who moved to communities with higher levels of PM_{10} showed decreased growth in lung function. The study concluded that changes in air pollution exposure during adolescent growth years have a measurable and potentially important

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255 Bhaskaran et al. 2011; Brook et al. 2011; Devlin et al. 2003; Gold et al. 2000; He et al. 2010, 2011; Lanki et al. 2008; Liao et al. 2010, 2011; Magari et al. 2002; Peters et al. 2001; Rosenthal et al. 2008; Vallejo et al. 2006.

256 78 FR 3124, January 15, 2013.

257 77 FR 126, p. 38923

258 Avol et al. 2001.

effect on lung function growth and performance. These factors suggest that there is a critical exposure time for children when air pollution may have long-term effects on respiratory health.[259] A review of adverse health effects of short-term exposure to PM in study areas where wood combustion was considered a major source of ambient PM found higher health risk associations than those found in areas dominated by other, non-wood sources of PM, especially for children.[260]

Children under the age of 17 have a higher resting metabolic rate and oxygen consumption rate per unit of body weight than adults.[261] When children engage in activities such as playing outdoors, the greater volume of air passing through their lungs could increase the amount of hazardous substances they take into their bodies. Several studies find respiratory effects of ambient air concentrations of $PM_{2.5}$ on children with asthma.[262] Ulirsch et al. found children under the age of 17 years old at greater risk of hospitalization due to respiratory disease with increased PM_{10} exposure.[263] Ostro et al. report a 4.1% greater risk of child hospitalization for respiratory effects associated with a 14.6 μg/m^3 increase in $PM_{2.5}$.[264] A study on the effects of particulate matter exposure conducted in Seattle on school children found that for every 10 μg/m^3 increase in concentrations of PM_1 (PM with aerodynamic diameter less than 1 μm, which is a subset of both PM_{10} and $PM_{2.5}$), there was an 18% increase in the occurrence of asthmatic symptoms, while symptoms increased 11% for a 10 μg/m^3 increase in PM_{10}.[265]

To assess potential impacts from subdaily exposures, $PM_{2.5}$ concentrations were examined on the 1-hour timescale (2nd highest value of daily peak modeled values, consistent with the approach for carbon monoxide, described below).

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259 Schwartz 2004.

260 Boman et al. 2003.

261 EPA 2008.

262 Delfino et al. 2004, 2008; Koenig et al. 2003, 2005; Naeher et al. 2007.

263 Ulirsch et al. 2007

264 Ostro et al. 2009

265 Yu et al. 2000.

9.4.2 Carbon Monoxide

Carbon monoxide (CO) is formed by incomplete combustion of carbon-containing fuels and by photochemical reactions in the atmosphere. CO is a colorless, odorless, tasteless and non-irritating gas that can be deadly. Initial symptoms of CO poisoning can be mistaken for flu symptoms. Depending on the air concentration of CO and the length of exposure, the following symptoms can arise: headaches, dizziness, nausea, weakness, loss of muscle control, shortness of breath, chest tightness, visual changes, sleepiness, fluttering of the heart, redness of the skin, confusion and mild behavioral effects such as slowed reaction time or altered driving skills. People with cardiovascular disease are particularly susceptible to the effects of CO.

Adverse health outcomes from CO arise from its ability to reduce oxygen delivery to organs and tissues. It can reduce oxygen delivery to the heart and cause chest pain (angina) during exercise in people with existing heart disease. Exposure to moderate and high levels of CO over long periods of time has also been linked with increased risk of heart disease. Exposures to elevated levels of ambient CO in the last trimester of pregnancy have been shown to be associated with low birth weight.[266] Short-term exposure to high levels of CO has also been shown to reduce cognitive ability.[267] People who survive severe CO poisoning may suffer long-term health problems. Short exposure to extreme levels (1,200 ppm) may cause death.[268] CO is regulated as a criteria air pollutant at a 1-hour concentration of 35 parts per million (ppm; 40 mg/m^3 or 40,000 µg/m^3) and an 8-hour concentration of 9 ppm (10 mg/m^3 or 10,000 µg/m^3), not to be exceeded more than once per year.

Because CO is a concern for combustion sources and the bulk storage of pellets, current American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Leadership in Energy & Environmental Design (LEED) and World Health Organization (WHO) recommendations for indoor air quality are relevant. ASHRAE and LEED suggest a limit of 9 ppm or no more than 2 ppm above ambient CO concentrations, whichever is lower. In a 2011 letter to USEPA, NESCAUM

266 Ritz and Yu 1999.

267 Amitai et al. 1998.

268 NIOSH 1994.

reported that for 2009, ambient CO levels averaged below 2.5 ppm across the Northeast states.[269] An indoor CO level greater than around 5 ppm could suggest the presence of a poorly controlled CO source. The WHO guidelines for indoor air quality recommend an upper limit of 10 milligrams of CO per cubic meter (mg/m3) of air (3.5 ppm) for any 8-hour period or 7 mg/m3 (2.45 ppm) for any 24 hour period.

9.4.3 Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a criteria air pollutant with a 1-hour health standard set at 100 parts per billion (ppb) (188 $\mu g/m^3$), eighth highest daily maximum value (98^{th} percentile), averaged over three years. The USEPA has also set a longer term NO_2 health standard at an annual mean of 53 ppb. NO_2 causes inflammation of the airways and increased symptoms for asthmatics. According to the USEPA, it is also a component of a group of highly reactive gases known as nitrogen oxides (NO_x), which contribute to the photochemical production of ground-level ozone and $PM_{2.5}$ (aerosol nitrate), as well as to acidic deposition (nitric acid).Other nitrogen oxides include nitrous acid and nitric acid.

NO_2 is an indicator for the larger group of nitrogen oxides, but NO_2 is the component of greatest interest because of its direct health effects. NO_2 forms quickly from NO_x emissions from combustion sources. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system. Current scientific evidence links short-term NO_2 exposures, ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma. Studies also show a connection between breathing elevated short-term NO_2 concentrations, and increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma. Susceptible populations include people with breathing problems including asthma, children, and the elderly.[270]

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[269] NESCAUM 2011.

[270] USEPA 2014.

9.4.4 Sulfur Dioxide

Sulfur dioxide (SO_2) is the result of combustion of materials that contain sulfur. Because wood contains sulfur, albeit less than coal and Nos. 4 and 6 fuel oils, burning wood releases sulfur oxides and in higher amounts than No. 2 distillate oil, which in NYS, is ultra-low sulfur heating oil (15 ppm S for combustion installations).[271] SO_2 has been associated with several adverse health outcomes, such as bronchoconstriction, and triggers asthma attacks, resulting in increased risk for emergency room visits after short-term exposure. At risk populations include children, the elderly, and asthmatics (particularly exercising asthmatics). The compound is regulated as a criteria air pollutant at a 1-hour health standard of 75 ppb (196 $\mu g/m^3$), fourth highest daily maximum level (99th percentile) averaged over three years. Ambient SO_2 can also be converted to $PM_{2.5}$ (aerosol sulfate) and contributes to acidic deposition (sulfuric acid).

9.4.5 Volatile Organic Compounds

Volatile organic compounds (VOCs) are a broad classification of carbon-containing volatile chemicals with a wide array of potential effects. Health effects from VOCs are chemical specific and dependent on exposure. VOCs also contribute to the formation of ground-level ozone, which is a criteria air pollutant. From a local air quality perspective, the VOCs of greatest health concern are those that are also hazardous air pollutants (HAPs), and include some polycyclic aromatic hydrocarbons (PAHs) and benzene, as well as other compounds that are known or suspected carcinogens or have other short- or long-term health impacts. For this analysis, the focus is on long-term exposures using an annual average metric to determine levels of potential aggregate exposure to VOCs. VOC emissions contribute to the formation of ground-level ozone, which can cause health effects and reduce visibility.

9.5 Technology Levels and Unit Types

Thermal storage *is a system designed collect heat for later use and can accompany and improve efficiency of a heating system.*

This local air quality impacts section is designed to assess and compare the impacts of various technologies at different installation types. The technologies have been categorized into business as usual technologies (BAU), best available technologies (BAT), and next best available technologies

[271] 6 NYCRR Part 225

(nBAT). See Table 9-2 for a summary of definitions and examples of these technology categories. BAU technologies represent current, widespread practice for units installed across NYS. Generally, compared to BAT and nBAT technologies, BAU wood technologies have higher emission rates, lack emission controls or thermal storage, and are installed with significant excess capacity (i.e. they are oversized). BAT units are those advanced technologies that have the lowest emission rates, highest efficiency, and are currently available for purchase and installation in NYS. BAT installations also tend have a higher level of integration with existing heating systems and therefore tend to be installed with less excess capacity. Unlike BAU and BAT units, nBAT units are currently not widely available for purchase and installation in NYS, but are expected to be on the market in the next five to 10 years. nBAT units are generally condensing units with the highest efficiency and extremely low emission rates. In addition to the wood units, oil-fired units using ultra-low sulfur heating oil (sulfur content no greater than 15 ppm) are included as a BAU technology, because this is the most likely alternative for a residence or institution considering the installation of a wood-fired thermal heating device.

***Cycling** is the process through which a boiler fires to meet a demand heat load and then shuts down when the load is met. Excessive cycling can reduce efficiency because of heat losses during cycling.*

***Oversizing** is the convention of installing a heating unit capable of delivering more heat than required to meet peak heat demand.*

Thermal energy storage is an energy efficiency measure whereby insulated tanks store heat during times when the building does not need it and supplies hot water during a call for heat without firing the boiler. Thermal storage enables a boiler to operate at higher efficiency to meet the building's call for heat, recharge the storage unit, and then shut down. The thermal storage can then respond quickly to an intermittent call for heat, thereby avoiding on-off cycling, or if it is a large demand, it can provide heat as the boiler energizes. Thermal storage not only reduces boiler cycling, but also minimizes the amount of time the boiler operates at low load (low efficiency). This strategy improves equipment longevity and reduces periods of high emissions during start-up by minimizing the number of start-ups. Minimizing start-ups is especially important for wide ranging diurnal and seasonal duty cycles as experienced in NYS and for mitigating impacts of oversizing boilers. Thermal storage can also temper return water to prevent thermal shock to the boiler. Oversizing is the installation of significant excess capacity, and is widespread practice by heating system designers and installers independent of fuel type (wood, oil, propane, etc.).

Oversizing results in units cycling on and off, as well as operating at partial load. This suboptimal efficiency leads to more fuel consumption and greater emissions. The partial load efficiency for boilers that burn homogeneous fuels like gas or oil is higher than for boilers that burn heterogeneous fuels like wood. Therefore, the adverse impact of oversizing is not as great for oil and gas-fired heating systems as it can be for solid-fuel heating systems such as wood. Chapter 11 addresses the issue of oversizing in greater detail.

Table 9-2. Technology Categories

Technology Category	Abbreviation	Description	Example(s)
Business as Usual Technology - Heating Oil Only	BAU	• Currently available heating oil boiler using 15 ppm S content oil	Modern heating oil boiler
Business as Usual Technology	BAU	• Current, widespread practice for units installed in NYS • Relatively high emission rates • Low efficiency • Few emission controls • No thermal storage • Significant excess capacity	Residential: Phase II outdoor cordwood boiler Institutions: Stoker chip boiler
Best Available Technology	BAT	• Currently available for purchase and installation (but not widespread practice) in NYS • Low emission rates • High efficiency • Advanced emissions controls • Thermal storage (in some cases) • Less excess capacity	Residential: 2-stage gasification pellet boiler, with storage; 2-stage gasification cordwood boiler, with storage Institutions: 2-stage gasification pellet boiler
Next Best Available Technology	nBAT	• Condensing units that will be available for purchase and installation in NYS in five to ten years • Lowest emission rates • Highest efficiency • Advanced emissions controls • Thermal storage (in some cases) • Installed at “right” size	Residential: Condensing pellet boiler, with storage Institutions: Condensing chip boiler, with advanced emissions controls

The following subsections provide an overview of the installations that were investigated in this analysis, and describe specific methodological considerations applied for each installation. A comprehensive data archive of emission characteristics and references can be requested from NESCAUM. Further details on unit technologies are presented in Chapter 8. A summary of technologies modeled in this analysis is presented in Table 9-3.

Table 9-3. Technologies and Unit Sizes

Notes: AEC=advanced emission controls (e.g., baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; ultra-low sulfur heating oil contains 15 ppm sulfur, and with or without storage refers to thermal storage; unit sizes are reported to three significant figures.

Building Type	Technology Level	Unit/Installation Type	Thermal Storage?	Unit Size (Btu)
Large School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	No	4,040,000
		Stoker Chip Boiler	No	7,130,000
	BAT	Advanced Chip Boiler w/AEC	No	5,120,000
		Advanced Chip Boiler w/AEC Using 30% Moisture Chips	No	5,120,000
		2-Stage Gasification Pellet Boiler	No	5,120,000
		RHNY-Qualified 2-Stage Gasification Pellet Boiler	Yes	1,430,000
	nBAT	Condensing Chip Boiler w/AEC	No	1,710,000
		Condensing Chip Boiler w/AEC Using 30% Moisture Chips	No	1,710,000
		Condensing Pellet Boiler w/AEC	No	1,710,000
Small School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	No	1,920,000
		Stoker Chip Boiler	No	3,390,000
	BAT	2-Stage Gasification Pellet Boiler	No	3,410,000
		Containerized 2-Stage Gasification Pellet Boiler (2 boilers)	No	Each: 1,710,000
	nBAT	Condensing Pellet Boiler w/AEC	No	1,020,000
Hospital	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	No	3,370,000
		Stoker Chip Boiler	No	7,130,000
	BAT	Advanced Chip Boiler w/AEC	No	5,120,000
	nBAT	Condensing Chip Boiler w/AEC	No	1,710,000
Residential Central Heating	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	No	118,000
		Phase II Outdoor Cordwood Boiler	No	208,000
		Pellet Boiler, No Storage	No	109,000
	BAT	Pellet Boiler, With Storage	Yes	109,000
		Advanced Cordwood Boiler, With Storage	Yes	109,000

Table 9–3 continued

	nBAT	Condensing Cordwood Boiler, No Storage	No	85,300
Residential Space Heating		Condensing Pellet Boiler, No Storage	No	85,300
		Condensing Pellet Boiler, With Storage	Yes	85,300
		USEPA-Certified, Catalytic Cordwood Stove	No	51,200
		Pellet Stove	No	60,000
	BAT	USEPA-Certified, Catalytic Cordwood Stove	No	51,200
	nBAT	Advanced Cordwood Stove w/AEC	No	51,200

9.5.1 Business as Usual Technologies

For institutional (schools and hospitals) heating systems, two BAU technologies were used: (1) oil-fired boilers using ultra-low sulfur heating oil (15 ppm sulfur), which is the legal limit for sulfur content in No. 2 heating oil in NYS; and (2) wood chip-fired stoker boilers using bole wood chips (with an assumed moisture content of 45%). Institutional BAU wood chip-fired units are assumed to be oversized by three times for the anticipated maximum heat load (i.e., 200% larger than required to meet the annual maximum hourly heat demand) based on common practice at schools in Vermont and NYS. A review of three installations in Vermont and Maine found sizing to be in the range of 3.0, consistent with this assumption.

Units were selected as being representative of BAU technologies at residential locations based on the results of the market inventory (see Chapter 3). For residential central heating systems, the BAU technologies used in the analysis were: (1) USEPA-certified Phase II outdoor cordwood boilers (conventional outdoor wood boilers, are illegal for sale in NYS); and (2) indoor pellet boilers without thermal storage. For residential BAU wood central heating (whole-house) technologies, an oversize factor of three was used based on the assumed maximum annual heat load. For supplemental space heating (i.e., single room), the BAU technologies included both catalytic and noncatalytic, USEPA-certified, cordwood-fired stoves and pellet stoves. Wood stoves are typically used as supplemental heating with an oil-fired boiler as backup, but for this analysis the combined effects of residential wood space heating and central heating (of either wood or oil heating technologies) were not assessed. A low-cost (typical efficiency) oil-fired boiler using ultra-low sulfur heating oil (15 ppm sulfur) was also included as BAU.

For both institutional and residential oil boilers, a 1.7 times oversize factor is assumed (i.e., units are 70% larger than required to meet the annual maximum hourly heat demand).

9.5.2 Best Available Technologies

Best available technologies (BAT) for institutional units included more sophisticated units with better performance characteristics than BAU technologies. The designs of these types of boilers are generally characterized by staged combustion, separate primary and secondary combustion chamber air supply, and sensors (e.g., flue gas temperature or oxygen) and controls to optimize combustion. The BAT options used for the analysis include: (1) two-stage gasification pellet-fired boilers; and (2) advanced wood chip-fired boilers with advanced emission control technology. The effect of using lower moisture content wood chips (defined as less than 30% moisture content) at some institutional BAT chip installations was also evaluated. This analysis assumed that the efficiency gain for using this lower moisture content was 3.4%, based on data provided by BioEnergy2020+ from theoretical differences in efficiency. There have been a few installations of institutional boilers in shipping containers placed adjacent to the building being served, so this scenario was also assessed. For residential central heating BAT units, a pellet boiler and an advanced (indoor) cordwood boiler, both with thermal storage, were included. For BAT space heating, a USEPA-certified catalytic cordwood stove was modeled.

The size assumed for institutional BAT units was two times the anticipated maximum heat load, and 1.7 times for residential BAT units.

In addition to the configuration described for BAT units, this study included units that met the requirements of the Renewable Heat NY (RHNY) program for units at large schools. RHNY provides State-financed incentives to install high-efficiency, low-emitting wood burning units for residential and commercial[272] installations. To qualify for RHNY incentives, among other requirements, commercial pellet boilers above 300,000 Btu/hr output must meet the following:[273]

- Be a qualified high-efficiency (85% or higher at full load), low-emissions pellet-fired boiler.
- Use premium quality pellets.
- Be sized at 60% of the facility peak heating load to minimize cycling.
- Include a thermal storage tank sized at 2.0 gallons per 1,000 Btu/hr rating.
- Have $PM_{2.5}$ emissions no higher than 0.080 lb/MMBtu, or no higher than 0.030 lb/MMBtu for locations that serve sensitive populations, including schools and health care facilities.

[272] This analysis describes impacts of wood heat at residential and institutional settings. In institutional buildings, commercial boilers are installed.

[273] Program details available at https://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/Biomass/RHNY-Technical-Guidance-for-Large-Commercial-Pellet-Boilers.pdf.

A RHNY-qualified two-stage gasification pellet boiler was included as a containerized BAT unit at the large school and incorporated thermal storage. The RHNY requirements specify $PM_{2.5}$ emission factors based on whether it is a commercial or institutional installation. Installations at institutions that serve sensitive populations must meet more stringent emissions and efficiency limits. Other institutional BAT units did not incorporate thermal storage because of a lack of data for non-RHNY-qualified units.

9.5.3 Next Best Available Technologies

For nBAT units in institutional settings, condensing pellet boilers and condensing chip boilers with advanced emission controls were included. As with institutional BAT units, the effect of using lower moisture content wood chips at some nBAT institutional installations was evaluated. Thermal storage was not included because of a lack of data for highest efficiency units.

In the residential setting for nBAT, condensing pellet boilers with and without thermal storage and a condensing cordwood boiler without thermal storage were included.

The nBAT units installed in residences and institutional settings were assumed to be approximately "right sized," that is, sized to exactly serve the maximum anticipated heat load. For institutional settings, consistent with the statewide analysis, a sizing multiplier of 0.75 was applied, which is 75% of the anticipated maximum heat load. This sizing is slightly larger than allowed to meet requirements of RHNY. Here it was assumed that an onsite backup oil boiler would supply additional heat on occasions when the thermal demand exceeded the boiler's full output rating, though additional air impacts from the backup oil boiler were not explicitly modeled. For nBAT home central boilers, a multiplier of 1.2, which is 20% higher than the maximum anticipated heat load, was applied because unlike institutions, homes were not assumed to have an oil backup, so they were slightly oversized so as to be sure to always meet all of the home's heating needs.

For residential space heating nBATs, an advanced cordwood stove with advanced emission controls was evaluated. Specifically, these stoves include electrostatic precipitator (ESP) technology and automatic air dampers for emissions controls, but do not have post-combustion catalyst. Some European manufacturers are currently designing residential scale wood stoves with ESP controls. ESPs on small residential cordwood stoves have very high efficiency, removing 80-90% of $PM_{2.5}$.

9.6 Regions

This analysis investigated the potential effects of emissions occurring in different regions and their associated terrain and meteorology, including two locations in mid-latitude and one location in upper-latitude NYS. These locations were selected based on existing (or nominal) population centers and representative terrain for flat, valley, and mountainous terrain types. The modeling study is intended to provide a sense of the range of potential impacts from wood burning equipment at residential and institutional settings in a representative range of NYS terrain, meteorology, and population density. It is not intended to represent actual air emissions or locations. To understand impacts at a single location in a particular location, site-specific modeling must be conducted.

9.6.1 Terrain

Because wood combustion sources are more likely to be located in less urban areas, the rural option in AERMOD was used at all three locations. Dispersion can be impeded by hills and other terrain elements. Terrain effects on individual sources are most significant for sources when plume interaction with terrain features is likely. Therefore, terrain is expected to have an important effect on impacts from individual sources, particularly when stack heights are insufficient to overcome local terrain features.

This study relied on digital elevation model (DEM) files for relevant areas of NYS as available on the Cornell University Geospatial Information Repository.[274] For the mountainous town area, an area was selected in upper-latitude NYS near a lake and with steep slopes near to the source. There is an especially steep uphill slope immediately to the west-northwest of the source. For the valley town area, an area in mid-latitude NYS was selected with rising terrain to southeast and southwest, and a ridge to the north of the source. For the flat area, a populated area in mid-latitude NYS was selected with relatively high population density, especially to the north and northwest of the source.

9.6.2 Meteorology

Meteorological modeling outputs were provided by NYSDEC. The NYSDEC modeling represents the agency's best practices for permit modeling, and includes data from the nearest National Weather Service Automated Surface Observing Systems station over the five year period from 2008 through 2012. These weather stations collect data at a one-minute resolution that enables use of the AERMINUTE program,

[274] CUGIR: Cornell University Geospatial Information Repository, http://cugir.mannlib.cornell.edu/datatheme.jsp?id=23

which dramatically increases the usability of meteorological data for AERMOD. These data include temperature inversion periods when atmospheric stability traps emissions near the ground, leading to higher ground-level concentrations. Inversions can have a dramatic effect on high-end concentrations over short timescales (e.g., 2nd high 1-hour concentrations).

Because National Weather Service data from airports were used, which are surrounded by flattened terrain cleared of obstacles, rather than data collected in valley areas where stagnant wind conditions are more common, these data may overestimate advection and dispersion and therefore underestimate air emission concentrations.

Simulated units in the local air impacts analysis are sized for the mid-State climate zone (based on climate data from Albany, New York) so that comparisons can be made on the basis of terrain and meteorological influences alone. This assumption only affects the unit sizing, not the selection of meteorology used in the air quality analysis (described later in this chapter). In other words, the local analysis studied the air impact in three locations of units that were all sized for the mid-state climate zone. For areas with upper-latitude climate zones and corresponding higher peak heat demand, units may tend to be installed at larger sizes; therefore, the impacts estimated in this analysis may be somewhat lower than would occur with a larger unit in the upper-latitude climate zones.

9.7 Data Inputs

This section describes the overall methodology and approach for developing the modeling inputs. Direct inputs to the model include emission rates of various pollutants from the combustion source, exhaust temperature and velocity, and stack height and diameter. Some values were indirect inputs to the model, such as the unit efficiency to calculate the wood consumed by (and resulting emissions from) a boiler at a given heat demand level. Although actual observed emission rates were preferred over those generated using emission factors, and observed exhaust flows over those calculated using engineering estimates, calculated values were used when observations were not available. These parameters are discussed in the following subsections. Appendix E provides a full accounting of the data used to model each technology.

9.7.1 Load and Efficiency

Thermal efficiency *is the ratio of heat output to heat input.*

Unit efficiencies at maximum and typical load conditions were generally based on an assumed load level and a theoretical efficiency curve for each installation type. The approach used to estimate efficiency is consistent with the approach described in Chapter 8. In summary, the efficiencies are based on a heat input to heat output relationship. Thermal efficiency represents the ratio of heat output to heat input. Heat output is the useful heat supplied by a heating unit, and heat input is the total heat value of fuel supplied to the heating unit. This method of calculating thermal efficiency contrasts with the stack loss method in that it accounts for jacket losses, which significantly impact the amount of useful heat supplied to the heat distribution system. These losses can be large, especially at part-load. For consistency, heat input and output were estimated for all fuel and technology types using the higher heating value, which is the convention for efficiency measures of heating appliances in the U.S. The load fraction is the ratio of the heat output level of the unit to the maximum rated heat output level of the unit. Table 9-4 presents the load fractions and efficiencies at maximum and typical emission conditions for each installation and technology type. A summary of these data by unit is presented in Appendix E.

Table 9-4. Summary of Load Fraction and Efficiency by Emission Scenario

Notes: AEC=advanced emission controls (e.g., baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted; ultra-low sulfur heating oil contains 15 ppm sulfur. Cordwood stoves are omitted from this table because efficiency and load level were not used in generating emissions estimates for them. Maximum operation for the containerized pellet units is two units operating together at 80%, whereas typical operation is one unit operating alone at 90%. Units with storage are assumed to always operate at maximum load. Because emissions from oil burning units are extremely low compared to wood burning units, it is conservatively assumed that oil units operate at maximum load. Values are reported to two significant figures.

Building Type	Tech. Level	Unit/Installation Type	Load Fraction		Efficiency (%)	
			Maximum	Typical	Maximum	Typical
Large School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	1.00	1.00	86	86
		Stoker Chip Boiler	0.60	0.41	70	65
	BAT	2-Stage Gasification Pellet Boiler	0.80	0.45	85	81
		RHNY-Qualified 2-Stage Gasification Pellet Boiler	1.00	1.00	85	85
		Advanced Chip Boiler w/AEC	0.80	0.45	75	70

Table 9-4 continued

Building Type	Tech. Level	Unit/Installation Type	Load Fraction		Efficiency (%)	
			Maximum	Typical	Maximum	Typical
Large School	BAT	Advanced Chip Boiler w/AEC Using 30% Moisture Chips	0.80	0.45	78	73
	nBAT	Condensing Pellet Boiler w/AEC	1.00	0.50	94	90
		Condensing Chip Boiler w/AEC	1.00	0.50	88	83
		Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1.00	0.50	91	85
Small School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	1.00	1.00	86	86
		Stoker Chip Boiler	0.60	0.41	70	65
	BAT	2-Stage Gasification Pellet Boiler	0.80	0.45	85	81
		Containerized 2-Stage Gasification Pellet Boiler (2 boilers)	0.80	0.90	85	85
	nBAT	Condensing Pellet Boiler w/AEC	1.00	0.50	94	90
Hospital	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	1.00	1.00	86	86
		Stoker Chip Boiler	0.60	0.41	70	65
	BAT	Advanced Chip Boiler w/AEC	0.80	0.45	75	70
	nBAT	Condensing Chip Boiler w/AEC	1.00	0.50	87	82
Residential Central Heating	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	1.00	1.00	83	83
		Phase II Outdoor Cordwood Boiler	0.70	0.40	78	68
		Pellet Boiler, No Storage	0.80	0.45	85	82
	BAT	Pellet Boiler, With Storage	1.00	1.00	86	86
		Advanced Cordwood Boiler, With Storage	1.00	1.00	86	86
	nBAT	Condensing Pellet Boiler, No Storage	0.90	0.50	94	90
		Condensing Pellet Boiler, With Storage	1.00	1.00	93	93
		Condensing Cordwood Boiler, No Storage	0.90	0.50	83	74
Residential Space Heating	BAU	Pellet Stove	1.00	0.50	78	66

9.7.2 Emissions

As stated previously, data from observations (stack tests) were preferred over emissions calculated using emission factors to develop emission rates. However, this latter approach was used when emission rate observations were not available. Whenever practicable, estimates at relevant timescales were relied upon. For example, for some 1-hour emissions, emission rates obtained over 1-hour timescales were used, whereas estimates taken from longer timescales were used to estimate 24-hour emission rates for the same units.

In this analysis, the default approach for estimating an emission rate was to take the product of the load fraction and the unit size in million Btu (MMBtu), divide by the efficiency (see the previous section) to derive fuel input required, and multiply by an emission factor (reported in units of mass per MMBtu). For cordwood stoves, it was assumed that there were six (maximum) or three (typical) charges per day of 25 lb of cordwood. Energy content of cordwood was assumed to be 7,000 Btu/lb.

The emission rates were scaled by the ratio of the size of the modeled unit to the tested unit when observed emission rates were used instead of emission factors. For example, the emission rate for the 3.4 MMBtu/hr chip stoker boiler at the small school was calculated by taking the product of the observed emission rate from a chip stoker boiler with a maximum rating of 7.1 MMBtu/hr and the ratio of 3.4 to 7.1 (3.4/7.1=0.48).

For several BAT and nBAT technologies, no specific data for emission factors for SO_2 and VOCs were available, and BAU emission factors were used instead. Because BAT/nBAT emissions for VOCs are likely to be lower than those from BAU units due to their improved combustion conditions, this assumption will result in higher concentrations than may be observed for VOCs. Because emissions of SO_2 are likely to be dominated by fuel characteristics (i.e., sulfur in the fuel) and not due to combustion, it is reasonable to assume equivalent SO_2 emission factors for BAU, BAT, and nBAT technologies.

NO_2 emissions were estimated in two ways. First, as a Tier 1 approach, it was assumed that all NO_x was converted to NO_2. Because NO_2 is the constituent of NO_x that has direct health impacts, assuming that all or most of NO_x emissions are comprised of NO_2 will result in concentrations that may be higher than observed. In actuality, in-stack ratios of NO_2 to NO_x are likely to be considerably lower, as suggested by the in-stack ratio database maintained by USEPA; for coal-fired boilers in the database, in-stack ratios of

NO_2 to NO_x are below 2%. Data from the Wild Center[275] indicate that the maximum ratio for NO_2 to NO_x was around 12% during the testing period for that unit (two-stage gasification pellet boiler). Therefore, this Tier 1 approach represents an extremely conservative approach and likely represents an over-prediction of NO_2 impacts. Tier 2 treated 80% of NO_x emissions as NO_2, rather than 100% as Tier 1 did Though less so than Tier 1, Tier 2 still represents a very conservative approach, and actual emissions from these types of sources are likely to be lower than modeled. Typical modeling analyses would model additional tiers using more advanced methods to treat plume chemistry, partially as a function based on distance from the source. Full conversion to NO_2 at extremely short distances, such as those used in this analysis, is unlikely. Therefore, the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented in this report likely represent an upper bound for near-source impacts. In one scenario for a pellet boiler at an institutional source, the emission factor and NO_2 conversion rate based on the installation at The Wild Center in Tupper Lake, NY, were applied. This emissions scenario can be compared to the higher emissions scenarios to provide insight into more typical emissions and resulting concentrations.

Values and sources for emission factors, emission rates, and other unit-specific data are presented in Appendix E.

9.7.2.1 Emissions - Annual

For the annual timescale, it was assumed that for summer months, unit operation would be curtailed at some installation types. For schools, it was assumed that boilers were not operated from May through September, therefore no emissions occurred during that period. For hospitals, it was assumed that some of the air-conditioned air needed to be reheated during summer months, so boiler operation continued through the summer.[276] At residences, it was assumed that stoves were not operated from May through September, and central heating equipment was only operated at 50% during that time to account for hot water heating. For residential central heaters, emissions during those summer months were scaled by 50% for the annual estimate.

[275] Hopke 2010

[276] Space reheating allows for precise control of relative humidity levels, but is especially energy intensive. The process is common in health care facilities where temperature, humidity, and other qualities of indoor air must be controlled precisely and where specifications may be determined by hospital code and licensing requirements.

9.7.2.2 Emissions – Daily and Hourly

To estimate the maximum 1-hour emission rate for $PM_{2.5}$ from the phase II outdoor cordwood boiler, the reported average emissions rate from Gullett et al. (2013) was used, with the assumptions that during damper closed cycles there were no emissions and that during the fresh burn period emissions were 50% higher. This led to a total scaling factor of 3.0, which when applied to the reported emission rate of 28.75 g/hr comes to about 86 g/hr. Scaled to the assessed unit size of 207,673 Btu/hr from the measured 160,000 Btu/hr rating, the maximum emission rate is 112 g/hr. The typical emission rate of 37.3 g/hr for $PM_{2.5}$ was calculated by using the reported emission rate of 28.75 g/hr and scaling to the unit size. An analogous approach was used to estimate the CO emission rate from these units.

For residential advanced cordwood boiler heating systems with thermal storage, it was assumed that recharging the storage tank required firing at full load for 3 hours. This assumption is consistent with the results of testing a unit with thermal storage.[277] During a 1-hour period, the emission rates for both typical and maximum emissions assume operation at full load. During an 8-hour period, the emission rate is the 1-hour emission rate multiplied by the ratio of 3 hours to 8 hours for both typical and maximum scenarios. During a 24-hour period, the emission rate is the 1-hour emission rate multiplied by the number of fuel recharges per day to the boiler's firebox divided by 24 hours. Under the maximum scenario, there are three fuel recharges per day; under the typical scenario, there is one recharge per day.

9.7.3 Stack and Exit Gas Parameters

Some stack parameters are completely dependent on physical infrastructure, like stack height and stack exit diameter. Exit gas temperature is a function of the combustion system, control technology, load level, and fuel. Exit gas velocity is a calculated value that depends on the mass throughput and stack diameter. These characteristics of the stack and stack gas have an important impact on dispersion and resulting impacts on the surrounding area. Without sufficient stack heights, plumes may impact nearby terrain or become trapped in building downwash cavities. Similarly, the buoyancy of the plume is a function of the exit gas temperature, which can combine with higher gas exit velocity to contribute to a higher effective stack height. Because the exit gas velocity is dependent on the exit diameter, temperature, and quantity

[277] Butcher et al. 2013.

and quality of fuel burned, engineering estimates based on prototypical stack designs were used and compared to a range of stack velocities observed in stack tests at similar installations. If available data include stack gas flow rates at relevant load conditions, those rates were used to determine exit velocity through the AERMOD software program interface.[278]

Stack designs in this analysis did not vary by location, terrain, or technology level, only by building type and installation type. That is, the existing stack design at the building is assumed to be maintained no matter what unit is installed. The stack height and diameters for each building and installation are presented in Table 9-5. Stack heights are reported in the table from ground level, not from roof level. Table 9-6 presents the exit gas temperature and velocity for each unit type and emission scenario. Additional assumptions were not made about augmenting exit gas velocities, such as installing blower fans. Blower fans would increase velocities and dispersion, reducing ground-level concentrations. Therefore, excluding blower fans is a conservative model assumption, especially for more advanced units that would more typically need to increase velocities through the use of a blower fan. Values for all stack parameters are also available for each unit in Appendix E.

Table 9-5. Stack Heights and Exit Gas Diameters by Building and Installation Type

Notes: Values reported to 2 significant figures.

Building Type	Installation Type	Stack Height (ft)	Stack Diameter (in)
Large School	Central Boiler	40	24
	Containerized Boiler	40	18
Small School	Central Boiler	40	19
	Containerized Boiler	14 or 25	18
Hospital	Central Boiler	50	24
Home	Chimney	20	6
	Shed	10	6

[278] The ORIS BEEST Suite AERMOD software program was used.

Table 9-6. Exit Gas Temperature and Velocity by Unit and Emission Scenario

Notes: AEC=advanced emission controls (e.g., baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Ultra-low sulfur heating oil contains 15 ppm sulfur. Maximum operation for the containerized pellet units is two units operating together at 80%, whereas typical operation is one unit operating alone at 90%. Maximum load conditions are identical to typical load conditions for units with storage, oil boilers, and USEPA-certified non-catalytic wood stoves. Values reported to the nearest °F for temperature, to the nearest 0.1 ft/s for velocity. Temperatures below 212 ºF for non-condensing units indicate that exhaust will condense in-stack, consistent with evidence.

Building Type	Tech. Level	Unit/Installation Type	Exit Gas Temp. (ºF)		Exit Gas Velocity (ft/s)	
			Max.	Typ.	Max.	Typ.
Large School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	369	369	4.3	4.3
		Stoker Chip Boiler	416	341	17.7	13.5
	BAT	2-Stage Gasification Pellet Boiler	356	176	11.1	5.1
		RHNY-Qualified 2-Stage Gasification Pellet Boiler	192	192	1.0	1.0
		Advanced Chip Boiler w/AEC	356	176	15.2	7.1
		Advanced Chip Boiler w/AEC Using 30% Moisture Chips	356	176	12.3	5.7
	nBAT	Condensing Pellet Boiler w/AEC	140	104	3.1	1.5
		Condensing Chip Boiler w/AEC	140	104	4.0	2.0
		Condensing Chip Boiler w/AEC Using 30% Moisture Chips	140	104	3.2	1.6
Small School	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	369	369	7.2	7.2
		Stoker Chip Boiler	416	341	14.4	9.7
	BAT	2-Stage Gasification Pellet Boiler	356	176	12.3	7.2
		Two Containerized 2-Stage Gasification Pellet Boiler	192	192	10.9	6.2
	nBAT	Condensing Pellet Boiler w/AEC	140	104	3.1	1.6
Hospital	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	369	369	7.6	7.6
		Stoker Chip Boiler	416	341	18.3	12.3
	BAT	Advanced Chip Boiler w/AEC	356	176	15.2	7.1
	nBAT	Condensing Chip Boiler w/AEC	140	104	4.0	2.0

Table 9–6 continued

Res. Central Heating	BAU	Oil Boiler Using Ultra-Low Sulfur Heating Oil	420	420	4.7	4.7
		Phase II Outdoor Cordwood Boiler	311	248	7.4	4.3
		Pellet Boiler, No Storage	248	160	3.3	1.7
	BAT	Pellet Boiler, With Storage	248	248	4.0	4.0
		Advanced Cordwood Boiler, With Storage	320	320	4.0	4.0
	nBAT	Condensing Pellet Boiler, No Storage	126	86	2.2	1.1
		Condensing Pellet Boiler, With Storage	126	126	2.4	2.4
		Condensing Cordwood Boiler, No Storage	266	196	2.8	1.6
Res. Space Heating	BAU	Non-USEPA Certified Cordwood Stove	592	548	15.0	13.5
	BAU	USEPA-Certified, Non-Catalytic Cordwood Stove	555	555	12.9	12.9
	BAU	USEPA-Certified, Catalytic Cordwood Stove	592	548	15.0	13.5
	BAU	Pellet Stove	554	542	12.9	11.8
	BAT	USEPA-Certified, Catalytic Cordwood Stove	500	392	3.1	1.2
	nBAT	Advanced Cordwood Stove w/AEC	500	392	2.8	1.3

9.7.4 Existing Conditions

This study used pollutant-specific concentrations for NAAQS-relevant averaging periods based on recent monitoring data at representative locations in NYS [279] to set existing conditions in the studied areas. Existing conditions are the levels of pollutants already experienced in urban and rural communities, and provide the air quality backdrop against which new heating units are installed. Existing conditions were determined from monitored values consistent with how the values are calculated in NAAQS for monitors that are representative of the types of areas modeled based on data from NYSDEC air quality monitoring reports. For example, for the "low density" (i.e., low population) locations, monitors placed in rural/unpopulated areas were selected.

[279] NYSDEC 2013.

For the 1-hour $PM_{2.5}$ concentrations, the concentrations representing existing conditions were determined based on the 3-year average of 98th percentile 1-hour measurements at TEOM® monitoring stations in NYS. These 1-hour measurements do not adequately reproduce 24-hour average measurements at collocated sites because they under-measure local $PM_{2.5}$ emissions, and therefore the measurements are biased on the low side (Felton 2009). This bias explains why the 1-hour levels for the flat terrain, high density location are lower for 1-hour than for a 24-hour average (see Table 9-7). The levels for existing conditions for the mountain terrain area are derived from testing performed by NESCAUM for NYSERDA at a site in the North Country of NYS. These concentrations were applied uniformly to the summary results after converting to consistent units. Table 9-7 presents concentrations for existing conditions used in this analysis.

Table 9-7. Concentrations for Existing Conditions by Location by Pollutant Metric

Notes: Existing condition concentrations are not available for VOCs. 1-hour $PM_{2.5}$ concentrations for existing conditions are based on unverified three-year averages of 98th percentile 1-hour observations at TEOM sites in NYS (for which data quality cannot be verified), and underestimate concentrations compared to the 24-hour federal reference method.

Pollutant	Averaging Time	Standard Level	Mountain terrain, low density	Valley terrain, low density	Flat terrain, high density
$PM_{2.5}$	24-hour	35 μg/m^3	15 μg/m^3	20 μg/m^3	23 μg/m^3
	Annual	12 μg/m^3	4.3 μg/m^3	7.0 μg/m^3	8.7 μg/m^3
	1-hour*	None	22.0 μg/m^3	21.2 μg/m^3	18.2 μg/m^3
CO	1-hour	35 ppm	1.1 ppm	0.5 ppm	1.1 ppm
	8-hour	9 ppm	0.7 ppm	0.5 ppm	0.7 ppm
NO_2	1-hour	188 μg/m^3	33 μg/m^3	33 μg/m^3	110 μg/m^3
SO_2	1-hour	196 μg/m^3	10 μg/m^3	31 μg/m^3	60 μg/m^3

9.8 Neighborhood Analysis

In addition to evaluating the effects of individual installations of wood-fired heating units, the effect of an installation at a large school surrounded by a neighborhood was assessed for the combined effect of adding the school installation to an existing baseload of wood-fired heating units. The approach for modeling the large school was consistent with the approach described in the previous sections for determining the terrain, unit size, emission rates, stack and exit gas parameters, existing conditions, etc. The neighborhood design and modeling scenarios are described here.

For the homes in the neighborhood, it was assumed that emissions would be typical on average because it is unlikely that maximum emissions will be produced by all residential units at the same time. Some individual homes may be producing maximum impacts, but this scenario was not specifically addressed in this analysis because the intention was to assess the combined impacts of aggregate impacts from a neighborhood of residential sources and the school. Both maximum and typical impacts from the large school were assessed.

Table 9-8 presents the scenarios that were assessed in the neighborhood impact analysis for each study location. The four scenarios allow the relative importance of decisions about wood burning technologies at a large source to be determined compared to the effects of efforts to control the neighborhood's existing smaller, yet more numerous, wood-burning sources. These scenarios address the increasing prevalence (or "growth") of wood burning technologies in homes using BAU units versus growth with BAT units, and the projected impacts of a limited program to changeout existing BAU technologies with cleaner burning units. The changeout program was assumed to replace 20% of the higher polluting units with cleaner units for some neighborhoods. These levels of changeout are not intended to be representative of average statewide changeout regimes.

The scenarios also allow for the following direct comparisons:

- Growth in the neighborhood with BAU (Scenario 1) versus growth with BAT technologies (Scenario 2).
- No changeouts of more to less polluting residential wood heating units (Scenario 2) versus 20% changeouts (Scenario 3).
- Installation of a BAU unit at the school (Scenario 1) versus installation of a BAT unit at the school (Scenarios 2-3).
- Installation of a BAT unit at the school (Scenarios 2-3) versus installation of an nBAT unit at the school (Scenario 4).

In developing the projection for how the mix of BAU sources in a neighborhood will grow, the county-level projections to 2023 were used to estimate ownership of wood-heating devices in homes consistent with Chapter 2 of this report. Next, the breakdown of wood devices (e.g. the proportion of outdoor hydronic heaters to indoor furnaces to BAT to BAU) for these counties was assumed to be proportional to those reported in USEPA's Residential Wood Combustion (RWC) tool used in the 2011 National Emissions Inventory with some additional assumptions as follows:

- All new outdoor hydronic heaters are phase II units. Conventional outdoor wood boilers are not legal for installation in NYS, so growth of conventional units would lead to unrealistic emissions for the model year.
- Indoor furnaces, which are still legal for installation in NYS, do not have reliable emission rate estimates, but are assumed to have comparable emissions rates to conventional outdoor cordwood boilers, which have been measured.[280]
- Because the RWC tool omits pellet boilers, they are not included as a BAU technology for the neighborhood analysis. This omission may inflate the projected benefits of moving from BAU to BAT technologies in the neighborhoods.
- Changeouts target only conventional and phase II outdoor cordwood boilers and non-USEPA certified cordwood stoves.
- All changeouts will be replaced with BAT pellet boilers with storage for central heating, and BAT cordwood stoves for space heating. BAT cordwood boilers were excluded for central heating because these units have higher emissions than the pellet units, and including them would diminish the effectiveness of the changeout program.

The density of homes in neighborhoods varies by location. The population density values are based on U.S. Census data (2014) for neighborhood density near town centers of areas that fit the modeled area design. Assuming an average of 2.25 people per household, the modeled area types with their density values are:

- **Mountain terrain, low density.** At a distance of 5 miles from a rural town center in North Country of NYS, the population is 195 (or 87 homes) per square mile. The modeled neighborhood area is 2.75 square miles.
- **Valley terrain, low density.** Based on a distance of 5 miles from a rural town center in the Southern Tier of NYS, the population is 337 (or 150 homes) per square mile. The modeled neighborhood area is 15 square miles.
- **Flat terrain, high density.** At 5 miles from an urban center in the Finger Lakes Region of NYS, the average population density is around 3,300 (or 1,500 homes) per square mile. The modeled neighborhood area is 25 square miles.

[280] Gullett et al. 2013

To ensure that the highest air quality impacts due to residential emissions in neighborhoods are captured by the model, the neighborhood density assumptions are at the higher end of the expected range. The total counts for each neighborhood area wood and oil-burning device used in this modeling exercise are presented in Table 9-9. Total emissions correspond with typical emissions for each unit type, and were distributed evenly across the neighborhood area. Visual representations of the neighborhoods (in the context of the large school) are presented in Figures 9-2 through 9-4. Conventional outdoor wood boiler emissions rates were assumed to be as follows (based on data reported in Gullett et al. 2013, rounded to two significant figures):

- $PM_{2.5}$ = 0.90 lb/hr
- CO = 9.3 lb/hr
- NO_2 = 0.060 lb/hr
- SO_2 = 0.066 lb/hr
- VOC [281] = 1.6 lb/hr

The $PM_{2.5}$ emission rate for the conventional outdoor wood boiler was derived from Gullett et al. (2013) using the reported daily emissions of 6.3 kg (approximately 260 g/hr or 0.58 lb/hr) and scaling by the ratio of unit sizes (250,000 Btu/hr modeled to 160,000 as tested). Other emission rates are based on emission factors reported by Gullett et al. 2013. [282] for the conventional outdoor wood boiler. Results and discussion of the neighborhood analysis are presented in Section 9.3.

281 Gullet, Brian (et al). Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater Technologies. NYSERDA, 2013.

282 Ibid.

Table 9-8. Summary of Neighborhood Scale Analysis Scenarios

Notes: AEC=advanced emission controls (e.g., baghouse, electrostatic precipitator). Chips are 45% moisture by weight.

Scenarios	Technology at a Large School	Technology at the Surrounding Residences
Scenario 1 *Business as Usual Growth*	BAU Stoker Chip Boiler (7.1 MMBtu/hr)	Projected Growth to 2023 Wood Deployment with BAU Technologies
Scenario 2 *Best Available Technology Growth*	BAT Advanced Chip Boiler w/AEC (5.1 MMBtu/hr)	2014 Deployment of BAU Units and Growth to 2023 with BAT Units
Scenario 3 *Best Available Technology Growth, with Changeouts*	BAT Advanced Chip Boiler w/AEC (5.1 MMBtu/hr)	2014 Deployment of BAU Units and Growth to 2023 with BAT Units, and 20% BAU to BAT Changeouts
Scenario 4 *Best Available Technology Growth, with Changeouts and Emerging Technology Deployment at the School*	nBAT Condensing Chip Boiler w/AEC (1.7 MMBtu/hr)	2014 Deployment of BAU Units and Growth to 2023 with BAT Units, and 20% BAU to BAT Changeouts

Table 9-9. Projected 2023 Device Counts, by Neighborhood, by Scenario

Notes: Total occupied units indicate the number of homes, which may be higher than the number of devices counted in the table because some homes use natural gas or other low-emitting fuels that are not counted here. Some fractional units are presented because units were not modeled individually.

Units	Scenario 1: BAU Growth			Scenario 2: BAT Growth			Scenarios 3 & 4: BAT Changeout		
	Mountainous Terrain, Low Density	Valley Terrain, Low Density	Flat Terrain, High Density	Mountainous Terrain, Low Density	Valley Terrain, Low Density	Flat Terrain, High Density	Mountainous Terrain, Low Density	Valley Terrain, Low Density	Flat Terrain, High Density
Total Occupied Units	**239**	**2,235**	**37,125**	**239**	**2,235**	**37,125**	**239**	**2,235**	**37,125**
Fuel Oil or Kerosene	99	181	540	99	181	540	99	181	540
Wood	67	164	267	67	164	267	67	164	267
BAU pre-NSPS outdoor cordwood boiler	2.7	5.2	4.8	2.0	4.1	4.4	1.6	3.2	3.5
BAU phase II outdoor cordwood boiler	8.7	15.1	4.5	6.4	11.8	4.1	5.1	9.4	3.3
BAU USEPA certified, catalytic cordwood stove	4.4	10.8	16.9	3.2	8.5	15.5	3.2	8.5	15.5
BAU USEPA certified, non-catalytic cordwood stove	12.7	32.5	50.6	9.3	25.4	46.5	9.3	25.4	46.5
BAU non-USEPA certified cordwood stove	31.3	80.4	125.4	23.0	62.9	115.2	18.4	50.3	92.2
BAU pellet stove	7.5	20.2	64.9	5.5	15.8	59.6	5.5	12.7	47.7
BAT USEPA certified, catalytic cordwood stove	0	0	0	14.9	31.3	20.9	19.5	47.1	55.8
BAT pellet boiler, with storage	0	0	0	3.0	4.4	0.8	4.7	7.6	2.5

Figure 9-2. Neighborhood Design for Mountainous Terrain, Low Density Location

Notes: The school building is located near the center of the receptor array. Total area of the neighborhood outlined in red is 2.75 square miles.

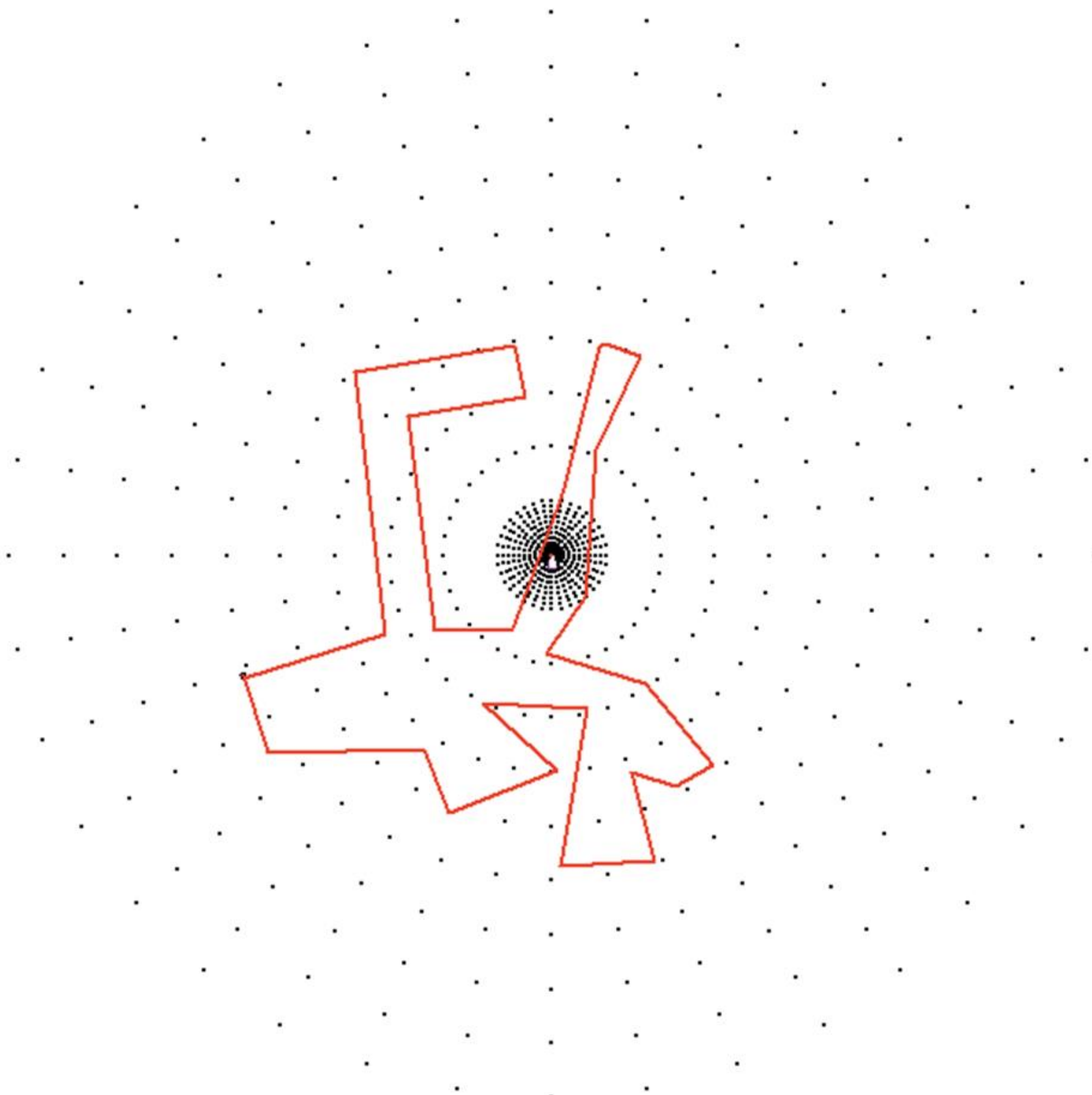


Figure 9-3. Neighborhood Design for Valley Terrain, Low Density Location

Notes: The school building is located near the center of the receptor array; total area of the neighborhood outlined in red is 15 square miles.

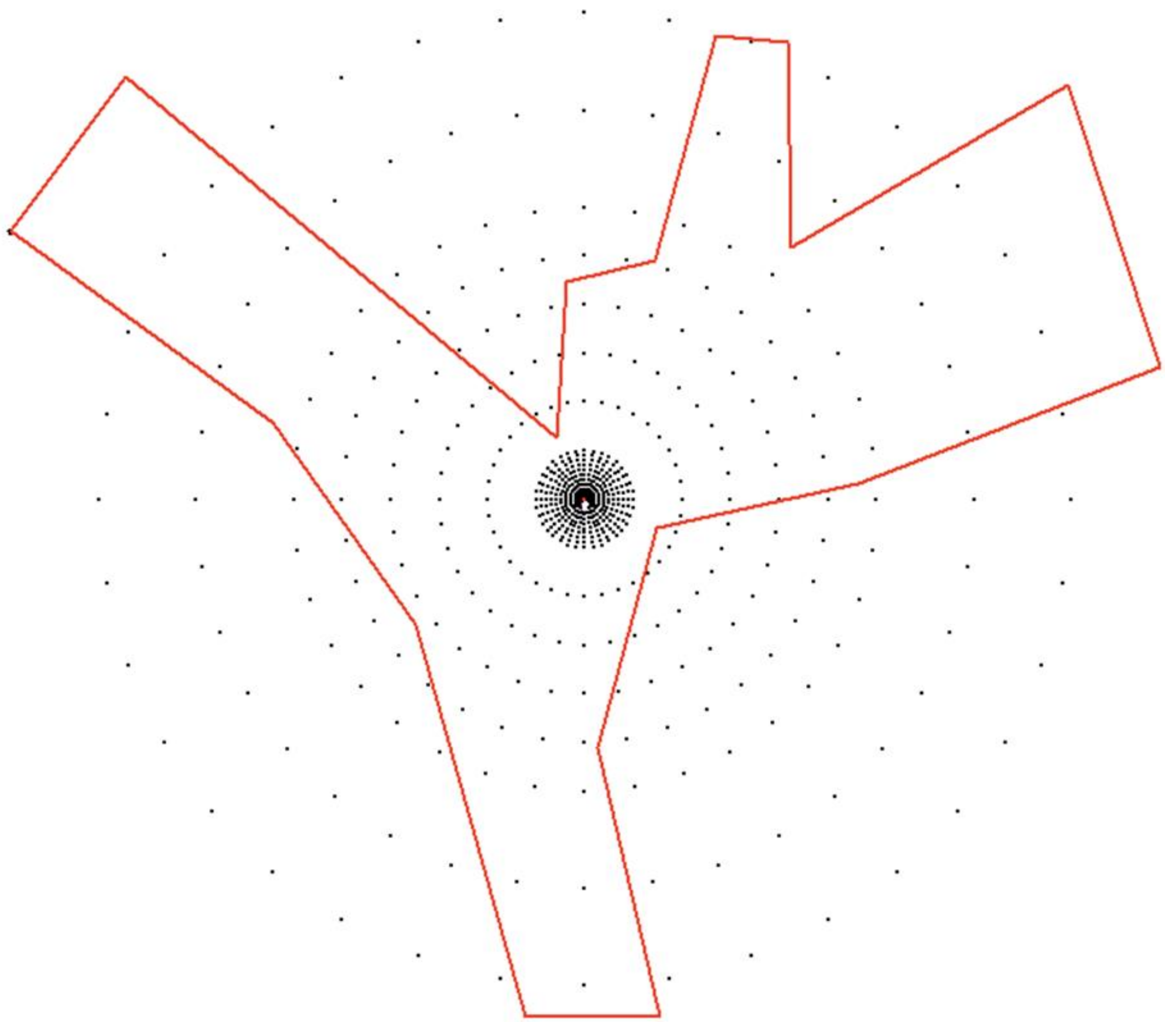
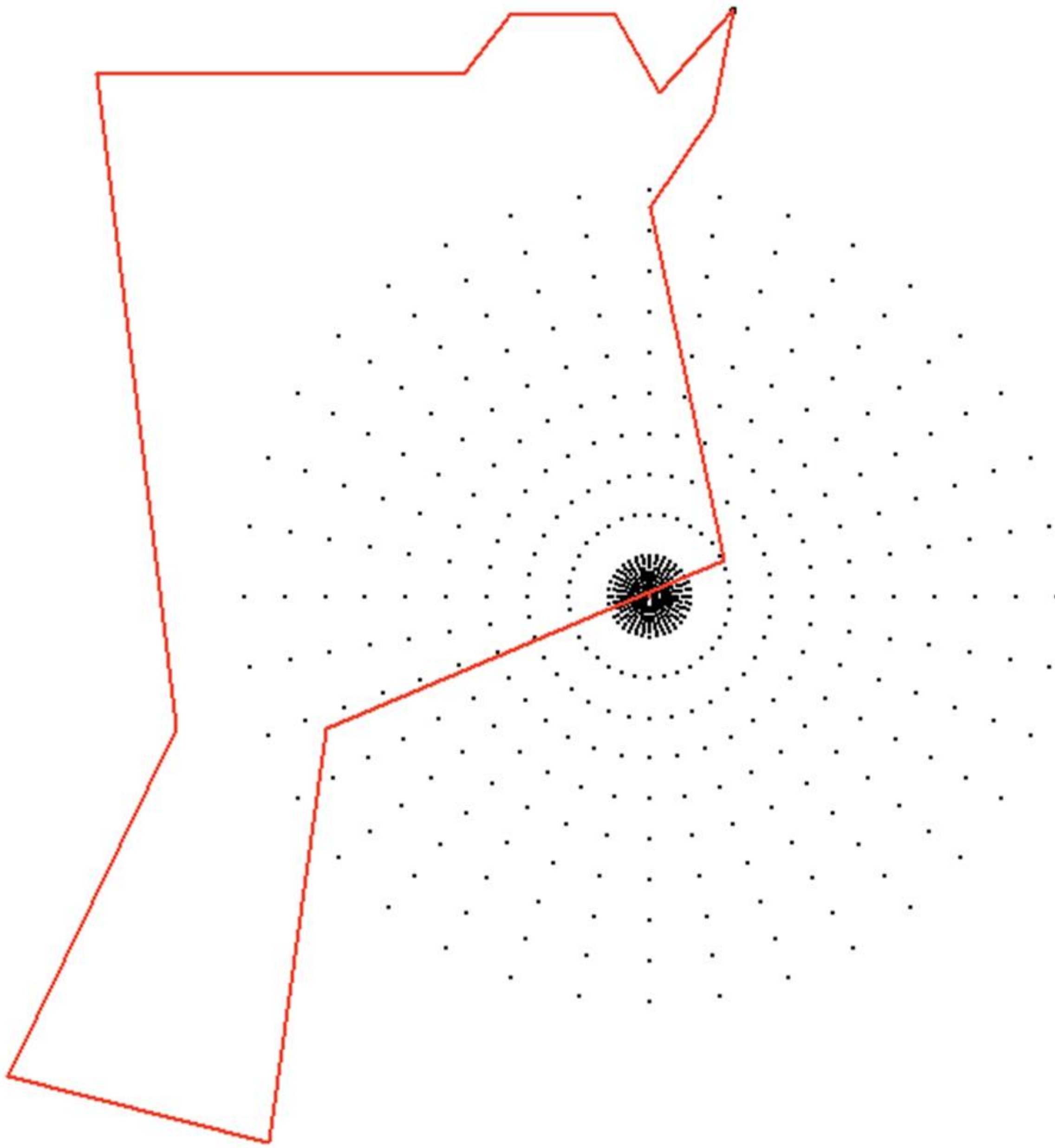


Figure 9-4. Neighborhood Design for Flat Terrain, High Density Location

Notes: The school building is located near the center of the receptor array. Total area of the neighborhood outlined in red is 25.0 square miles.



9.9 Results and Discussion for Individual Sources

This section presents and discusses results from the air quality modeling of individual wood-fired heating unit installations organized by building type for areas in NYS. For each building type, a summary table of results is presented for each pollutant that shows the range of potential impacts from each installation type across all modeled locations. The results presented in these sections incorporate both concentrations for existing conditions and direct impacts from the emissions source.

The tables in each of the following subsections present the range of highest predicted impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOC for installations at each modeled building type. These tables show the highest impacts for studied metrics for each pollutant based on typical and maximum operating scenarios, with existing conditions included when available. For annual VOC, the direct results are presented without added existing conditions, because those data are not available for that pollutant. These tables represent the highest predicted typical and maximum effects over all locations.

9.10 Large School

Tables 9-10 through 9-14 present the highest typical and maximum impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOC, respectively, at installations for large school buildings. The boiler size for each technology modeled ranged from 1.4 to 7.1 MMBtu/hr depending on the unit/installation type and is given in Table 9-2.

For all pollutants, concentrations for oil-fired units installed at the large school setting were well below the NAAQS for daily, hourly, and annual metrics.

Of the wood burning technologies, the BAU stoker chip boiler had the highest resulting $PM_{2.5}$ levels, with typical emissions resulting in 24-hour concentrations as high as 46.9 $\mu g/m^3$ (existing conditions included), and with maximum emissions resulting in 24-hour concentrations as high as 65.9 $\mu g/m^3$ (existing conditions included). Figure 9-5 shows the range of typical and maximum direct impacts for 24-hour $PM_{2.5}$ for the BAU stoker chip boiler at the mountain town location. This figure indicates that direct impacts (excluding existing conditions) at levels above 10 $\mu g/m^3$ would extend to within 150 meters of the source for typical conditions, or up to 250 meters with maximum conditions, and show that the highest impacts would occur very close (50 meters) to the school building. BAU stoker chip boilers led to annual $PM_{2.5}$ levels as high as 12.8 $\mu g/m^3$ (existing conditions included). These levels are higher than the NAAQS for $PM_{2.5}$ and indicate that operation of these BAU units at large schools represents a potential source of concern. Note that the highest levels for 24-hour and annual concentrations were modeled at the high population density area with higher existing conditions, with the 24-hour $PM_{2.5}$ at 23.0 μg/m^3 and the annual $PM_{2.5}$ at 8.7 μg/m^3. These levels were already elevated and therefore even typical operation of BAU wood burning units at these large schools may lead to levels higher than the NAAQS. Even for BAU stoker chip boiler installations in more rural areas with lower existing conditions for $PM_{2.5}$, the 24-hour levels for both typical and maximum emissions scenarios were still higher than the NAAQS, but annual average concentrations are lower than the NAAQS. The 1-hour $PM_{2.5}$ levels under the typical and maximum emissions from the BAU stoker chip boiler were 115 μg/m^3 and 186 μg/m^3, respectively. These levels were the highest among all 1-hour concentrations assessed for institutional buildings.

The modeled $PM_{2.5}$ levels from the BAT technologies were below the $PM_{2.5}$ NAAQS, and were lower than from the BAU stoker chip boiler, but were higher than from the BAU oil boiler. The lowest levels from the BAT technologies were from the RHNY-qualified two-stage gasification pellet boiler heating system, which has thermal storage. The RHNY program includes two distinct $PM_{2.5}$ emission factor limits, and both were assessed in this analysis. The resulting concentrations for the annual $PM_{2.5}$ levels were similar between the two RHNY emission factors, but the 24-hour $PM_{2.5}$ levels were around 2 μg/m^3 lower for the "institutional" factor, designated for installation in areas with sensitive populations such as schools and health care facilities. The $PM_{2.5}$ levels for the RHNY-qualified commercial boilers are lowest among BAT units because the installations are required to meet careful sizing and system integration requirements. These commercial building heating system retrofits retained the existing operational oil-fired boiler as a back-up and supplemental heat source. This design allowed for a boiler with considerably smaller maximum output rating (60% of peak design-day load) to be installed. These units run at maximum efficiency more often (i.e., have more full-load hours of operation) than for units sized at 100% of peak load (or larger).

The RHNY pellet-fired heating systems are also required to be installed with thermal storage, which allows the boiler to operate for fewer total hours and at higher loads than pellet boiler heating systems that do not have thermal storage capacity. Sizing the pellet boiler at 60% of peak load, the maximum allowed in RHNY for large commercial systems, meets an estimated 93% of annual heating needs. The remaining heating needs, during peak periods or very early or late in a heating season, can be met with the back-up oil-fired boiler.

Examination of pollutant dispersion for the RHNY-qualified BAT pellet units and the BAU stoker chip boiler and conventional BAT pellet boiler reveals the extent to which the RHNY program may reduce impacts from wood boilers at schools. Figure 9-6 shows dispersion around the large school building at the mountain town location for these four unit types under the maximum emission scenario. This figure presents the four units in highest to lowest impact levels from top left to bottom right. The highest localized impacts at the school for all units occurs very near to the source, as marked by the "+" symbol. Each dot represents a receptor in the receptor grid, and the box at the center represents the large school. Colored areas show the domain in which direct resulting concentrations are within bounds as indicated in the color scale. Grey (5-10), slate blue (2-5), and white (0-2), as noted in the footnote, represent levels below 10 $\mu g/m^3$, while other colors represent levels above 10 $\mu g/m^3$ as marked. The highest level for the BAU chip stoker boiler is 51 $\mu g/m^3$, though that level is constrained to a very small area, barely visible in the figure.

However, a wide area is affected by the emissions from the BAU boiler at levels above 5 $\mu g/m^3$. As shown in part B of Figure 9-6, the BAT 2-stage gasification pellet boiler has considerably less widespread impact and lower overall levels, though direct impacts over a wide area within 150 meters of the school are above 5 $\mu g/m^3$. Installation of the RHNY-qualified unit (commercial specifications) addresses the majority of the impacts at the 24-hour metric for $PM_{2.5}$, though effects in the downwash of the school remain above 5 $\mu g/m^3$ in a limited area near the school. Finally, the institutional specifications for the RHNY-qualified boiler drives the resulting concentrations to approximately 2 $\mu g/m^3$ or less, minimizing impacts on the children at the school. This analysis demonstrates the potential effectiveness of the more stringent RHNY institutional requirements in reducing exposures to harmful air pollutants for sensitive populations.

Figure 9-5. Predicted 24-Hour $PM_{2.5}$ Concentrations for Stoker Chip Boiler at Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

Notes: Typical (left) and maximum (right) impacts. Concentrations are in µg/m^3; + marks the location of the maximum modeled concentration. Direct impacts (excluding existing conditions) levels above 10 µg/m^3 would extend to within 150 meters of the source for typical conditions, or up to 250 meters in maximum conditions. The highest impacts would occur very close (50 meters) to the school building.

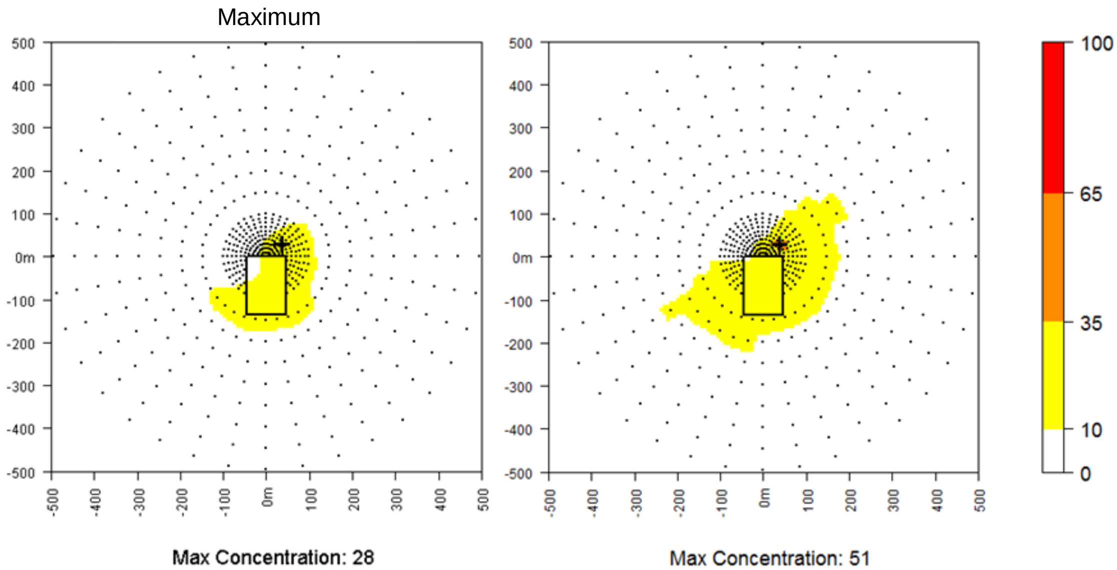
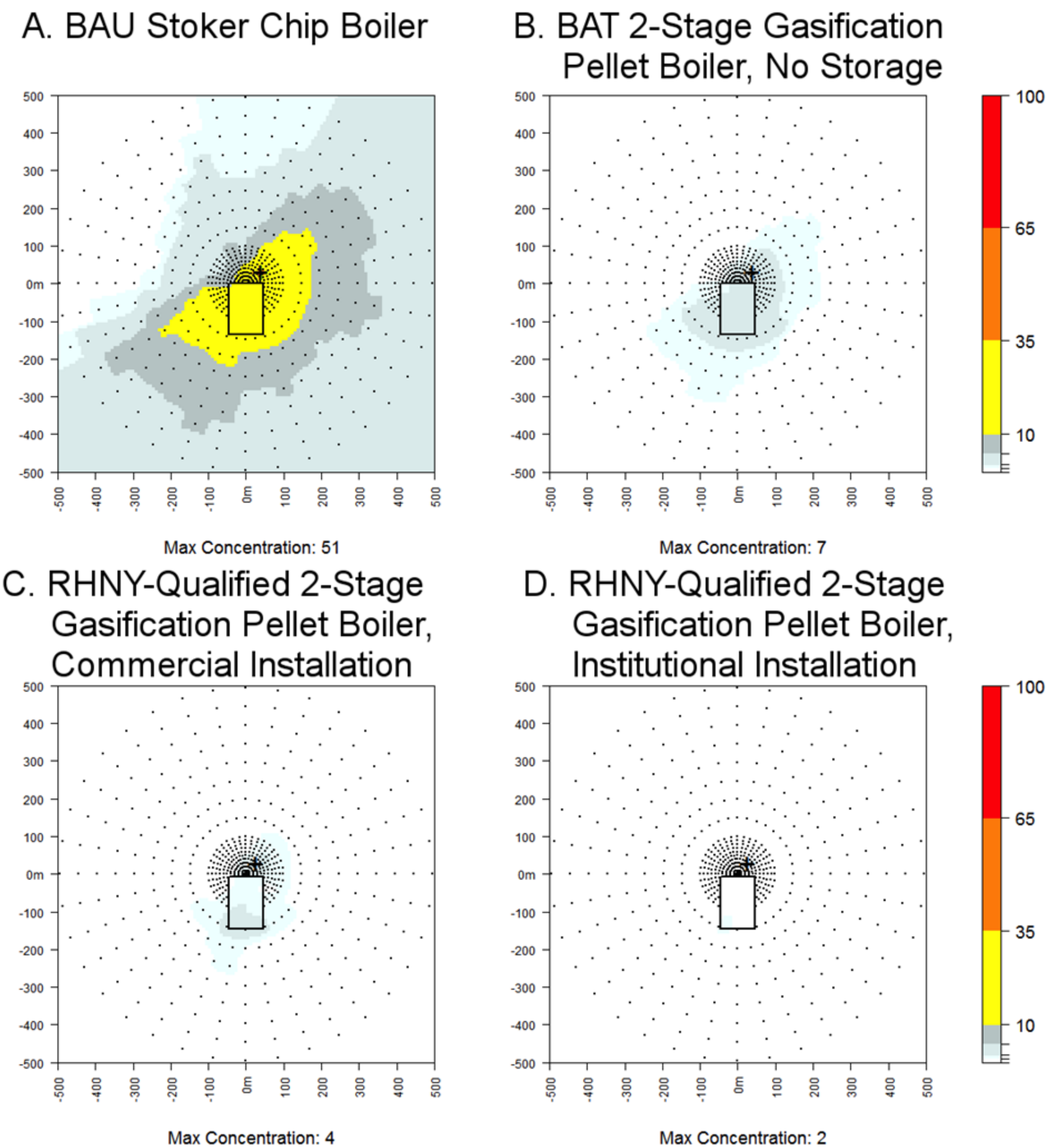


Figure 9-6. Comparison of Maximum 24-Hour $PM_{2.5}$ Levels for RHNY-Qualified Pellet Boilers Against Non-Qualified Boilers at the Large School in the Mountain Town Location, No Existing Conditions

Notes: Low-end scale colors are white (0-2 μg/m^3), slate blue (2-5 μg/m^3), grey (5-10 μg/m^3). All concentrations are μg/m^3. + marks the location of the maximum modeled concentration. Plots are ordered in highest to lowest emissions from top left to bottom right.



$PM_{2.5}$ levels resulting from the nBAT technologies are comparable to those from the oil-fired boiler, though slightly higher, due to their somewhat higher emission rates.

BAU chip stoker boilers also had the highest VOC concentrations, with levels as high as 1.20 $\mu g/m^3$. There is no federal health-based standard or threshold for VOCs. Annual VOC levels from the BAT units ranged from 0.46 to 0.50 $\mu g/m^3$, and annual VOC levels from the nBAT units were between 0.23 and 0.24 $\mu g/m^3$.

NO_2 was assessed under a two-tier approach. Tier 1 assumed that 100% of NO_x is NO_2, and Tier 2 assumed that 80% of NO_x is NO_2. NO_2 concentrations were elevated for BAU stoker chip boilers and even higher for non-RHNY-qualified BAT boilers under both Tier 1 and Tier 2 assumptions. The NO_2 levels from the RHNY-qualified units are lower than those from other BAT units, even assuming the same emission factors,[283] reflecting the difference in the unit sizing. The BAT boiler was higher than the BAU stoker chip boiler because these units do not control for NO_x emissions. The combustion temperature is higher in BAT boilers, leading to greater efficiency but also greater NO_x creation, which results in the higher BAT NO_x emissions. Smaller unit size for the nBAT units reduces NO_x emissions considerably. As an additional sensitivity analysis, the RHNY-qualified pellet boilers were assessed using emission factors derived based on measurements from the boiler at the Wild Center.[284]

As presented in Table 9-12, several units had NO_2 levels above the standard under Tier 1 and/or Tier 2. Because of the conservatism of the inputs to this analysis, a sensitivity case was examined to determine the extent to which emission rates and NO_2 to NO_x ratios affect the potential for exceedances of the standard. Testing data from the Wild Center were used as the basis for this sensitivity scenario. Although this sensitivity is based on only one series of measurements, the results indicate that there may be considerably lower NO_2 concentrations resulting from wood-fired boilers, even under the Tier 1 assumption. Using the highest observed NO_2 to NO_x ratio of 12%[285] for Tier 2, the levels drop to nearly those of the existing conditions, well below the NAAQS (and lower than levels from the oil boiler). These sensitivity results raise questions about whether 1-hour NO_2 is a significant health risk

[283] Musil Schlaffer 2010.

[284] Hopke 2010.

[285] Hopke 2010.

at these types of installations, and suggests that further research, including stack testing, into typical NO_2 emission rates and in-stack NO_2 to NO_x fractions is warranted. Therefore, NO_2 may be present at health-relevant levels, and is a pollutant that should be studied further at these types of installations; however, NO_2 results should be interpreted cautiously in this analysis. NO_2 levels from nBAT units are below the NAAQS as with the RHNY-qualified BAT units, reflecting the lower unit sizes for these units.

Concentrations for CO and SO_2 were well below the NAAQS (relative to the federal health-based standard) for all assessed installation types at all locations.

Impacts from advanced two-stage gasification chip boilers using 30% moisture content fuel are comparable to those from advanced two-stage gasification chip boilers using 45% moisture content chips, as conventionally used. Moisture content in fuels is inversely correlated with thermal efficiency. Water must be heated until it evaporates and is exhausted, and it contains no heating value. Furthermore, boilers burning higher moisture fuels must burn more fuel to achieve the same heat load. As discussed earlier, the gain in efficiency was assumed to be 3.4% for switching from 45 to 30% moisture content fuel in the advanced two-stage gasification chip boiler, based on data from BioEnergy2020+. In this analysis, units burning lower moisture content fuels were assumed to achieve identical heat load for all timescales. For this assumption to be the case, the primary difference between higher and lower moisture content fuel, other than the change in efficiency, is the exit gas velocity. Higher moisture fuels will have higher exit velocity because of the greater mass of fuel that must be burned to achieve equal heat load, and therefore a greater volume of exhaust will pass through the stack per unit time. Therefore, the effect of greater exit velocity (and thus greater dispersion) from burning higher moisture content chips partially counters the effect of burning fewer lower moisture content chips (due to higher efficiency combustion), making the emission impacts comparable between lower and higher moisture content chips.

For the BAT chip boilers, typical impacts are slightly lower while maximum impacts are slightly higher when comparing lower moisture content chips to higher moisture content chips for 1-hour $PM_{2.5}$ and NO_2. For SO_2 and VOC, impacts for higher moisture chips result in higher typical impacts but equal maximum impacts. These effects are likely the result of the interplay between the higher emission rate for the higher moisture content chips against the increased exit velocity. When higher moisture content fuels are used, the higher exit velocity compensates for the higher emission rates resulting in similar or even lower impacts; in the typical scenario, the exit velocities are more similar so the higher emissions tend to dominate over the differences in exit velocity. For the nBAT boilers, impacts from the lower moisture content chips were lower or equal for $PM_{2.5}$ and NO_2 but slightly higher for SO_2. For these units, the exhaust gas velocity is already quite low for the 45% moisture content chips, so reducing the emission rate through use of the more-efficient lower moisture chips has a stronger effect in reducing ground-level concentrations than does reducing the exit velocity in increasing concentrations. SO_2 may not follow the same trend because the form of the metric (second highest level) is prone to more variability than for the other 1-hour metrics (8th highest daily maximum).

Impacts from boilers using pellet fuels, which have moisture content in the range of 6 to 8%, were lower than chip boilers for comparable technology categories for $PM_{2.5}$, NO_2, SO_2, and VOC, but not considerably different for CO. Annual concentrations were only slightly lower ($PM_{2.5}$ and VOC), while concentrations at the 1-hour timescale ($PM_{2.5}$, NO_2, and SO_2) show the greatest differences. The CO impacts are not noticeably different because the direct impacts for CO are very low. In other words, because the mass of CO emitted is very small, unless CO concentrations are very high, there are few impacts to the ambient air.

In summary, based on this analysis, BAU wood boilers at large schools can produce emission levels near or above relevant air quality standards for $PM_{2.5}$ when those emissions are added to the emissions from existing conditions during even typical operation, while CO and SO_2 remain low for all studied boiler types. Existing conditions for $PM_{2.5}$ and NO_2 can be elevated in some communities (see Table 9-7), making it more likely that the additional emissions from higher emitting units will result in overall levels above the level of the NAAQS for these pollutants. The general trend of impacts was consistent with emission rate data of the various technologies, with BAU wood units generally producing the greatest impacts, moderate impacts from BAT, and very low impacts from nBAT due to small unit size and low emission rates. RHNY-qualified units, which incorporate thermal storage, had very greatly improved pollutant levels, on par with or below levels for nBAT units. Oil-fired units produced low impacts; even so, the nBAT units were often only slightly above the oil boiler results. Sensitivity analysis results for NO_2 for in-stack ratios indicate that the conservative analysis for NO_2 may result in overestimates of NO_2 levels. Further research is needed on NO_2 emissions for small wood boilers.

Table 9-10. Highest Predicted $PM_{2.5}$ Concentrations for Large School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Values rounded to the nearest tenth of a microgram per cubic meter. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. For technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage. Unit sizes are reported to three significant figures. RHNY-qualified pellet boilers were not assessed for 1-hour $PM_{2.5}$. 1-hour average existing conditions are biased low (Felton 2009).

	Unit Size (Btu)	Concentration (μg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		**T**	**M**	**T**	**M**	
Applicable Air Quality Standard		None	None	35.0	35.0	12.0
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	22.0	22.0	23.0	23.0	8.7
Stoker Chip Boiler	7,130,000	115.1*	186.3*	46.9*	65.9*	12.8*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	50.6	52.4	30.8	30.5	10.0
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	49.5	54.4	30.6	31.0	10.0
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	42.4	45.2	29.3	28.8	9.8
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	26.0	27.3	9.1
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	24.1	24.6	8.9
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	23.4	24.0	23.5	23.7	8.8
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	23.4	24.0	23.4	23.7	8.8
Condensing Pellet Boiler w/AEC	1,710,000	23.2	23.5	23.4	23.5	8.8

Table 9-11. Highest Predicted CO Concentrations for Large School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Values rounded to the nearest 0.1 ppm. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. No technologies modeled for the large school analysis for CO incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	7,130,000	1.5*	1.2*	0.9*	0.7*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	1.2	1.2	0.8	0.8
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	1.2	1.2	0.8	0.8
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	1.2	1.2	0.8	0.8
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	1.1	1.2	0.7	0.7
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.1	1.2	0.7	0.7
Condensing Pellet Boiler w/AEC	1,710,000	1.1	1.2	0.7	0.7

Table 9-12. Highest Predicted NO_2 Concentrations for Large School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Values rounded to the nearest microgram per cubic meter. For technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage. Applied emission factors based on both European testing data (Musil-Schlaffer 2010) and the Wild Center (Hopke 2010) for the RHNY-qualified 2-stage gasification pellet boiler. Tier 2 analysis assumes 80% of NO_x is NO_2, except for the RHNY-qualified 2-stage gasification pellet boiler using the emission factor from Hopke (2010), which assumes 12% conversion based on the testing data. Unit sizes are reported to three significant figures. The suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

	Unit Size (Btu)	1-Hour Concentration (μg/m^3)			
		Tier 1 (100% of NOx is NO_2)		Tier 2	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		188	188	188	188
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	163	163	152	152
Stoker Chip Boiler	7,130,000	206	221	187	198
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	243	263	216	233
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	238	270	213	238
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	207	226	188	203
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Musil-Schlaffer Emission Factor	1,430,000	176	176	163	163
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Hopke Emission Factor and NO_2 to NOx Ratio	1,430,000	128	128	112	112
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	180	205	166	186
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	179	203	165	185
Condensing Pellet Boiler w/AEC	1,710,000	170	179	158	165

Table 9-13. Highest Predicted SO_2 Concentrations for Large School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Values rounded to the nearest microgram per cubic meter. No technologies modeled for the large school analysis for SO_2 incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration ($\mu g/m^3$) 1-hour	
T=Typical, M=Maximum		**T**	**M**
Applicable Air Quality Standard		196	196
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	11	11
Stoker Chip Boiler	7,130,000	23	24
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	20	20
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	20	21
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	19	20
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	15	17
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	16	17
Condensing Pellet Boiler w/AEC	1,710,000	15	17

Table 9-14. Highest Predicted VOC Concentrations for Large School Setting for the Three Regional Locations (No Existing Conditions)

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight unless otherwise noted. Values rounded to the nearest 0.01 microgram per cubic meter. No technologies modeled for the large school analysis for VOC incorporated thermal storage. Unit sizes are reported to three significant figures.

		Concentration (μg/m^3)
	Unit Sizes (Btu)	**Annual: Typical**
Applicable Air Quality Standard		None
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.21
Stoker Chip Boiler	7,130,000	1.20
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.49
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	0.50
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	0.46
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.24
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	0.24
Condensing Pellet Boiler w/AEC	1,710,000	0.23

9.11 Small School

Tables 9-15 through 9-19 present the highest typical and maximum impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOCs at installations for small school buildings. For the small school analysis, no technologies were modeled with thermal storage. The boiler size for each technology modeled ranged from 1.0 to 3.4 MMBtu/hr depending on the unit/installation type and is given in Table 9-2.

As with the units at the large school, concentrations for all pollutants from the oil-fired units using ultra-low sulfur oil at the small school were the lowest of assessed technologies, and were well below the air quality standard levels.

Though the highest $PM_{2.5}$ emissions were from the BAU stoker chip boiler, the highest resulting 24-hour average $PM_{2.5}$ levels were from the relatively cleaner burning BAT containerized two-stage gasification pellet boiler with a 14-ft stack. The typical operation of a BAU stoker chip boiler with a 45-ft stack results in 24-hour average $PM_{2.5}$ concentrations as high as 31.1 $\mu g/m^3$, whereas typical operation of the BAT containerized pellet boiler with the 14-ft stack results in levels as high as 41.5 $\mu g/m^3$ (existing conditions included). Maximum operation of these units results in levels as high as 40.1 $\mu g/m^3$ and 48.2 $\mu g/m^3$ (existing conditions included), respectively. These results highlight the critical influence that stack height can have on ground-level concentrations, indicating that improper installation can negate potential improvements from cleaner burning technologies.

Design, planning, and construction of the exhaust stack is a critical element of pollution control, in addition to the choice of wood-burning technology. For the BAU unit, high 24-hour levels resulting from maximum operation of BAU stoker chip boilers may be higher than the NAAQS for $PM_{2.5}$, indicating a potential health concern. It is of interest that the BAT pellet unit (14-ft stack) has the highest levels, though only for the area with flat terrain; for other locations, the BAU stoker chip boiler has the highest results with levels slightly above the NAAQS for 24-hour $PM_{2.5}$. Once the stack height is increased to 25-ft, the containerized BAT pellet boiler results in much lower levels that are 1 to 3 $\mu g/m^3$ higher than from the oil boiler. 1-hour $PM_{2.5}$ levels for the BAU stoker chip boiler are considerably higher than those from any other assessed technology type at the small school.

The non-containerized BAT pellet boiler, which has a 40-ft stack, resulted in lower 1-hour $PM_{2.5}$ levels than the BAT containerized pellet boiler with a 25-ft stack, but the 24-hour and annual average $PM_{2.5}$ values for it are only slightly lower. Annual $PM_{2.5}$ levels were minimal, below the NAAQS for all unit types and dominated by the existing conditions; the highest annual $PM_{2.5}$ highest levels were from the BAT containerized pellet boiler with a 14-ft stack.

$PM_{2.5}$ levels resulting from the nBAT condensing pellet boiler are nearly equivalent to those from the oil-fired boiler and are well below all standard thresholds. The differences in emissions from nBATs compared to BATs are due to both small unit size and lower emission rates.

The two-tier approach was used for NO_2, with Tier 1 assuming that 100% of NO_x is NO_2, and Tier 2 assuming that 80% of NO_x is NO_2. As presented in Table 9-17, for the unit with the 14-ft stack, the modeled levels are significantly higher than the standard for under both Tier 1 and Tier 2 of the analysis. These results indicate the potential for significant impacts for NO_2 from sources with insufficient emission height. Note that these assumptions may be biased high, as indicated in the sensitivity analysis performed for the RHNY-qualified installation at the large school using the in-stack ratio and emission factor derived from testing performed at the Wild Center. [286] See the discussion about large schools in the previous section for further details regarding NO_x assumptions. Levels for large, central installations of pellet boilers for the BAU, BAT, and nBAT technology categories have effects that are lower than the NO_2 standard, with the highest levels from the BAT technology. The BAT boiler was higher than the BAU boiler because these units do not control for NO_x emissions. The combustion temperature is higher in BAT boilers, leading to greater efficiency but also greater NO_x creation, which results in the higher BAT NOx emissions. Smaller unit size for the nBAT units reduces NO_x emissions considerably. The BAT containerized pellet boilers resulted in considerably higher levels compared to the other studied units, and resulted in levels above the level of the standard based on the conservative Tier 1 and Tier 2 assumptions with existing conditions included. These results indicate that containerized wood-fired boilers without proper NO_x emission controls may result in concentrations of potential concern, though further research is warranted to determine if low in-stack ratios of NO_2 to NO_x may reduce the potential for unacceptably high levels to occur.

[286] Hopke 2010.

Concentrations for CO and SO_2 were well below the standard for all assessed installation types at the small school at all locations.

The influence of both technology choice and stack height are also apparent in the VOC results. The highest direct VOC impacts were from the BAT pellet boiler with a 14-ft stack, while levels from the BAT pellet boiler with a 25-ft stack and the BAU pellet boiler were similar. A BAT pellet boiler with a typical in-building installation (40-ft stack) resulted in considerably lower direct annual VOC impacts compared to the BAT containerized pellet boilers due to the increased stack height, and compared to the BAU stoker chip boiler due to the lower emission rate.

To summarize, impacts at a small school from the highest emitting units, or improperly installed units, can be substantial, despite the fact that units are considerably smaller than those at a large school. Daily and subdaily $PM_{2.5}$ levels at the small school for the highest emitting units can reach levels approaching the standard in some areas. Annual VOC impacts are dependent on selection of technology/fuel type and stack height. The modeling data indicated that considerable near-source air quality improvement can be achieved by selecting cleaner-burning units compared to conventional technologies, even in small institutional settings. The results also indicated that proper siting and installation are key to realizing these improvements. Levels of CO and SO_2 remain low for all studied boiler types. Levels of NO_2 may be high for BAU, BAT, and nBAT units, assuming high in-stack ratios of NO_2 to NO_x. However, interpretation of NO_2 results in this analysis must be cautious, as indicated in the results of the sensitivity analysis in the large school setting. Further research on these in-stack levels is needed to determine the extent to which NO_2 exposure may or may not be problematic as a result of single installations of wood-fired boilers.

Table 9-15. Highest Predicted $PM_{2.5}$ Concentrations for Small School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest tenth of a microgram per cubic meter. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. No technologies modeled for the small school analysis incorporated thermal storage. Unit sizes are reported to three significant figures. 1-hour average existing conditions are biased on the low side (Felton 2009).

	Unit Size (Btu)	**Concentration (μg/m³)**				
		1-hour		**24-hour**		**Annual**
T=Typical, M=Maximum		**T**	**M**	**T**	**M**	
Applicable Air Quality Standard		None	None	35.0	35.0	12.0
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	22.0	22.0	23.0	23.0	8.7
Stoker Chip Boiler	3,390,000	97.6*	158.0*	31.1*	40.1*	9.6*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack	1,710,000	66.8	81.3	41.5	48.2	11.3
Containerized 2-Stage Gasification Pellet Boiler w/25-ft Stack	1,710,000	48.7	49.7	25.3	26.8	9.0
2-Stage Gasification Pellet Boiler	3,410,000	34.3	45.1	24.6	25.1	8.9
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	22.5	22.9	23.1	23.1	8.7

Table 9-16. Highest Predicted CO Concentrations for Small School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest 0.1 ppm. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. No technologies modeled for the small school analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		35	35	9	9
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	3,390,000	1.5*	1.2*	0.8*	0.7*
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack	1,710,000	1.3	1.4	0.8	0.9
Containerized 2-Stage Gasification Pellet Boiler w/25-ft Stack	1,710,000	1.2	1.2	0.7	0.8
2-Stage Gasification Pellet Boiler	3,410,000	1.2	1.2	0.7	0.7
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	1.1	1.1	0.7	0.7

Table 9-17. Highest Predicted NO_2 Concentrations for Small School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions; AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter. No technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

	Unit Size (Btu)	1-Hour Concentration (μg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		188	188	188	188
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	127	127	123	123
Stoker Chip Boiler	3,390,000	148	147	140	139
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack	1,710,000	376	462	323	392
Containerized 2-Stage Gasification Pellet Boiler w/25- Stack	1,710,000	208	257	188	228
2-Stage Gasification Pellet Boiler	3,410,000	156	160	147	150
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	133	144	128	137

Table 9-18. Highest Predicted SO_2 Concentrations for Small School Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest microgram per cubic meter. No technologies modeled for the small school analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration (µg/m³) 1-hour	
T=Typical, M=Maximum		**T**	**M**
Applicable Air Quality Standard		196	196
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	10	10
Stoker Chip Boiler	3,390,000	17	17
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack	1,710,000	32	39
Containerized 2-Stage Gasification Pellet Boiler w/25-ft Stack	1,710,000	18	22
2-Stage Gasification Pellet Boiler	3,410,000	16	16
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	13	14

Table 9-19. Highest Predicted VOC Concentrations for Small School Setting for the Three Regional Locations (No Existing Conditions)

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest 0.01 microgram per cubic meter. No technologies modeled for the small school analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration ($\mu g/m^3$)
		Annual: Typical
Applicable Air Quality Standard		None
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.04
Stoker Chip Boiler	3,390,000	0.30
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack	1,710,000	0.89
Containerized 2-Stage Gasification Pellet Boiler w/25-ft Stack	1,710,000	0.33
2-Stage Gasification Pellet Boiler	3,410,000	0.11
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	0.05

9.12 Hospital

Tables 9-20 through 9-24 present the highest typical and maximum impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOC at installations for hospitals. For the hospital analysis, no technologies were modeled with thermal storage. The boiler size for each technology modeled ranged from 1.7 to 7.1 MMBtu/hr depending on the unit/installation type and is indicated in Table 9-2.

Results for all pollutants and all metrics except NO_2 followed expected trends based on emission rates from BAU, BAT, and nBAT technology categories. Concentrations for all pollutants from the oil-fired units using ultra-low sulfur oil at the hospital were the lowest of assessed technologies, and were well below the standard levels. The BAU stoker chip boiler had the highest emission rates and subsequently the highest direct impacts among studied units. The BAT advanced chip boiler (with advanced emission controls [AEC]), smaller in size and with greater efficiency and emission controls than the BAU stoker chip boiler, had the next higher impacts, and the nBAT condensing chip boiler, smallest and most efficient and advanced of the studied wood burning units, had levels on par with existing conditions.

The one exception to this trend was for NO_2, where, as with the schools, the BAT technology resulted in higher impacts than did the BAU stoker chip boiler. The BAT boiler was higher than the BAU boiler because of the higher combustion temperature and lack of post-combustion control. Though much of the heat is transferred prior to exhaust (leading to greater efficiency), the higher combustion temperature leads to greater NO_x emissions. The smaller unit size for nBAT units reduces NO_x emissions considerably compared to the BAT or BAU units. As with the schools, the analysis for NO_2 included a two-tier approach, with Tier 1 assuming that 100% of NO_x is NO_2, and Tier 2 assuming that 80% of NO_x is NO_2. Note that these assumptions may be biased on the high side, as indicated in the sensitivity analysis performed for the RHNY-qualified installation at the large school using the in-stack ratio and emission factor derived from testing performed at the Wild Center (Hopke 2010). See the discussion about large schools in the previous section for further details regarding NO_2 assumptions. Further research is warranted to validate or provide evidence against the existence of near-source impacts for NO_2 from small commercial/institutional wood boilers.

Concentrations for CO and SO_2 were well below the standard for all assessed installation types at the hospital at all locations.

Table 9-20. Highest Predicted $PM_{2.5}$ Concentrations for Hospital Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. No technologies modeled for the hospital analysis incorporated thermal storage. Unit sizes are reported to three significant figures. 1-hour average existing conditions are biased on the low side (Felton 2009).

	Unit Size (Btu)	Concentration (μg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		**T**	**M**	**T**	**M**	
Applicable Air Quality Standard		None	None	35.0	35.0	12.0
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	22.0	22.0	23.0	23.0	8.7
Stoker Chip Boiler	7,130,000	106.6*	166.9*	38.1*	52.1*	13.5*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	46.8	48.3	28.2	27.6	10.3
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	23.3	23.7	23.3	23.4	8.8

Table 9-21. Highest Predicted CO Concentrations for Hospital Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest 0.1 ppm. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. No technologies modeled for the hospital analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		35	35	9	9
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	7,130,000	1.5*	1.2*	0.9*	0.7*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	1.2	1.2	0.8	0.8
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	1.1	1.1	0.7	0.7

Table 9-22. Highest Predicted NO_2 Concentrations for Hospital Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest microgram per cubic meter. No technologies modeled for the hospital analysis incorporated thermal storage. Unit sizes are reported to three significant figures. The suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

	Unit Size (Btu)	1-Hour Concentration (μg/m^3)			
		Tier 1 (100% of NO_x is NO_2)		Tier 2 (80% of NO_x is NO_2)	
T=Typical, M=Maximum		**T**	**M**	**T**	**M**
Applicable Air Quality Standard		188	188	188	188
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	141	141	135	135
Stoker Chip Boiler	7,130,000	191	198	175	180
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	223	234	200	210
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	158	187	149	171

Table 9-23. Highest Predicted SO_2 Concentrations for Hospital Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest microgram per cubic meter. No technologies modeled for the hospital analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Concentration ($\mu g/m^3$) 1-hour	
T=Typical, M=Maximum		**T**	**M**
Applicable Air Quality Standard		196	196
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	11	11
Stoker Chip Boiler	7,130,000	21	21
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	18	18
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	14	16

Table 9-24. Highest Predicted VOC Concentrations for Hospital Setting for the Three Regional Locations (No Existing Conditions)

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator). Chips are 45% moisture by weight. Values rounded to the nearest 0.01 microgram per cubic meter. No technologies modeled for the hospital analysis incorporated thermal storage. Unit sizes are reported to three significant figures.

		Concentration ($\mu g/m^3$)
	Unit Size (Btu)	**Annual: Typical**
Applicable Air Quality Standard		None
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.16
Stoker Chip Boiler	7,130,000	1.43
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.56
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.28

9.13 Residential

Tables 9-25 through 9-29 present the highest typical and maximum impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOCs at installations for homes using residential central heating and residential space heating. For the residential analysis, three technologies (BAT pellet, BAT advanced cordwood, and nBAT condensing pellet boiler) were modeled with thermal storage; all others were modeled without thermal storage. The boiler output ratings for each technology modeled ranged from 51,000 to 208,000 Btu/hr, depending on the unit/installation type, and are provided in Table 9-2. Residential space heaters ranged in output capacity from 51,000 to 60,000 Btu/hr.

Concentrations from the oil-fired units using ultra-low sulfur heating oil at the residential setting were the lowest of assessed technologies for $PM_{2.5}$, CO, NO_2, SO_2, and VOCs. These levels were below the applicable standards.

Resulting levels of $PM_{2.5}$ from the BAU phase II outdoor cordwood boiler were the highest among all assessed technologies. These levels reach a 1-hour average of as high as 111 μg/m^3 for a typical emissions scenario, or 261 μg/m^3 under the maximum emissions scenario, existing conditions included. For context, a 2013 NYS Department of Health testing study for conventional outdoor wood boilers [287] found maximum concentrations comparable and higher than those described in Table 9-25 of this report, though direct comparison is hindered by different data reporting in the two documents. A NESCAUM study found levels of woodsmoke PM to be as high as 35 μg/m^3 during the period of study at a stationary monitoring location observing neighborhood-scale sources. [288] For the 24-hour average, levels reach as high as 52.7 μg/m^3 for typical conditions and 106.7 μg/m^3 for the maximum emissions scenario for the phase II outdoor cordwood boiler.

Dispersion plots for 24-hour levels of $PM_{2.5}$ for the mountain town location and 1-hour levels for the valley town location are presented in Figure 9-7 and Figure 9-8, respectively, for the BAU phase II outdoor cordwood boiler. These figures present both typical and maximum levels. Figure 9-7 demonstrates the extremely high levels that can occur both within the immediate vicinity of the home, with highest impacts at 30 meters, and the impact on nearby locations, extending beyond 100 meters from the source with direct impacts (i.e., levels without existing conditions added) above 10 μg/m^3. The importance of terrain and building downwash are also evident, as these areas of impact are highest behind the structure and in the lower-lying areas. Annual levels are as high as 16.6 μg/m^3 (including existing conditions).

Levels from the phase II outdoor cordwood boiler are the highest levels presented in this analysis for any building type or unit type, and are above the level of the applicable standards for 24-hour and annual metrics. Note that emissions from this source type were calculated based on stack measurements as reported in Gullett et al. (2012), as opposed to the use of emission factors. The phase II outdoor cordwood boiler emission rate is about six times higher than the maximum allowable emission rate from the 2015 New Source Performance Standards (NSPS) for outdoor cordwood boilers, which allow units

287 NYS DOH 2013

288 NESCAUM 2010.

to emit during testing at no higher than 18 grams $PM_{2.5}$ per hour.[289] The unit presented in this analysis (as tested) would not comply with the 2015 NSPS. Because of the difference in methodology, caution is advised in interpreting between this unit and most other unit types; if comparable testing for other unit types were available, it is possible that results for those other units would be higher than the results reported here using emission factors. All BAU cordwood stoves also had levels above the standard for both typical and maximum emissions for at least one studied location, reflecting the relative low efficiency and high emissions from uncontrolled combustion of cordwood. The high $PM_{2.5}$ levels (with existing conditions included) were modeled for both non-USEPA certified stoves—24-hour levels as high as 41.6 μg/m^3 (typical) and 57.7 μg/m^3 (maximum)—and both catalytic and non-catalytic USEPA certified cordwood stoves—levels as high as 35.4 μg/m^3 (typical) to 47.2 μg/m^3 (maximum). Even the BAT cordwood boiler with thermal storage had very high 1-hour concentrations, though 24-hour and annual impacts were lower.

Comparing the pellet units to the cordwood units revealed the effect of higher efficiency pellet fuel systems against lower efficiency cordwood units. Among the BAU boilers, the pellet boiler had the lowest resulting levels for $PM_{2.5}$. Similarly, among the BAU stoves, the pellet stove had the lowest resulting $PM_{2.5}$ levels. The BAU pellet boiler without storage had 24-hour $PM_{2.5}$ levels that were 4.4 μg/m^3 below those from the BAT cordwood boiler for the maximum emissions scenario, and 24-hour $PM_{2.5}$ levels that were only slightly higher (approximately 1 μg/m^3) than those from the nBAT condensing cordwood boiler without storage. The BAT pellet boiler with storage had the lowest $PM_{2.5}$ levels among BAT units, considerably lower than the levels from the BAT cordwood boiler with storage. This comparison, however, must be tempered because of the differences in methodology in estimating emission rates. Similarly, the inefficiency of the cordwood boiler is highlighted by the relatively higher 1-hour CO levels resulting from the BAT cordwood boiler with storage. These levels are considerably below the level of the standard, but they point to the lower efficiency of units fueled by cordwood in general compared to those fueled by pellets.

The effect of thermal storage was evident from the differences in resulting levels from the BAU pellet boiler and the BAT pellet boiler with storage. These units were identically sized, but resulting levels from the unit with storage were lower due to the thermal storage system increasing the efficiency and reducing cycling effects. For 24-hour $PM_{2.5}$ levels, this effect was about 2.0 μg/m^3 for the maximum emissions scenario. The effect of thermal storage was less pronounced for nBAT units, where the lower emission

289 80 FR 50: 13671-13753

rates appeared to have the largest effect on overall levels from these units. The difference between an nBAT condensing pellet boiler without storage and an identical unit with storage for 24-hour $PM_{2.5}$ levels was only 0.1 μg/m^3 under the typical emissions scenario. Slightly higher (0.1 μg/m^3) 1-hour typical impacts resulted from the nBAT unit with storage compared to the unit without storage because units with storage were assumed to typically operate at full load, whereas the units without storage were assumed to typically operate at partial load.

As with the institutional units, this modeling analysis resulted in higher NO_2 levels for BAT units than for BAU units. None of the units resulted in impacts with existing conditions included that were above the level of the standard for NO_2. These units are too small to generate sufficient NO_2 to cause a problem for this pollutant. The two-tier approach was used for NO_2, with Tier 1 assuming that 100% of NO_x is NO_2, and Tier 2 assuming that 80% of NO_x is NO_2. Note that these assumptions may be biased on the high side, as indicated in the sensitivity analysis performed for the RHNY-qualified installation at the large school using the in-stack ratio and emission factor derived from testing performed at the Wild Center.[290] See the discussion about large schools in the previous section for further details regarding NO_2 assumptions. The BAT boilers created greater levels of NO_x because the combustion temperature is higher in BAT boilers and high temperatures lead to NO_x creation.

Concentrations for SO_2 were well below the standard for all assessed installation types at the residential setting at all locations. The highest levels occurred for the BAU phase II outdoor cordwood boiler, and were also relatively higher for other cordwood central heating units. These levels were not of particular concern, but do indicate that with ultra-low sulfur heating oil, emissions from oil boilers are extremely low so heating with wood may increase SO_2 levels compared to oil. The effects of this change may be less of a local issue than a statewide emissions issue, which is discussed in further detail in the statewide scale-up analysis (Chapter 10).

In summary, impacts from residential units are highest for the cordwood fuel units for all studied pollutants except NO_2, for which pellets generated somewhat higher results. Levels for $PM_{2.5}$ were potentially very high for residential cordwood units, especially for the phase II outdoor cordwood boiler and even for the BAT advanced cordwood boiler with thermal storage. Thermal storage led to lower impacts because of the reduced cycling and, therefore, greater efficiency.

[290] Hopke 2010.

Figure 9-7. Predicted 24-Hour $PM_{2.5}$ Concentrations for Phase II Outdoor Cordwood Boiler at Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

Notes: Typical (left) and maximum (right) impacts; concentrations are in µg/m³. + marks the location of the maximum modeled concentration. High levels occur due to downwash from the structure and levels above 10 µg/m³ extend beyond 100 m from the source, following terrain features.

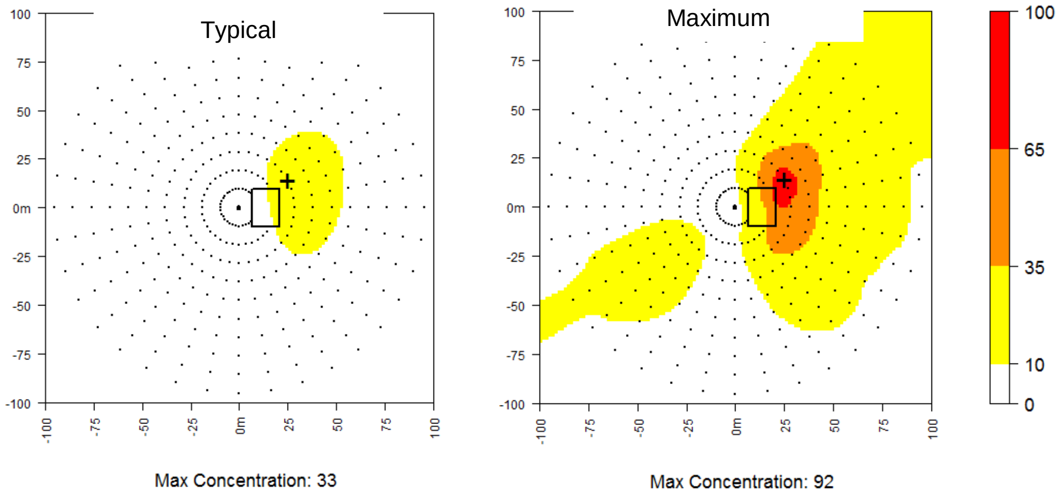


Figure 9-8. Predicted 1-Hour $PM_{2.5}$ Concentrations for Phase II Outdoor Cordwood Boiler at Residential Setting – Valley Terrain, Low Density (No Existing Conditions)

Notes: Typical (left) and maximum (right) impacts. Concentrations are in µg/m³. + marks the location of the maximum modeled concentration. Highest levels are influenced by building downwash and follow terrain features, with levels above 80 µg/m³ occurring beyond 100 meters from the source.

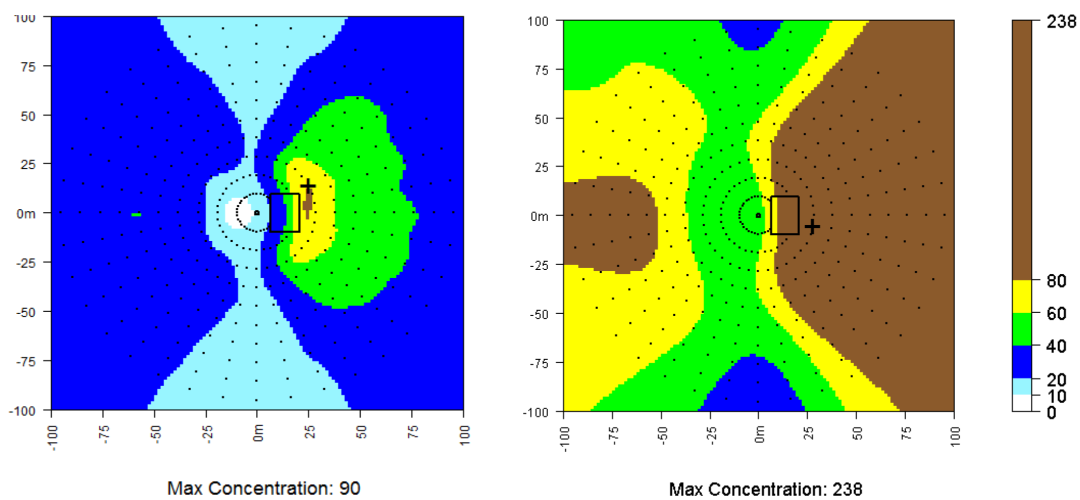


Table 9-25. Highest Predicted $PM_{2.5}$ Concentrations for Residential Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (electrostatic precipitator). Values rounded to the nearest tenth of a microgram per cubic meter. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. “Non-USEPA certified” cordwood stoves include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1. Unit sizes are reported to three significant figures. 1-hour average existing conditions are biased on the low side (Felton 2009).

	Unit Size (Btu)	Thermal Storage	Concentration (µg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			**T**	**M**	**T**	**M**	
Applicable Air Quality Standard			None	None	35.0	35.0	12.0
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	22.0	22.0	23.0	23.0	8.7
Phase II Outdoor Cordwood Boiler	208,000	No	111.3*	261.1*	52.7*	106.7*	16.6*
Pellet Boiler, No Storage	109,000	No	27.4	28.4	24.7	25.6	9.3
Non-USEPA Certified Cordwood Stove	51,200	No	55.4	83.7	41.6	57.7	13.9
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	44.1	66.3	35.1	47.2	12.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	44.2	63.2	35.4	46.2	12.1
Pellet Stove	60,000	No	31.5	37.3	28.1	31.3	10.1
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	101.1*	101.1*	25.1*	29.2*	10.3*
Pellet Boiler, With Storage	109,000	Yes	25.8	25.8	23.2	23.6	8.8
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	24.1	25.0	23.8	24.3	8.9
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	25.7	25.6	23.8	24.2	9.0
Condensing Pellet Boiler, No Storage	85,300	No	22.4	22.5	23.1	23.1	8.7
Condensing Pellet Boiler, With Storage	85,300	Yes	22.5	22.5	23.0	23.1	8.7
Advanced Cordwood Stove w/AEC	51,200	No	22.5	22.7	23.2	23.3	8.7

Table 9-26. Highest Predicted CO Concentrations for Residential Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (electrostatic precipitator). Values rounded to the nearest 0.1 ppm. Items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors. “Non-USEPA certified” cordwood stoves include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	**Thermal Storage**	**Concentration (ppm)**			
			1-hour		**8-hour**	
T=Typical, M=Maximum			**T**	**M**	**T**	**M**
Applicable Air Quality Standard			35	35	9	9
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	1.1	1.1	0.7	0.7
Phase II Outdoor Cordwood Boiler	208,000	No	1.2*	1.4*	0.8*	0.9*
Pellet Boiler, No Storage	109,000	No	1.3	1.3	0.8	0.8
Non-USEPA Certified Cordwood Stove	51,200	No	1.3	1.5	0.9	1.0
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	1.2	1.4	0.8	0.9
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	1.2	1.3	0.8	0.8
Pellet Stove	60,000	No	1.2	1.2	0.8	0.8
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	4.2*	4.2*	1.0*	1.0*
Pellet Boiler, With Storage	109,000	Yes	1.1	1.1	0.7	0.7
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	1.2	1.2	0.7	0.8
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	1.1	1.1	0.7	0.7
Condensing Pellet Boiler, No Storage	85,300	No	1.1	1.1	0.7	0.7
Condensing Pellet Boiler, With Storage	85,300	Yes	1.1	1.1	0.7	0.7
Advanced Cordwood Stove w/AEC	51,200	No	1.1	1.2	0.7	0.7

Table 9-27. Highest Predicted NO_2 Concentrations for Residential Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (electrostatic precipitator). Values rounded to the nearest microgram per cubic meter. “Non-USEPA certified” cordwood stoves include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1. Unit sizes are reported to three significant figures. The suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

	Unit Size (Btu)	Thermal Storage	1-Hour Concentration (μg/m³)			
			Tier 1 (100% of NO_x is NO_2)		Tier 2 (80% of NO_x is NO_2)	
T=Typical, M=Maximum			**T**	**M**	**T**	**M**
Applicable Air Quality Standard			188	188	188	188
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	127	127	123	123
Phase II Outdoor Cordwood Boiler	208,000	No	126	131	123	127
Pellet Boiler, No Storage	109,000	No	130	135	126	130
Non-USEPA Certified Cordwood Stove	51,200	No	113	115	112	114
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	112	114	112	113
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	112	114	112	113
Pellet Stove	60,000	No	137	153	131	144
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	137	137	132	132
Pellet Boiler, With Storage	109,000	Yes	139	139	133	133
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	116	119	115	117
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	137	140	131	134
Condensing Pellet Boiler, No Storage	85,300	No	132	137	127	132
Condensing Pellet Boiler, With Storage	85,300	Yes	139	139	133	133
Advanced Cordwood Stove w/AEC	51,200	No	116	119	115	117

Table 9-28. Highest Predicted SO_2 Concentrations for Residential Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. AEC=advanced emission controls (electrostatic precipitator). Values rounded to the nearest microgram per cubic meter. “Non-USEPA certified” cordwood stoves include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Thermal Storage	Concentration (μg/m^3) 1-hour	
T=Typical, M=Maximum			**T**	**M**
Applicable Air Quality Standard			196	196
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10	10
Phase II Outdoor Cordwood Boiler	208,000	No	29	35
Pellet Boiler, No Storage	109,000	No	13	14
Non-USEPA Certified Cordwood Stove	51,200	No	10	11
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	10	11
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10	11
Pellet Stove	60,000	No	11	11
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	15	15
Pellet Boiler, With Storage	109,000	Yes	15	15
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	11	12
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	16	16
Condensing Pellet Boiler, No Storage	85,300	No	14	15
Condensing Pellet Boiler, With Storage	85,300	Yes	15	15
Advanced Cordwood Stove w/AEC	51,200	No	11	12

Table 9-29. Highest Predicted VOC Concentrations for Residential Setting for the Three Regional Locations (No Existing Conditions)

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.01 microgram per cubic meter. "Non-USEPA certified" cordwood stoves include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1. Unit sizes are reported to three significant figures.

	Unit Size (Btu)	Thermal Storage	Concentration ($\mu g/m^3$)
			Annual: Typical
Applicable Air Quality Standard			None
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.20
Phase II Outdoor Cordwood Boiler	208,000	No	20.99
Pellet Boiler, No Storage	109,000	No	1.47
Non-USEPA Certified Cordwood Stove	51,200	No	10.76
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2.48
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	3.05
Pellet Stove	60,000	No	0.02
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	0.46
Pellet Boiler, With Storage	109,000	Yes	0.22
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.34
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	0.30
Condensing Pellet Boiler, No Storage	85,300	No	0.11
Condensing Pellet Boiler, With Storage	85,300	Yes	0.18
Advanced Cordwood Stove w/AEC	51,200	No	0.34

9.14 Results and Discussion for Neighborhood Sources

This section presents results from the neighborhood-scale air quality modeling analysis for areas in NYS. Section 9.8 describes the neighborhoods assessed, including type of technologies and projected growth of wood-burning technologies through 2023 for residential units in the studied neighborhoods (Table 9-8). The results presented in these sections incorporate both existing conditions and direct impacts from the biomass heating technologies modeled for each scenario.

Tables 9-30 through 9-34 present the range of highest predicted impacts for $PM_{2.5}$, CO, NO_2, SO_2, and VOCs from combined neighborhood and school emissions at the studied locations. These tables show the highest impacts for studied scenarios for each pollutant based on typical and maximum operating scenarios, with existing conditions included when available. For pollutants and metrics for which no existing conditions data are available (annual VOC), direct results are presented without added existing conditions. These tables represent the highest typical and maximum effects seen over all locations.

The neighborhood analysis of all pollutants modeled ($PM_{2.5}$, CO, NO_2, and VOC) indicated that the typical and maximum emissions concentrations for Scenario 1 (Business as Usual Growth) can exceed the 24-hour standard for $PM_{2.5}$, but all other scenarios remain below the standard. When comparing levels to the annual standard (12.0 $\mu g/m^3$), all average $PM_{2.5}$ concentrations are below the standard, but Scenario 1 is highest (10.7 $\mu g/m^3$) and may be a concern depending on how standards change when the NAAQS is revisited in the future. Typical and maximum 1-hour concentrations may be health-relevant for all neighborhood scenarios depending upon the health literature, although there is no subdaily standard for $PM_{2.5}$. The CO and SO_2 concentrations remained well below the levels of the standards for both the typical and maximum concentrations predicted in the analysis. The NO_2 values were close to or above the standard for typical and maximum concentrations. As discussed previously, however, interpretation of NO_2 levels must be done cautiously because emissions used in the modeling for institutional units may be biased high as described in the sensitivity analysis.

In neighborhoods where distances between homes with wood-burning devices are large, a large institutional wood-fired boiler will be the predominant source of woodsmoke. Controlling the institutional boiler in these cases will have the biggest potential for health-relevant effects. In neighborhoods with a high density of inefficient wood-fired boilers with poor emissions controls, installing improved wood-fired boiler technology at the large institution can significantly mitigate air impacts, but the existing residential sources will continue to produce moderate air impacts on the neighborhood.

Figure 9-9 shows maximum 1-hour $PM_{2.5}$ levels at the mountainous terrain location, at which BAU wood ownership is already widespread in the neighborhood. The figure compares the effect of changing the technology used at the school from BAU to nBAT concurrent with adjusting the mix of BAU and BAT technologies in the neighborhood. In Scenario 1, it is clear that the terrain surrounding the school controls the extent and location of the high impact level of emissions from the BAU stoker chip boiler at the large school. In Scenario 2, with the BAT pellet boiler at the school instead of the BAU stoker chip boiler, the air emissions disperse differently so the maximum impact location shifts farther away from the school source because the relative importance of the school's impact decreases compared to the emissions from the homes in the neighborhood.

Because the emissions from the school are lessened, the impact of the emissions from the existing BAU neighborhood sources begins to predominate. This effect occurs despite the fact that the new residential sources are cleaner BATs, because the existing BAU units have emissions that already contribute significantly to ground level concentrations. The extent of the area with higher concentrations is somewhat smaller in Scenario 3 than in Scenario 2 due to the effect of the residential changeouts, with maximum concentrations decreasing by about 8 $\mu g/m^3$. Even in Scenario 4, where an nBAT unit is installed at the school, the new home sources are BAT units, and the 20% residential BAU to BAT changeouts have been implemented in the neighborhood, the other 80% of original BAU home sources are still exerting a significant effect on air emissions. Therefore, after an nBAT school installation in a mountainous terrain location, reducing concentrations further would require additional changeouts in the neighborhood beyond the 20% modeled.

In contrast, at the location with flat terrain and a high population density, where wood-burning unit ownership is low and air dispersion is greater, controlling the technology installed at the school (progress from Scenario 1, top left, to Scenario 4, bottom right in Figure 9-10) appears to largely control higher concentrations of 1-hour $PM_{2.5}$ of concern. Changeouts do not appear to have additional effects. These results indicate that in these types of neighborhoods, where wood heating in homes is not widespread, controls at large sources should largely mitigate air impacts from wood burning.

By comparing the results for the same technologies installed at the large school, both with and without a surrounding neighborhood, the influence of the wood burning equipment at the school versus the neighborhood can be seen. Figure 9-11 shows the maximum 1-hour $PM_{2.5}$ concentrations for the neighborhood with the large school for Scenarios 1 (growth with BAU) and 2 (growth with BAT, BAT chip boiler at the school) and the corresponding technology for only the large school (without the neighborhood) at the mountainous terrain location (where there is a high level of existing wood unit ownership). This example shows how, especially for Scenario 1 (growth with BAU), adding the wood heat installation at the large school has widespread air quality impacts in the neighborhood, and the effect is exacerbated by the neighborhood sources. By controlling the emissions from the school using a BAT unit in Scenario 2, the school impacts are greatly diminished for all studied pollutants except NO_2, but the existing load of neighborhood emissions (largely from conventional and phase II outdoor wood boilers) results in significant 1-hour levels of $PM_{2.5}$ in the neighborhood. The effect of terrain is notably important for the school sources at this location, as the plume impact sites against ridges to the northwest of the source are evident in the dispersion chart. Similarly, Figure 9-12 shows the same detail (Scenarios 1 and 2 and relevant large school technologies) for the flat terrain (where there is a low level of existing wood unit ownership, despite high population levels). At the populated flat area, direct impacts from the residential units in the neighborhood are extremely low because wood burning at homes is rare; therefore, direct impacts from the school dominate in this location.

Figure 9-9. Predicted Maximum 1-Hour $PM_{2.5}$ Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

Notes: See Table 9-8 for more descriptions of each scenario. Black lines indicate area of neighborhood. + marks the location of the maximum modeled concentration. In Scenario 1, emission from the school dominate. In Scenarios 2 through 4, increasingly, the levels are mainly influenced by the residences within the neighborhood bounds because the school has installed improved BAT technologies while many residences still have conventional wood burning technologies in operation.

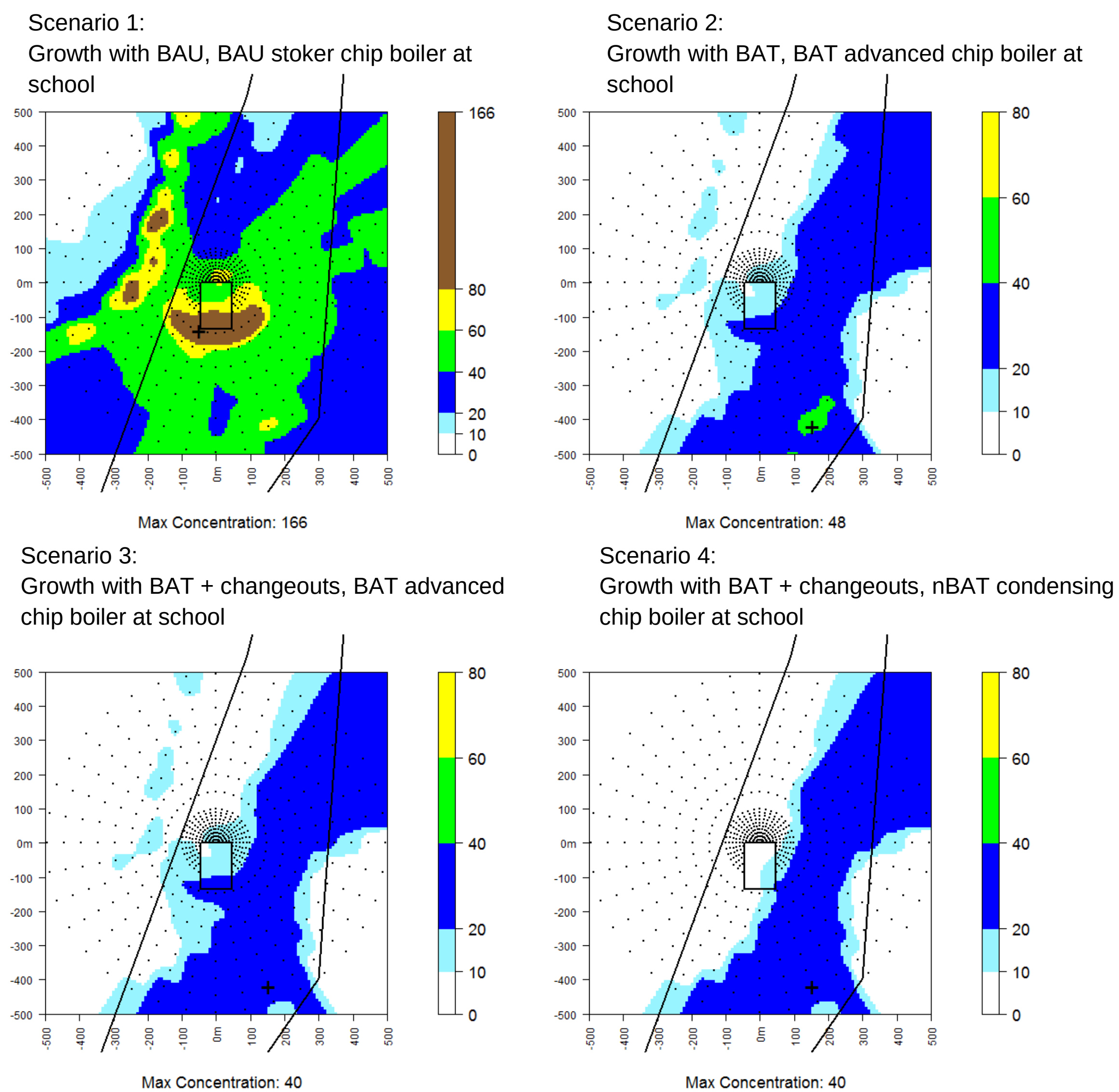
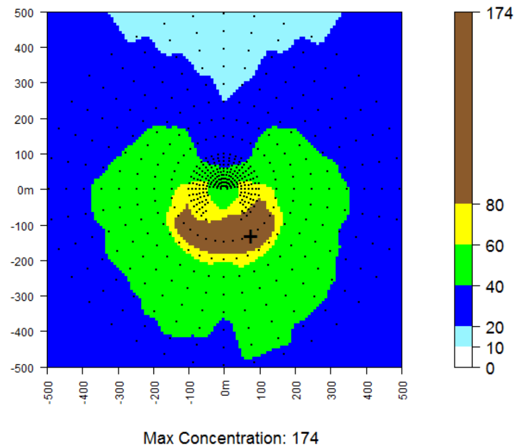


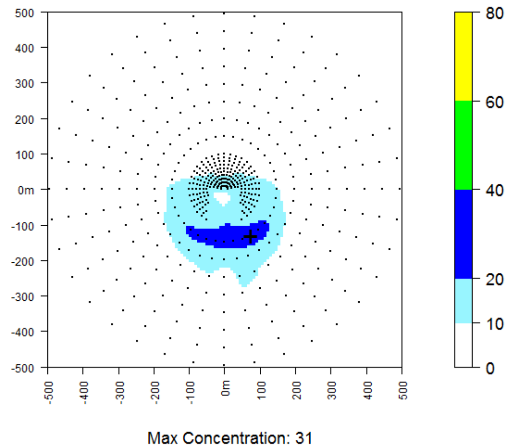
Figure 9-10. Predicted Maximum 1-Hour $PM_{2.5}$ Concentrations for Neighborhood Setting – Flat Terrain, High Density (No Existing Conditions)

Notes: See Table 9-8 for more descriptions of each scenario. The area of the neighborhood extends beyond the bounds of the plot. + marks the location of the maximum modeled concentration. In Scenario 1, emission from the school dominate. In Scenarios 2 and 3, emissions from the BAT advanced chip boiler at the school mitigate the impacts (compared to Scenario 1), and with the installation of the nBAT condensing chip boiler at the school in Scenario 4, levels are extremely low; the effect of residential sources in the neighborhood are imperceptible in this location because residential wood burning is so uncommon.

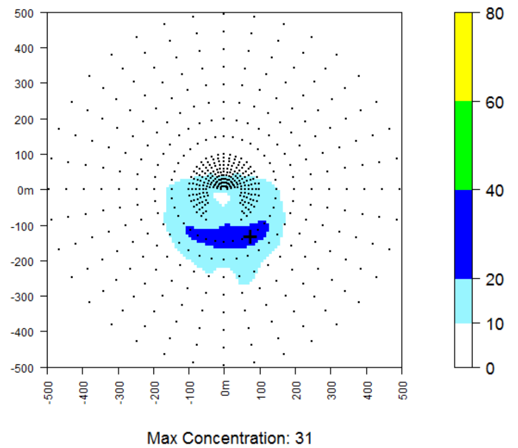
Scenario 1:
Growth with BAU, BAU stoker chip boiler at school



Scenario 2:
Growth with BAT, BAT advanced chip boiler at school



Scenario 3:
Growth with BAT + changeouts, BAT advanced chip boiler at school



Scenario 4:
Growth with BAT + changeouts, nBAT condensing chip boiler at school

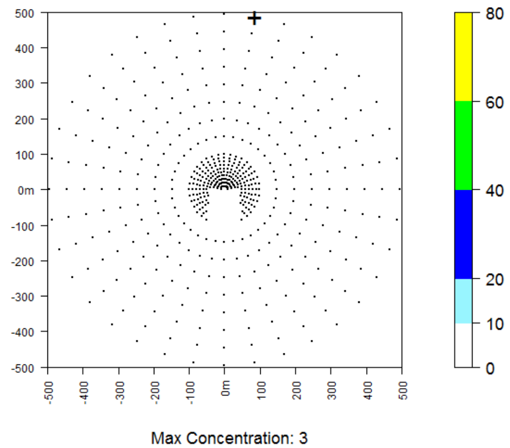


Figure 9-11. Comparison of Predicted Maximum 1-Hour $PM_{2.5}$ Concentrations for Neighborhood Setting and Corresponding Large School Installation – Mountainous Terrain, Low Density (No Existing Conditions)

Notes: Neighborhood Scenarios 1 (top left) and 2 (top right), and large school BAU stoker chip boiler (bottom left) and BAT advanced chip boiler (bottom right). The neighborhood is outlined partially by the black lines that cut across the dispersion charts. + marks the location of the maximum modeled concentration. Differences between the top dispersion charts (school plus neighborhood residential sources) and bottom dispersion charts (school only) reveal the extent to which neighborhood residential sources versus a central school source influence impacts for this pollutant metric. For the BAU stoker chip boiler, the pollution signal from the school is strong and the school emissions explain most of the levels around the source. For the BAT advanced chip boiler, the neighborhood residential sources explain most of the effects. The effect of terrain for the school sources is evident in this location, with the plume impacting on ridges to the northwest of the source.

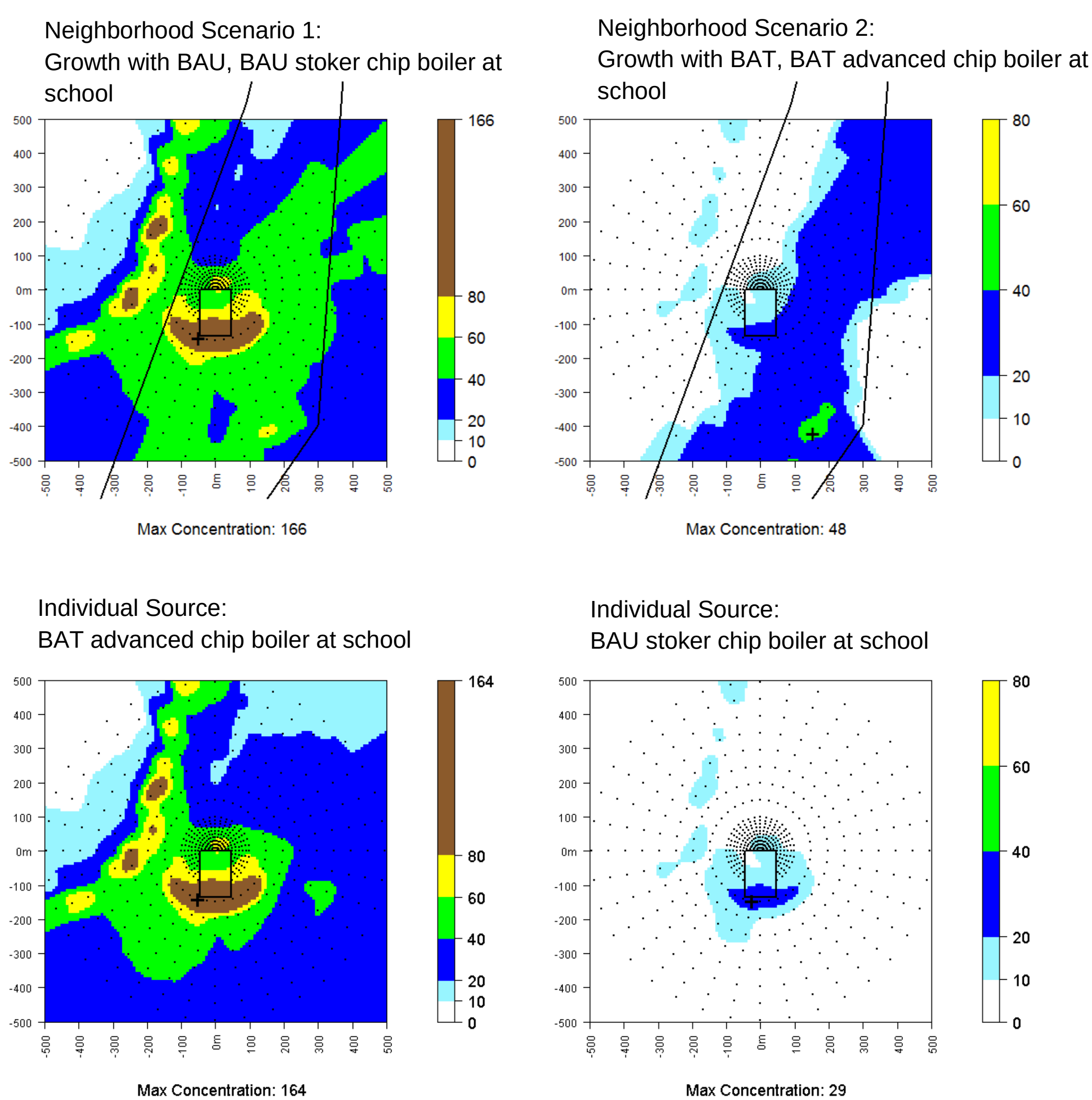
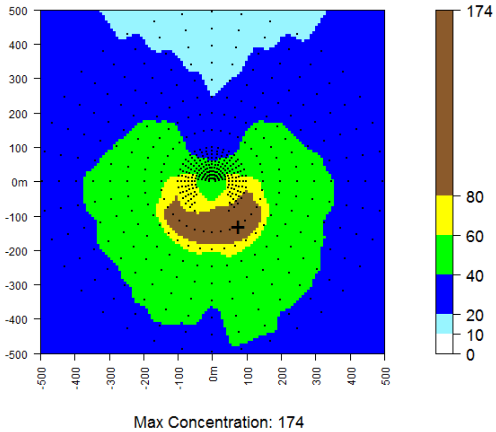


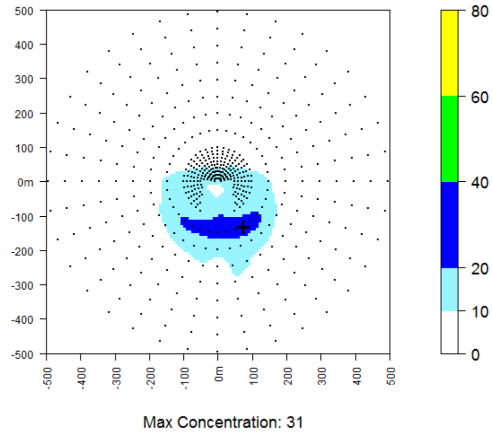
Figure 9-12. Comparison of Predicted Maximum 1-Hour $PM_{2.5}$ Concentrations for Neighborhood Setting and Corresponding Large School Installation – Flat Terrain, High Density (No Existing Conditions)

Notes: Neighborhood Scenarios 1 (top left) and 2 (top right), and large school BAU stoker chip boiler (bottom left) and BAT advanced chip boiler (bottom right). The area of the neighborhood extends beyond the bounds of the plot. + marks the location of the maximum modeled concentration. Differences between the top dispersion charts (school plus neighborhood residential sources) and bottom dispersion charts (school only) reveal the extent to which neighborhood residential sources versus a central school source influence impacts for this pollutant metric. For both the BAU stoker chip boiler and the BAT advanced chip boiler, the pollution signal from the school explains nearly all of the resulting levels around the source because wood burning at residences in this location is rare.

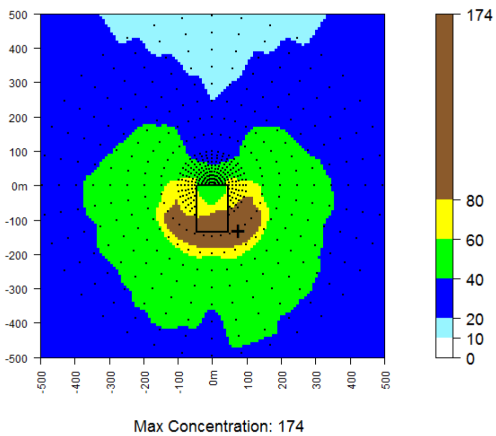
Neighborhood Scenario 1:
Growth with BAU, BAU stoker chip boiler at school



Neighborhood Scenario 2:
Growth with BAT, BAT advanced chip boiler at school



Individual Source:
BAU stoker chip boiler at school



Individual Source:
BAT advanced chip boiler at school

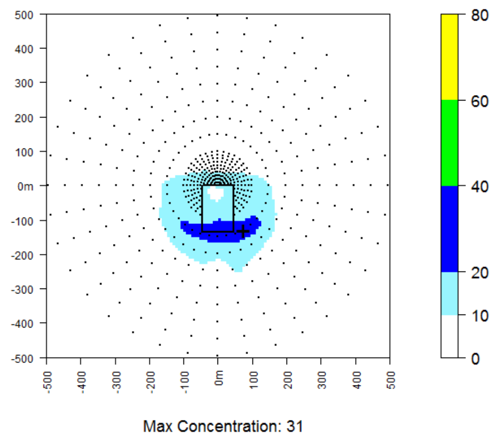


Table 9-30. Highest Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. Values rounded to the nearest tenth of a microgram per cubic meter.

	Concentration (µg/m³)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	**T**	**M**	**T**	**M**	
Applicable Air Quality Standard	None	None	35.0	35.0	12.0
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	94.3	165.7	44.0	66.4	10.7
Scenario 2: Best Available Technology Growth	47.8	47.8	24.1	24.6	7.1
Scenario 3: Best Available Technology Growth, with Changeouts	39.5	39.5	23.5	24.5	6.6
Scenario 4: Best Available Technology Growth, with Changeouts and Next best Technology Deployment at the School	39.5	39.5	22.4	22.4	6.5

Table 9-31. Highest Predicted CO Concentrations for Neighborhood Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions; values rounded to the nearest 0.1 ppm.

	Concentration (ppm)			
	1-hour		8-hour	
T=Typical, M=Maximum	**T**	**M**	**T**	**M**
Applicable Air Quality Standard **Neighborhood Scenario**	35	35	9	9
Scenario 1: Business as Usual Growth	1.6	1.6	1.0	0.9
Scenario 2: Best Available Technology Growth	1.4	1.4	0.9	0.9
Scenario 3: Best Available Technology Growth, with Changeouts	1.4	1.4	0.8	0.8
Scenario 4: Best Available Technology Growth, with Changeouts and Next best Technology Deployment at the School	1.4	1.4	0.8	0.8

Table 9-32. Highest Predicted NO_2 Concentrations for Neighborhood Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. Values rounded to the nearest microgram per cubic meter. The suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

	1-Hour Concentration ($\mu g/m^3$)			
	Tier 1 (100% of NO_x is NO_2)		Tier 2 (80% of NO_x is NO_2)	
T=Typical, M=Maximum	**T**	**M**	**T**	**M**
Applicable Air Quality Standard	188	188	188	188
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	181	193	160	170
Scenario 2: Best Available Technology Growth	230	239	200	207
Scenario 3: Best Available Technology Growth, with Changeouts	230	239	200	207
Scenario 4: Best Available Technology Growth, with Changeouts and Next best Technology Deployment at the School	150	191	136	169

Table 9-33. Highest Predicted SO_2 Concentrations for Neighborhood Setting for the Three Regional Locations (with Existing Conditions)

Notes: Levels for existing conditions are not displayed because values are the highest result from three locations that have different existing conditions. Values rounded to the nearest microgram per cubic meter.

	Concentration ($\mu g/m^3$) 1-hour	
T=Typical, M=Maximum	**T**	**M**
Applicable Air Quality Standard	196	196
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	23	24
Scenario 2: Best Available Technology Growth	20	20
Scenario 3: Best Available Technology Growth, with Changeouts	20	20
Scenario 4: Best Available Technology Growth, with Changeouts and Next best Technology Deployment at the School	15	17

Table 9-34. Highest Predicted VOC Concentrations for Neighborhood Setting for the Three Regional Locations (No Existing Conditions)

Notes: Values rounded to the nearest 0.01 microgram per cubic meter.

	Concentration ($\mu g/m^3$)
	Annual: Typical
Applicable Air Quality Standard	None
Neighborhood Scenario	
Scenario 1: Business as Usual Growth	6.52
Scenario 2: Best Available Technology Growth	4.80
Scenario 3: Best Available Technology Growth, with Changeouts	3.90
Scenario 4: Best Available Technology Growth, with Changeouts and Next best Technology Deployment at the School	3.89

9.15 Conclusions

The local air quality impacts analysis presented in this section provides a comprehensive picture of how technology type, sizing, thermal storage installation, and other factors can affect air quality in regions of NYS when wood heating technologies are deployed. This section summarizes the conclusions drawn from the results and discussion.

The results presented in this chapter indicate that moving from oil to wood will increase air quality impacts, which may have associated health impacts (not quantified here), but that those impacts can be significantly reduced through use of BAT or nBAT technologies, best practices, and proper installation. The results of this analysis show the potential for some installations of wood-fired technologies at residential and institutional sources to cause near-source pollutant levels—namely for $PM_{2.5}$ and NO_2—to be above the level of federal air quality standards.

Technology choice

The most significant decision in controlling air impacts resulting from installation of a wood-fired heating unit is the choice of technology. Higher emissions from dirtier units may be mitigated through taller stacks, proper sizing, thermal storage, and improved fuel quality, but choosing a cleaner technology with advanced emission controls is likely the most effective strategy for reducing air impacts. Not surprisingly, selecting units with higher emission rates leads to higher air pollution impacts. When comparing installations in a particular setting, impacts were generally highest from BAU wood units, followed by BAT wood units, and then nBAT wood units. Impacts from oil-fired units burning ultra-low sulfur diesel were the lowest for $PM_{2.5}$ and other pollutants.

For the wood-fired technologies, moving from BAU to BAT resulted in lower concentrations of all pollutants except NO_2 when other aspects of the installation were similar (e.g., using the same stack/chimney). However, results from BAT technologies indicate that health-relevant concentrations of air pollutants persist for some installations. For instance, the BAT advanced cordwood boiler with thermal storage at homes resulted in potential typical and maximum direct 1-hour $PM_{2.5}$ concentrations above 70 $\mu g/m^3$ (without existing conditions for $PM_{2.5}$ levels added) and maximum direct impacts for 24-hour $PM_{2.5}$ of 5-7 $\mu g/m^3$. Health studies have indicated that increases in $PM_{2.5}$ levels can have a measureable health effect with no known lower threshold. That is, there is no known “safe” level of exposure to $PM_{2.5}$. Therefore, even the levels potentially produced from BAT units may be of concern for sensitive populations, so installations should be carefully designed and operated to reduce potential impacts.

Results of the analysis indicated that the condensing nBAT units produce air emission levels much closer to those produced by oil boilers using ultra-low sulfur diesel, and these units represent the lowest potential impacts of all the wood-fired heaters studied in this analysis. At levels produced by lower emission units such as the oil boilers and nBAT wood units, the existing conditions (background levels of emissions) become the primary concern for the area, rather than the additional emissions from the heating unit.

This analysis also suggests that installation of cleaner wood burning technologies, which create slower exit velocities in the stack because they are burning less wood, may lead to poorer dispersion, which can counteract some of the benefits of the emissions reductions and lead to less beneficial ground-level pollutant concentrations. The installation of blower fans or other methods to improve exhaust dispersion can be considered best practice for these devices and will lead to lower near-source exposures.

Sizing

Proper sizing can significantly mitigate the air impacts from units. It was clear from the impact levels of the BAU units, which were oversized to three times their required size based on thermal demand, that proper sizing would significantly reduce the overall air quality impacts.

Fuel choice

Pellet-fired units evaluated in this study operate more efficiently and have reduced emission rates when compared to the wood chip- or cordwood-fired units, resulting in lower air quality impacts. The combustion of this more uniform fuel (which also has a low fuel moisture content) can be more effectively optimized than combustion of chips or cordwood, especially when using more sophisticated technologies as described in Chapter 8. In addition, CO emissions are higher with lower efficiency units, therefore using pellets considerably mitigates higher CO in-stack levels. Cordwood technologies produced the highest maximum potential impacts at residential installations, which was higher than any building type for $PM_{2.5}$ and CO for the technologies evaluated. Switching from cordwood stoves to pellet stoves, even at the same technology level (i.e., BAU), results in significant improvement in local air quality impacts. Note that NYS DOH recommends that pellets be stored outside the main building because of concerns over CO off-gassing.

$PM_{2.5}$

Levels of $PM_{2.5}$ very close to the large school can be above the NAAQS levels, especially for the mountainous terrain location (see Figure 9-2). BAU units installed in homes can also produce NAAQS-relevant concentrations for $PM_{2.5}$ (see Figure 9-5 and Figure 9-6). BAT and nBAT units produced significantly lower concentrations. BAT units with insufficient stack height at the small school produced levels potentially above similar BAU wood units, illustrating the importance of proper stack height in design of the installation. In all cases, oil boilers burning ultra-low sulfur oil had the lowest potential impacts for all installation types.

Given the findings of these health studies combined with our results, $PM_{2.5}$ emissions from BAU, and potentially BAT installations, should be carefully reviewed and assessed for potential health impacts.

NO_2, CO, and SO_2

BAT units have more optimized combustion conditions than BAU units, so they convert more energy from the fuel into heat in the combustion chamber than BAU units do. The BAT units also have superior heat transfer in the heat exchanger, resulting in more heat delivered to the heat distribution system (rather than lost up the stack or emitted from the boiler jacket) and higher output thermal efficiency. Hotter combustion temperatures create more NO_2, which is reflected in the modeling analysis, including the potential for levels above the NAAQS for NO_2. This effect, however, may be an artifact of the conservative (i.e., upper-end) assumptions embedded in this analysis. Concentrations of CO may be of concern for indoor air quality. Elevated CO levels may be especially important for cordwood- or chip- fired units due to higher moisture content and for technologies that do not optimize combustion through sensors and controls. CO emissions may even be of concern for pellet-fired boilers during transient operation such as cycling. This report does not address CO levels or indoor air quality concerns. Levels of SO_2 presented here are considerably below ambient air quality standard levels.

VOCs

Because VOCs were modeled consistent with assumptions for $PM_{2.5}$ annual (except for emission rates), the results for VOCs scale identically with those for annual $PM_{2.5}$ results. Impacts for VOCs tended to be worst for BAU units and best for nBAT units, consistent with the trends noted for other pollutants. Additional analysis would be required to determine the impacts from particular compounds in the VOC classification, and that is a limitation of this analysis.

Need for observed emissions rate data

The analysis presented in this chapter relied largely on emissions factors to calculate emissions rates. These factors provide average performance over multiple load levels and do not necessarily reflect operations during which performance is not typical, such as startup and shutdown conditions. These conditions are not rare, and may contribute to peak 1-hour impacts on a regular basis. Those units for which reliable emissions rate data were available showed significantly higher impacts than those units for which emissions rates were derived using emissions factors. This pattern suggests that maximum impacts at health-relevant levels may be higher than predicted using average emission factors.

Thermal storage

The benefit from installing thermal storage with heating systems is dramatic at both the annual and daily timescales. By allowing the unit to fire less often overall, and operate at maximum efficiency more often, thermal storage may reduce maximum air quality impacts by a factor of 5 to 10, based on the type of residential central heating unit. ICI boilers with thermal storage studied in this analysis (i.e., RHNY-qualified boilers at the large school) had lower 24-hour average $PM_{2.5}$, annual $PM_{2.5}$, and 1-hour NO_2 levels compared to other BAT and BAU wood boilers. For air impacts at the 1-hour level, however, the situation is different because the units (with storage) were assumed to be firing at maximum load but with greater dispersion when compared to units without storage that fire at partial load. Therefore, when comparing 1-hour concentrations from units with and without thermal storage, levels are generally only somewhat lower (0% to 8%) at the units with storage than without.

For nBAT units, there is a slightly higher impact at the 1-hour metric for units that include storage over those that do not because units with storage typically fire at higher load than those without; however, the overall impacts of those nBAT units, both with and without storage, are extremely low. For the annual and daily metrics, nBAT units with storage have significantly lower emissions compared to BAT or BAU units with or without thermal storage. For ICI units with storage in this analysis, the thermal storage allowed for operation at higher loads and less cycling as well as design of a significantly smaller unit size, which resulted in much lower emission rates. Therefore, this analysis indicates that thermal storage is an important strategy for reducing impacts from wood-fired heating at residential and institutional settings.

Fuel moisture content

During typical unit operation, using lower moisture content wood chips provides measurable, but marginal benefits on local air quality. When considering maximum air emissions impact, however, the increased efficiency of the units and the lower quantity of fuel burned to supply the same heat load when using lower moisture content wood chips results in lower stack flows and correspondingly lower dispersion, marginally *increasing* local air quality impacts. These results (see Tables 9-10 through 9-14) suggest that improving the fuel quality typically is an advantage, but that emission characteristics should be carefully considered and mitigation tactics (perhaps installation of additional controls or exhaust fans) be considered prior to installation to ensure lower impacts during inversion events. One research need is determining whether lower moisture chips have a different emission profile than higher moisture chips.

Pellet boilers at the large school produced significantly lower concentrations for most pollutants (except CO, of which it produced essentially equal levels) when compared to the comparable technology category of an advanced chip boiler. The increased efficiency and lower emission rates for pellets is in part a function of the lower moisture content of pellets compared to chips or cordwood.

Installation characteristics

Ground-level air impacts are highly sensitive to stack height and other operational characteristics. The example of BAT pellet boilers installed with insufficient stack height (14 ft) and exhaust temperature of 192 °F adjacent to a small school shows that near source impacts may be at or above levels from central installations of BAU cordwood chip stoker boilers with a stack height of 40 ft and exhaust temp of 416 °F. Emissions from a stack without sufficient height or buoyancy, also an issue for outdoor wood boilers, may get trapped near ground-level and produce significant pollutant levels under certain meteorological conditions, such as when air stagnates during a temperature inversion. These examples demonstrated the importance of proper stack design and installation and how inadequate stack design can adversely affect air quality, even for relatively small units.

Building downwash

Examination of dispersion charts from this analysis demonstrated the importance of building downwash on impacts. Often, air impacts are greatest in the cavity created next to the building. Results suggest that the placement and design of the stack must consider the shape and placement of the building with respect to terrain features in order to mitigate potential impacts.

Terrain

The effect of terrain on concentrations was most apparent when comparing the mountainous terrain location to the other two locations. With the mountainous terrain, the collision of the emissions against a ridge to the northwest of the source creates a high air emission impact area in that region, and elevates overall concentrations. These results suggested that proper siting and stack design must go hand in hand, and that technologies must be designed to disperse smoke above trapping terrain features. For homes, terrain influences may dramatically increase concentrations, and adjustments to chimney design to improve dispersion may not be feasible. This result suggested that highly polluting technologies should be avoided in areas where terrain may contribute to air quality impacts.

Existing conditions

According to regional regulatory air monitoring networks, NYS was in attainment for the $PM_{2.5}$ NAAQS as of March 2015, but there may be more localized areas without air monitors that can exceed the annual or 24-hour NAAQS. In addition, areas with higher populations or otherwise more numerous existing sources of pollution and correspondingly higher pollutant concentrations have less “room” for impacts from additional sources before health-relevant concentrations begin to arise. In these areas, the results of this analysis indicate that where existing conditions have high pollutant levels, selection of technology level is of great importance; a single polluting boiler or stove can lead to levels greater than the health-based NAAQS in the immediate vicinity of the source.

Neighborhood influence

The neighborhood level analysis demonstrated that choice of technology (and associated emissions) at a large institution in a neighborhood has a demonstrable effect on local air quality, especially in areas where wood burning was not already widespread. In areas where wood burning was already widespread, existing BAU wood units at the homes may lead to health-relevant concentrations even when the institutional unit is controlled with nBAT level technology. In neighborhoods where wood burning was already widespread, impacts from an institutional source can be exacerbated by the neighborhood impacts, and vice-versa. The effect of changeouts in neighborhoods is noticeable, but also indicates that aggressive changeout regimes will be necessary to fully address potential problems. This conclusion is consistent with the experience of Libby, Montana, where even extremely aggressive changeout programs resulted in large (50%) reductions in woodsmoke levels, but did not entirely resolve the problem. While changeouts were successful in areas with significant wood burning levels, changeout of BAU wood units did not appear to have a pronounced effect on impacts in neighborhoods where there was not a significant density of BAU wood units, as expected. For locations where many residences rely on conventional wood heating devices already, changeout programs are shown in this analysis to result in noticeable reductions for 1-hour (both typical and maximum) and annual impacts, as shown in Table 9-30.

Emissions

The modeling suggested that installation of some technologies has potential implications for local $PM_{2.5}$ air pollution levels above a health-based NAAQS. The modeling performed in developing the local air impacts estimates had conservative elements so as to capture maximum expected impacts in addition to typical expected impacts. These potential levels indicated the importance of properly installing technologies with adequate controls and emission rates, especially in areas where there are sensitive populations, such as at homes, schools, and hospitals. It should be noted that monitoring was not typically performed at these types of installations.

For institutional settings, BAU stoker chip boilers may produce unacceptable levels of fine PM that may be health-relevant at hourly, daily, and even annual timescales. The modeling indicates that at residential settings, BAU technologies have among the highest potential impacts, including the potential for exceeding $PM_{2.5}$ health standards at homes with phase II outdoor wood boilers or BAU cordwood stoves.

The modeling indicates that both BAU and BAT installations at schools, and BAT installations at hospitals, result in 1-hour NO_2 levels that warrant further investigation. These modeled levels are based on extremely upper-end assumptions and it is likely that actual impacts are lower, but it is an area where further modeling, stack testing, and impacts measurement are needed.

9.16 Limitations and Future Research Needs

This analysis is constrained by a number of limitations in scope, data availability, and methodology. These limitations and uncertainties were described in context in this chapter, and are presented here in a consolidated list:.

- This study made use of air quality modeling rather than direct observations of air impacts. Uncertainties associated with simulations apply to the results from the air modeling. Model performance within a factor of two is generally regarded as adequate, and thus the results may be uncertain by a factor of two because of the modeling approach.
- This analysis examined maximum and typical emissions scenarios for a range of wood burning technologies of particular sizes; emissions at actual installations may differ somewhat from those evaluated in this study.
- Because this analysis examines theoretical sources in a variety of terrains, meteorological conditions, and emission scenarios, the results are not necessarily directly comparable to direct observations at actual sources. To determine actual impacts for a specific site, one would need to perform a careful site analysis. Results from this study are not necessarily transferable to any individual site.

- For most of the technologies and pollutants described in this analysis, appropriate stack testing data were not available and average unit performance data, including emission factors, were used instead of directly observed emission rates at the specified operating conditions. This limitation hampers direct comparison between the few technologies for which direct emission rates were available and those for which emission factors were used.
- Building downwash may overestimate concentrations somewhat in the building cavity region for elongated buildings, producing air impacts that are biased high.
- This study did not take into account ozone impacts, climate impacts, or impacts from specific compounds other than those explicitly listed (e.g., individual VOCs).
- There is no federal standard for hourly exposure to fine particulates. It is unclear what the best metric is for examining potential exposures of fine particulate for analysis.
- There were insufficient data to support using a different emission rate for wood fuel inputs with different moisture content in this analysis. Any difference in results for units with lower versus higher moisture content fuels is accounted for by differences in efficiency (3.4%) for 30% versus 45% moisture content, and the resulting fuel throughput.
- Meteorological data is from airport locations that may not be the best representation of in-neighborhood meteorological conditions. Neighborhoods may experience lower wind speeds because of obstructions to the wind including vegetation, homes, institutional and commercial buildings, and other structures that interfere with the wind flow. On-site wind data are preferred for on site assessment, but such data were rarely available at neighborhood sites.
- Estimates of thermal efficiency discounted losses due to jacket loss, which can be a significant portion of thermal efficiency loss.
- Lack of direct measurements of in-stack NO_2 to NO_x ratios lead to high estimates of near-source impacts of 1-hr NO_2. In addition, additional measurements of NO_x emission rates would add confidence to the analysis. The values presented in this analysis for NO_2 impacts show levels of potential concern that should be validated with additional measurements.
- Measurements of 1-hr $PM_{2.5}$ for the existing conditions may be biased low.
- This analysis did not address health impacts resulting from the air impacts described in the analysis.

Based on this study, the following needs for additional research or refinement of inputs for future local air quality analysis were identified:

- Actual stack testing data under typical and maximum firing conditions. These data would include stack flow characteristics, and, most critically, emission rates for all relevant pollutants. These observations would replace calculated values based on theoretical performance of the units.
- Startup and shutdown emissions.
- Measured, rather than estimated, unit efficiency.
- Meteorological measurements in modeled neighborhood locations.
- More robust field data indicating typical oversizing factors for wood appliances.
- Better characterization of the impact of thermal storage on cycling and, in turn, the impact on short-term emissions.

- In-stack ratios of NO_x species. These data could provide some additional insight into whether the reported impacts of NO_2 near sources are of concern, or whether refining the Tier 2 assumptions with lower stack ratios would result in more accurate model outputs that show acceptable concentrations, especially for BAT units installed at schools. In-stack ratios are likely to vary as a result of unit performance and may be variable within a single unit depending on conditions.
- More representative levels for existing conditions of NO_2 in more remote locations of NYS. This includes on-site monitoring data for actual installations to measure stack concentrations and near-source levels (including levels at air intakes for school air handling systems). These data could be used to evaluate the conclusions of this and other modeling exercises.

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10 Technology Cost and Macroeconomic Analysis

Building on the assessment of wood heating technologies detailed in Chapter 8, the broader economic impacts associated with installation of these technology options were examined on both a micro- and macroeconomic basis. The analysis was performed on three levels:

- An evaluation of costs and emission profiles associated with owning and operating the available technology options.
- The evaluation of four statewide scenarios of future trends in the adoption of heating technologies for emission and cost impacts.
- A macroeconomic analysis of the four statewide scenarios for impacts on employment and gross regional product (GRP).

The analysis concluded that using wood heating technologies may provide cost savings relative to oil over the lifetime of the units but cost savings are highly dependent on future wood and oil prices. Using properly sized and installed BAT wood heating units instead of BAU will substantially reduce emissions of particulate matter and carbon monoxide and yield cost savings even with lower oil prices. While all growth scenarios showed emission increases, if NYS grows the market with BAU wood technologies, particulate matter emissions could increase by as much as 530 tons annually, which represents an approximate 3% increase in total statewide particulate matter emissions. Large increases in the use of wood heating will have a relatively small impact on the State's overall economy, however, the benefits are expected to be concentrated in certain regions of NYS where county level impacts may be greater. This analysis estimated that the growth in wood fuel production and device manufacturing could generate between 5,000 and 10,000 jobs over a 20-year time period, which corresponds to average job creation that ranges between 285 and 495 jobs per year over the entire 21-county study region.[291]

10.1 Technology Characterizations

This study examined the costs and emissions associated with owning and operating BAU wood, BAU oil, BAT wood, and nBAT wood heating technologies. The specific heating technologies evaluated for use in both the residential and commercial vary by sectors, as summarized in Table 10-1.

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[291] Jobs include both temporary and permanent jobs.

Table 10-1. Technology Types Characterized in this Study, by Sector

Technology	Residential Sector	Commercial and Institutional Sectors
BAU Wood	Phase 2 outdoor wood boiler	Stoker chip boiler, Phase 2 outdoor wood boiler
BAU Oil	oil boiler	oil boiler
BAT	cordwood stove, pellet boiler (with and without thermal storage), cordwood boiler (with and without thermal storage)	cordwood boiler (with thermal storage), pellet boiler (with and without thermal storage), chip boiler (with and without thermal storage)
nBAT	cordwood stove, pellet boiler (with and without thermal storage), cordwood boiler (with and without thermal storage)	cordwood boiler (with thermal storage), pellet boiler (with and without thermal storage), chip boiler (with and without thermal storage)

Multiple building types were modeled within each sector, reflecting differences in building function, size, and geographic location. A short list of the building types is summarized in Table 10-2. Appendix G contains a full list of the technology configurations evaluated for each building type.

Table 10-2. Building Types Characterized in this Analysis

Building Type	Heated Space
Single Family Residence	1,500 sq. ft.
Single Family Residence	2,500 sq. ft.
Small School	55,000 sq. ft.
Large School	130,000 sq. ft.
Office	20,000 sq. ft.
Retail	10,000 sq. ft.
Small Dairy	NA - 110 cows
Large Dairy	NA - 711 cows
Greenhouse	10,000 sq. ft.
Hospital	100,000 sq. ft.

Building sizes were determined based upon the best available data and input from industry experts. In order to evaluate the costs and emissions associated with heating technologies in different buildings types, it was necessary to establish assumptions characterizing technology size, annual efficiency, and emission factors. Appendix G contains a complete list of the technology assumptions for each scenario analyzed.

Figure 10-17. Direct Inputs by Input Concept (High Units, High Technology) for All Regions Analyzed

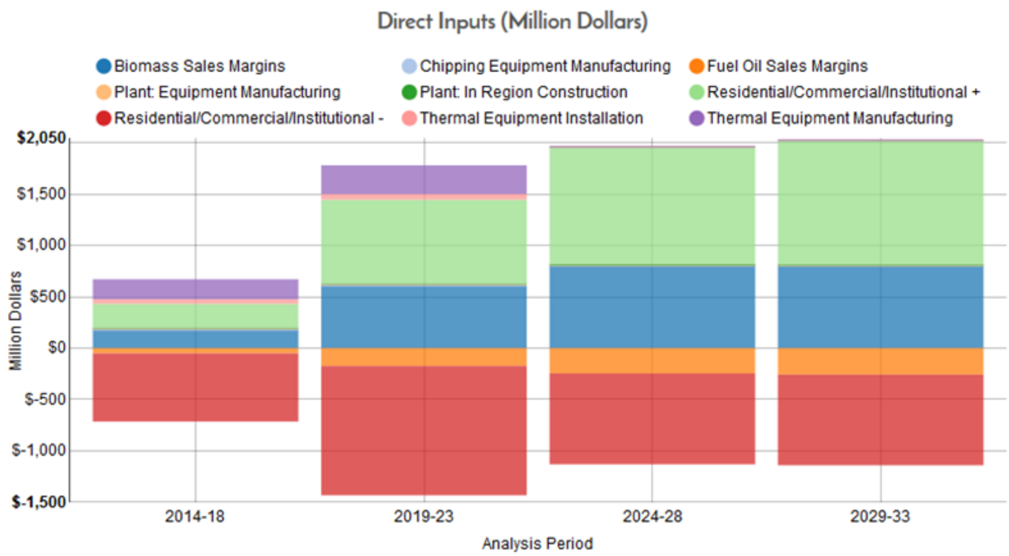


Table 10-16. Direct Inputs by Input Concept (High Units, High Technology) for All Regions Analyzed

$ Million

Indicator	2014-18	2019-23	2024-28	2029-33	Total
Residential / Commercial / Institutional, inflow	$294	$1,058	$1,511	$1,616	$4,479
Biomass Sales Margins	$188	$632	$835	$828	$2,483
Thermal Equipment Manufacturing	$194	$280	$0	$0	$474
Thermal Equipment Installation	$45	$56	$0	$0	$101
Plant: Equipment Manufacturing	$14	$14	$7	$7	$41
Plant: In Region Construction	$8	$8	$4	$4	$23
Chipping Equipment Manufacturing	$0	$1	$0	$0	$1
Fuel Oil Sales Margins	-$65	-$224	-$320	-$339	-$947
Residential / Commercial / Institutional, outflow	-$671	-$1,280	-$913	-$907	-$3,771
Total	$8	$544	$1,123	$1,210	$2,884

10.7.2 Summary of Modeling Inputs by Analysis Region

The economic inputs were also summarized by region. The comparisons in the following figures and tables focus on the Low Units, Low Technology scenario, and the High Units, High Technology scenario. Each of the tables and figures below presents the inputs at the intermediate level of new pellet mill construction, which assumes six new pellet plants. Figure 10-18 and Table 5 reflect the Low Units, Low Technology scenario. Figure 10-19 and Table 10-18 reflect the High Units, High Technology scenario.

the modules, along with the results from each stage of analysis, is described in the following subsections. For simplicity, this analysis assumes a static cost for oil over the study period. While this is an unlikely outcome, the cost of wood and oil tend to track one another over time. Therefore, from a relative perspective, the results provide a useful comparison.

10.3 Base Case Module

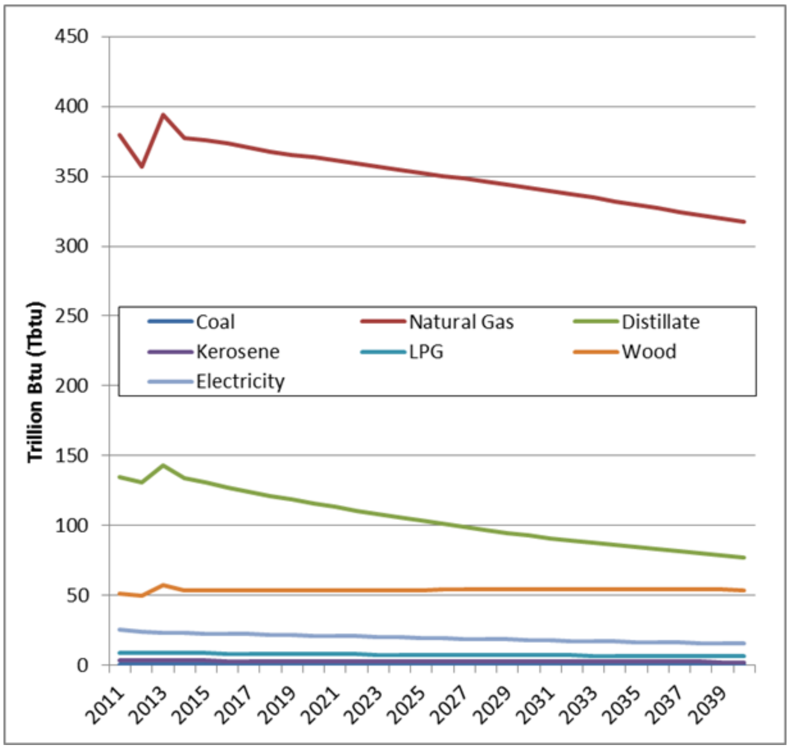
The base case module projects future year heating fuel consumption and expenditures based on NYS-specific historical data and regional projections of fuel consumption. This project limited the analysis to the residential and commercial/institutional sectors. Accordingly, no projections for future year industrial consumption were made.

The primary source of historical sector-wide energy demand data for the residential and commercial sectors was the Energy Information Administration's State Energy Data System (SEDS) database, which lists historical fuel consumption by sector and fuel type. At the time that the analysis commenced, these data were complete through year 2011. In order to project these trends to future years, this analysis used EIA's Annual Energy Outlook (AEO) 2015, which includes projections of energy demand by sector and fuel type specific to the Mid-Atlantic region, including NYS, Pennsylvania, and New Jersey. By scaling regional trends from the AEO based on the most recent state-specific annual consumption numbers in the SEDS database, this analysis was able to project future year fuel use for the residential and commercial sectors as a whole. EIA projects a moderate decline in use of many fuels over the coming decades, presumably as a result of the implementation of energy efficiency measures.

Next, the share of total energy consumption used for space and water heating was estimated by fuel type and sector. In the residential sector, assumptions from the Northeast MARKet ALlocation (NE-MARKAL) model were used to determine the share of each fuel used for heating. For the commercial sector, data from EIA's Commercial Buildings Energy Consumption Survey (CBECS) were used to determine the share of natural gas, distillate oil, and electricity used for space and water heating. Due to similarities in fuel type and technology, the share of residual oil used for heating purposes was assumed to match the share of distillate oil used for the same purpose. However, the CBECS survey did not include information about the share of coal, kerosene, propane, and importantly, wood, used for heating in the commercial sector. Thus, the same NE-MARKAL assumptions for share of fuel consumption used for heating in the residential sector were applied to projections for commercial fuel consumption of these fuels. For all fuels, there is substantial uncertainty surrounding projections for consumption. In particular, the near-flat projection for residential wood consumption published in the

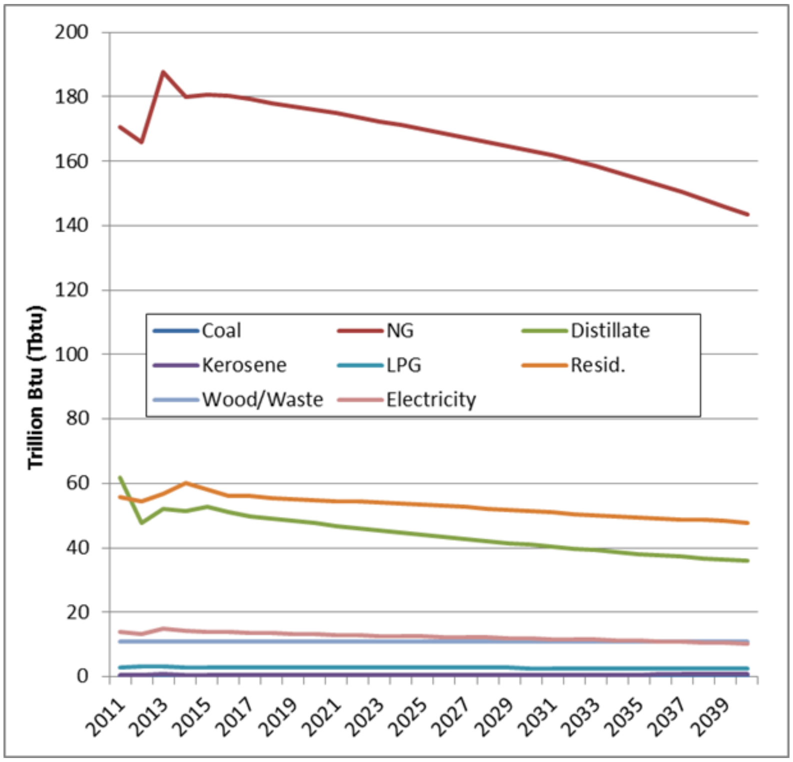
AEO does not seem consistent with observed trends in the heating market, or even with other materials published by EIA.[292] In addition, data published by the USEPA give a much higher value for current consumption, possibly due to differences in accounting for cordwood, much of which is harvested and sold in an informal manner. As such, these projections for consumption of heating fuel should be considered only rough estimates that give a sense of magnitude and establish context for the changes discussed in the scenarios; they are not used as inputs to the analysis. Figure 10-1 plots the total projected residential heating demand in NYS, and Figure 10-2 depicts the same for commercial demand.

Figure 10-1. Projected Residential Heating Demand in New York State



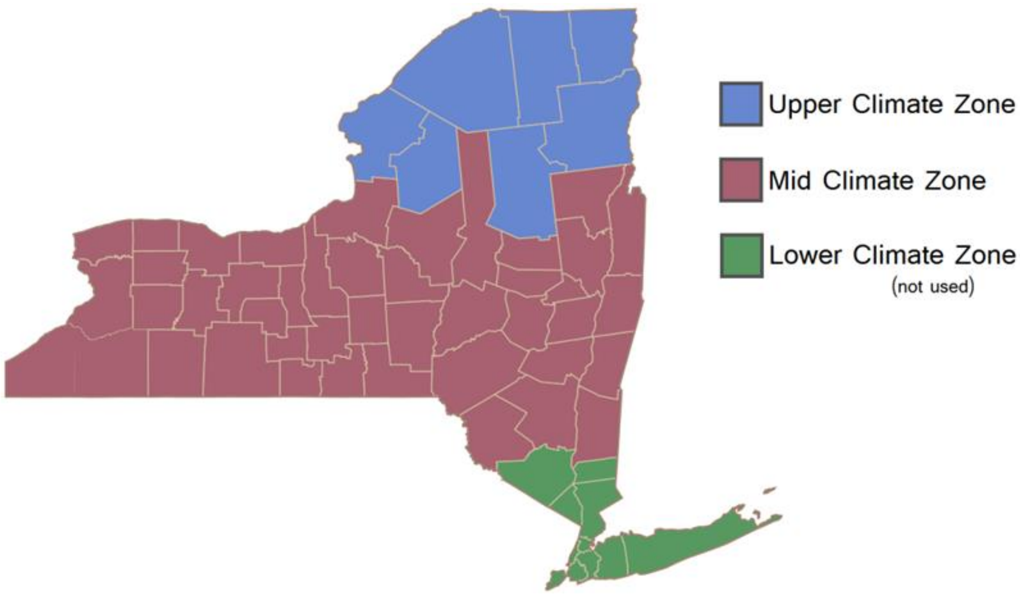
292 U.S. Energy Information Administration. "Increase in wood as main source of household heating most notable in the Northeast." March 17, 2014, http://www.eia.gov/todayinenergy/detail.cfm?id=15431

Figure 10-2. Projected Commercial Heating Demand in New York State



The number of residential heating units by fuel type in each county was derived from annual NYSERDA *Patterns and Trends* reports, which in turn, rely on American Community Survey census data. As this analysis focused only on conversions from distillate oil and propane to wood heating, only those units for which distillate and propane were the primary heating fuel were considered candidates for conversion. To account for the observed trend of conversions of distillate to natural gas over the period of 2000 to 2011, a linear trend in each county was extrapolated to estimate the remaining number of distillate and propane units in the first program year of 2014. Finally, the unit counts by county were aggregated into three climate zones, as determined by heating load modeling (Figure 10-3). The lower climate zone, consisting of New York City, Long Island, and the Hudson Valley, was not considered a target market for wood heating unit conversion for a variety of reasons including access to natural gas and fuel transportation costs. The 289,030 residential distillate and propane units in the middle and upper climate zones were the best candidates for conversion to wood.

Figure 10-3. Climate Zones in New York State



Commercial heating unit candidates for wood conversion were derived from a USEPA database of permitted boilers in NYS. The list was filtered to select only boilers using propane or oil as a primary fuel, and geographically restricted to areas not served by pipeline natural gas, as determined from the New York State GIS Clearinghouse. This selection method yielded 2,374 boilers with output greater than 0.5 MMBtu/hr, and roughly 7,600 smaller permitted boilers as candidates for conversion. Because some smaller units may not have been registered, this number was increased by approximately 5%, yielding a total of 8,000 small commercial boilers that are considered candidates for conversion to wood heat.

10.4 Single Unit Module

The single unit module calculates the economic and emissions impact of each separate technology when used in each building profile. Calculations are based on assumptions of heating demand for each building profile, as well as oversize factors characteristic of each technology type. Four heating technology categories were evaluated: oil, business-as-usual (BAU) wood, and two categories of emerging wood technologies. Additional load modeling of each heating unit type determined overall efficiency and fuel consumption to meet heating demand. Capital, installation, and annual operation and maintenance costs for each heating unit were subsequently determined. The price of oil was derived from the AEO 2015 regional forecast for the mid-Atlantic region, under both the reference case and the high oil price case. State market prices for seasoned cordwood were assumed to be $225/cord under the reference case and high oil price case.[293] Cordwood for use in outdoor wood boilers, which often may be harvested by the consumer or derived from other lower-cost sources, was assumed to be $100/cord under both cases. Wood chip and pellet prices for NYS were provided by Innovative Natural Resource Solutions. 2015 wood pellets prices were assumed to be $250 per ton of wood pellets and 2015 wood chip prices were assumed to be $47 per ton.

For each year, this analysis assessed the costs of each type of heating system, based on first year capital and installation costs, as well as annual operating and maintenance costs along with fuel expenditures based on fuel consumption and fuel price. Cumulative costs were assessed in terms of net present value, using a discount rate of 5% for the residential sector and 3% for the commercial and institutional sector. The payback period for each wood heating unit was calculated relative to a new oil unit for each building profile. Additionally, this analysis projected annual emissions of particulate matter (PM), carbon monoxide (CO), and oxides of nitrogen (NO_x).

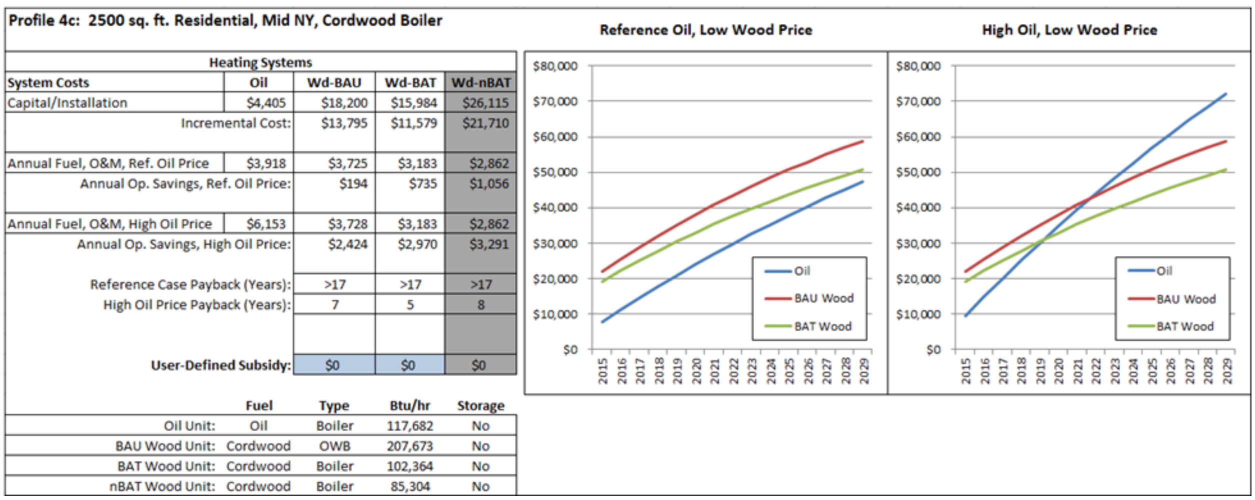
Due to the large number of scenarios, and similar results for related building types, rather than discussing each scenario in detail, this section summarizes the general trends that emerged from the analysis. Appendix G contains a complete description of each building profile and technology, as well as a detailed economic and emissions analysis for each profile.

Because outdoor wood boilers are typically significantly oversized, the efficiency of these units is low and fuel consumption is high, thus making their cost effectiveness highly sensitive to cordwood prices. At the higher market price for cordwood, in the $225-$250/cord range, in contrast to the oil boilers, these units did not achieve a full return on investment within 17 years following installation, the maximum length of time computed by the model. At the lower $100/cord price, however, they provided fuel savings on the order of $2,000-3,000 per year under reference oil prices, with a full return on investment in 9 to 11 years.

[293] Oil prices were modeled based on 2015 prices.

In spite of higher capital, installation, and fuel costs, residential BAT boilers also achieved fuel savings relative to oil boilers under high oil prices and had similar paybacks as OWBs under reference oil prices, and the return on investment under the high oil price scenario was generally in the range of a year less than OWBs due to gains in efficiency. A sensitivity analysis was performed to gauge the effect of thermal storage, which accelerated the payback of a BAT cordwood significantly. The payback under reference oil prices decreased to 8 years under reference oil prices and decreased from 5 to 3 years under high oil prices. Figure 10-4 and Figure 10-5 illustrate unit economics for residential cordwood boilers with and without thermal storage, compared to a BAU outdoor wood boiler and an oil boiler. Full economic results for residential units are listed under Profiles 1 through 4f in Appendix G.

Figure 10-4. Economics for Residential Cordwood Boiler, 2015

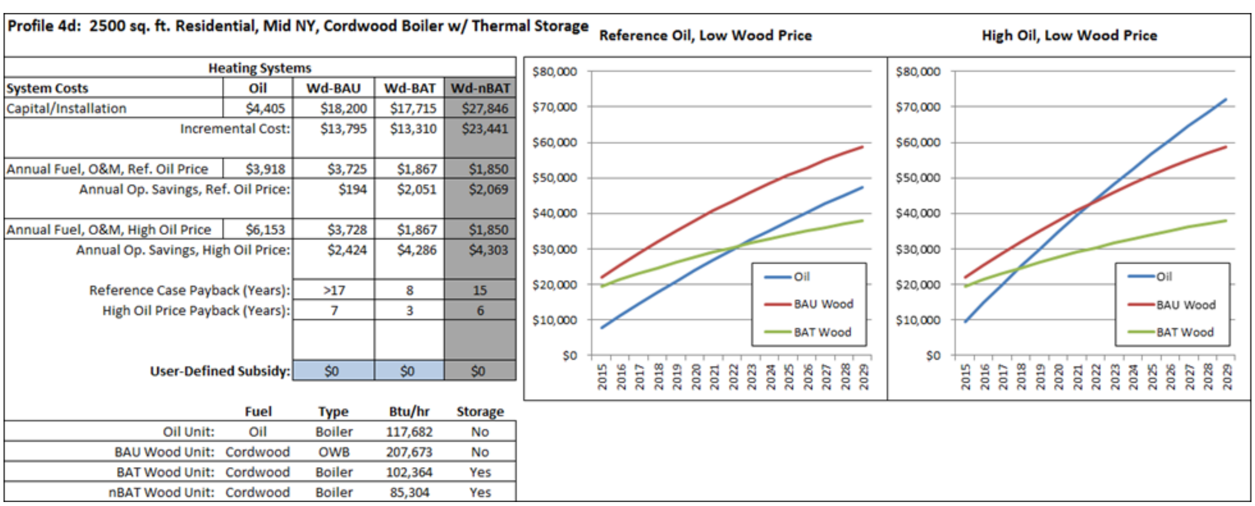


Profile 4c: 2500 sq. ft. Residential, Mid NY, Cordwood Boiler

System Costs	Oil	Wd-BAU	Wd-BAT	Wd-nBAT
Capital/Installation	$4,405	$18,200	$15,984	$26,115
Incremental Cost:		$13,795	$11,579	$21,710
Annual Fuel, O&M, Ref. Oil Price	$3,918	$3,725	$3,183	$2,862
Annual Op. Savings, Ref. Oil Price:		$194	$735	$1,056
Annual Fuel, O&M, High Oil Price	$6,153	$3,728	$3,183	$2,862
Annual Op. Savings, High Oil Price:		$2,424	$2,970	$3,291
Reference Case Payback (Years):		>17	>17	>17
High Oil Price Payback (Years):		7	5	8
User-Defined Subsidy:		$0	$0	$0

	Fuel	Type	Btu/hr	Storage
Oil Unit:	Oil	Boiler	117,682	No
BAU Wood Unit:	Cordwood	OWB	207,673	No
BAT Wood Unit:	Cordwood	Boiler	102,364	No
nBAT Wood Unit:	Cordwood	Boiler	85,304	No

Figure 10-5. Economics for Residential Cordwood Boiler with Thermal Storage, 2015



Profile 4d: 2500 sq. ft. Residential, Mid NY, Cordwood Boiler w/ Thermal Storage

System Costs	Oil	Wd-BAU	Wd-BAT	Wd-nBAT
Capital/Installation	$4,405	$18,200	$17,715	$27,846
Incremental Cost:		$13,795	$13,310	$23,441
Annual Fuel, O&M, Ref. Oil Price	$3,918	$3,725	$1,867	$1,850
Annual Op. Savings, Ref. Oil Price:		$194	$2,051	$2,069
Annual Fuel, O&M, High Oil Price	$6,153	$3,728	$1,867	$1,850
Annual Op. Savings, High Oil Price:		$2,424	$4,286	$4,303
Reference Case Payback (Years):		>17	8	15
High Oil Price Payback (Years):		7	3	6
User-Defined Subsidy:		$0	$0	$0

	Fuel	Type	Btu/hr	Storage
Oil Unit:	Oil	Boiler	117,682	No
BAU Wood Unit:	Cordwood	OWB	207,673	No
BAT Wood Unit:	Cordwood	Boiler	102,364	Yes
nBAT Wood Unit:	Cordwood	Boiler	85,304	Yes

In space heating applications, pellet and wood stoves were assumed to provide the majority of heat for each residential profile, but the devices were supplemented by an existing oil boiler during periods of highest heat demand. These units had much shorter paybacks than BAT boilers – in the range of 2 to 4 years under reference oil prices. These units typically had much lower capital and installation costs than hydronic boilers used for the same building profile, and provided substantial fuel savings relative to oil. Both BAT boilers and stoves showed substantially lower emissions in all categories relative to outdoor wood boilers, with an especially pronounced reduction in CO; however, both BAU and BAT wood technologies showed increased emissions in all categories relative to oil boilers. Figure 10-6 depicts the magnitude of CO emissions from different boilers heating a mid-size home. Figure 10-7 depicts emissions of PM and NO_x from the same units.

Figure 10-6. Annual CO Emissions (lbs) from Residential Boilers in a 2,500-sq.-ft. Residence in an Average New York State Climate Zone

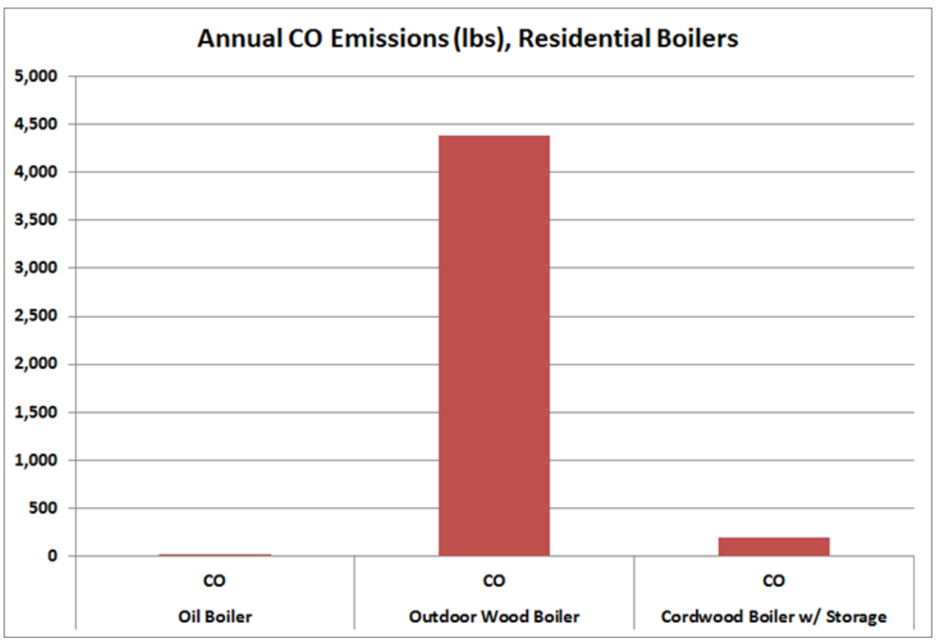
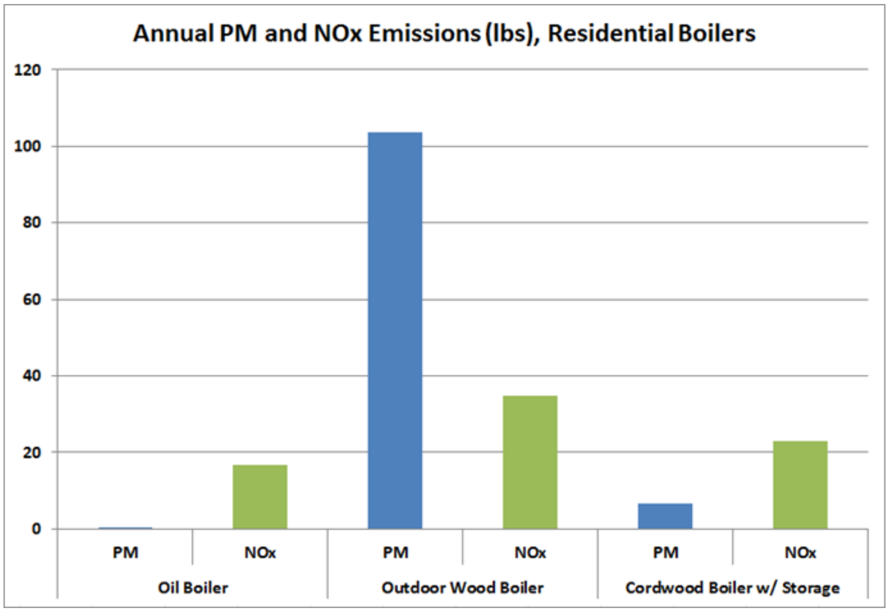


Figure 10-7. Annual PM and NO_x Emissions (lbs) from Residential Boilers in a 2,500-sq-ft. Residence in a Mid New York State Climate Zone



Commercial and institutional applications showed a wider range of economic impacts depending on the building profile, but as in the residential sector, there were some similar overall trends between profiles. Generally, BAU chip boilers required a much more expensive fuel handling system (i.e. heated and covered chip storage) than BAT technologies, which was the dominant factor driving the economics. For small and large schools in both climate zones, the capital and installation cost of the BAU chip unit exceeded the total capital and installation costs of a comparable oil system by close to $1 million, predominantly due to the cost of the fuel handling system. Annual fuel savings are highly dependent on oil prices. Under reference oil prices fuel savings range are minimal, typically under $5,000 for both small and large schools. Under high oil prices, however, fuel savings become more significant, and can be as much as $47,000 and up to $60,000 if thermal storage is used. The large up-front installation cost caused the BAU units to be more expensive than oil units, even after 17 years, the longest time period considered in the model.

By contrast, BAT pellet units for schools showed lower capital costs than BAU chip units due to less expensive fuel handling systems, and generated significant annual fuel savings relative to oil under the high oil price case. These systems delivered a return on investment within an 8 to 14 year timeframe, depending on the building profile and the system being installed, assuming high oil prices. In some cases, thermal storage systems were effective in increasing annual fuel savings and accelerating system paybacks. In the example shown in Figure 10-8 and Figure 10-9, annual fuel expenditures for the BAT unit equipped with a thermal storage system decreased from roughly $70,000 to $57,000, compared to $74,000 in fuel expenditures under reference oil prices and $117,00 under high oil prices from an oil boiler.

Figure 10-8. Economics for Large School, BAT Pellet Boiler, No Thermal Storage, 2015

Profile 7a: 130000 sq. ft. School, Mid NY

Heating Systems				
System Costs	**Oil**	**Wd-BAU**	**Wd-BAT**	**Wd-nBAT**
Capital/Installation	$63,314	$1,229,000	$381,607	$390,652
Incremental Cost:		$1,165,686	$318,293	$327,338
Annual Fuel, O&M, Ref. Oil Price	$74,807	$49,532	$69,925	$59,543
Annual Op. Savings, Ref. Oil Price:		$25,275	$4,882	$15,264
Annual Fuel, O&M, High Oil Price	$117,147	$51,833	$69,925	$62,370
Annual Op. Savings, High Oil Price:		$65,314	$47,222	$54,777
Reference Case Payback (Years):		>17	>17	>17
High Oil Price Payback (Years):		>17	8	7
User-Defined Subsidy:		$0	$0	$0

	Fuel	Type	Btu/hr	Storage
Oil Unit:	Oil	Boiler	4,042,049	No
BAU Wood Unit:	Chip	Boiler	7,133,028	No
BAT Wood Unit:	Pellet	Boiler	5,118,213	No
nBAT Wood Unit:	Pellet	Boiler	1,706,071	No

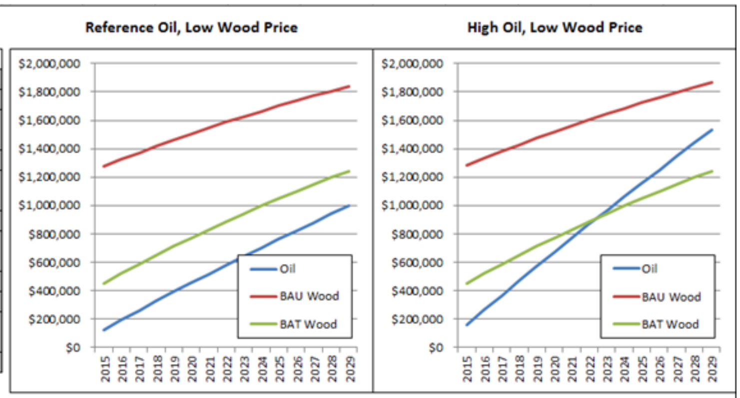
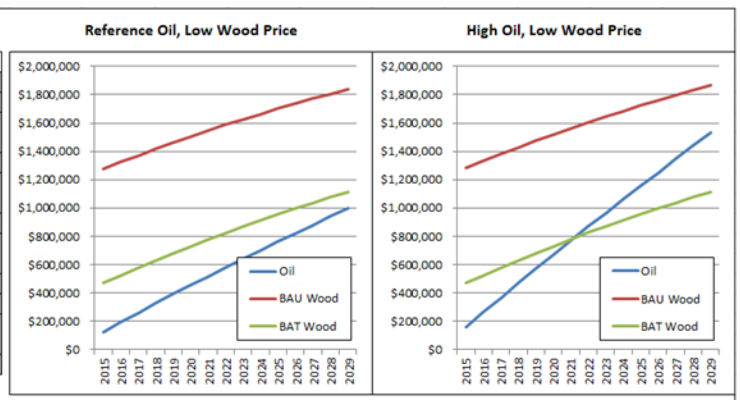


Figure 10-9. Economics for Large School, BAT Pellet Boiler with Thermal Storage, 2015

Profile 7b: 130000 sq. ft. School, Mid NY, w/ Thermal Storage

Heating Systems				
System Costs	**Oil**	**Wd-BAU**	**Wd-BAT**	**Wd-nBAT**
Capital/Installation	$63,314	$1,229,000	$412,756	$401,036
Incremental Cost:		$1,165,686	$349,442	$337,722
Annual Fuel, O&M, Ref. Oil Price	$74,807	$49,532	$57,006	$51,655
Annual Op. Savings, Ref. Oil Price:		$25,275	$17,801	$23,151
Annual Fuel, O&M, High Oil Price	$117,147	$51,833	$57,006	$51,655
Annual Op. Savings, High Oil Price:		$65,314	$60,141	$65,492
Reference Case Payback (Years):		>17	>17	16
High Oil Price Payback (Years):		>17	7	6
User-Defined Subsidy:		$0	$0	$0

	Fuel	Type	Btu/hr	Storage
Oil Unit:	Oil	Boiler	4,042,049	No
BAU Wood Unit:	Chip	Boiler	7,133,028	No
BAT Wood Unit:	Pellet	Boiler	5,118,213	Yes
nBAT Wood Unit:	Pellet	Boiler	1,706,071	Yes



The BAU chip boilers used in school applications emitted significantly higher emissions of PM, CO, and NO_x relative to oil boilers and BAT chip boilers. However, the BAT pellet technologies equipped with more advanced emissions controls, such as bag filters or electrostatic precipitators, had significantly lower emissions than the BAU chip technologies (Figure 10-10).

Figure 10-16 and Table 10-15 present the inputs for the Low Units, Low Technology scenario. Figure 10-17 and Table 10-16 present the inputs for the High Units, High Technology scenario. These two technology scenarios represent the low and high ends, respectively, of the possible economic input values.

Figure 10-16. Direct Inputs by Input Concept (Low Units, Low Technology) for All Regions Analyzed

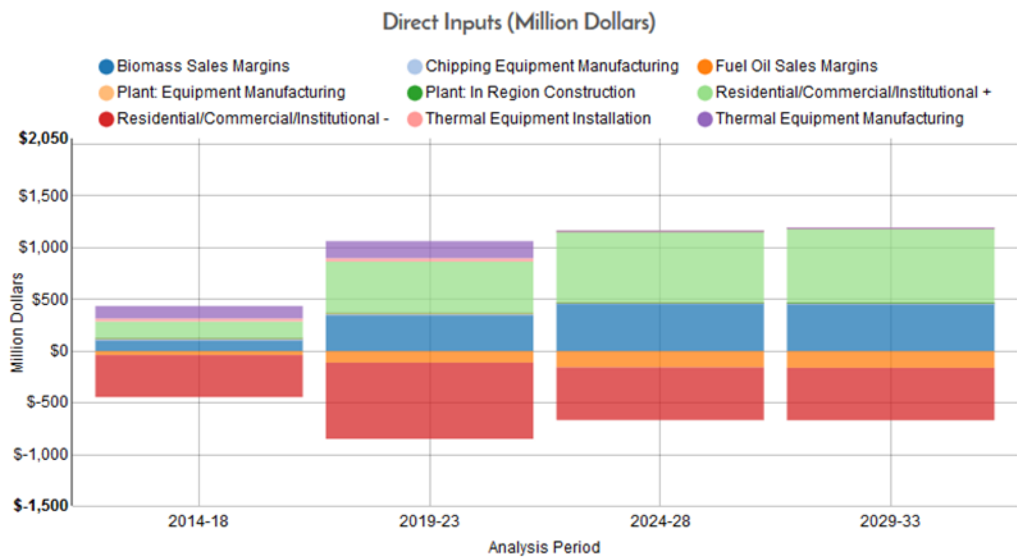


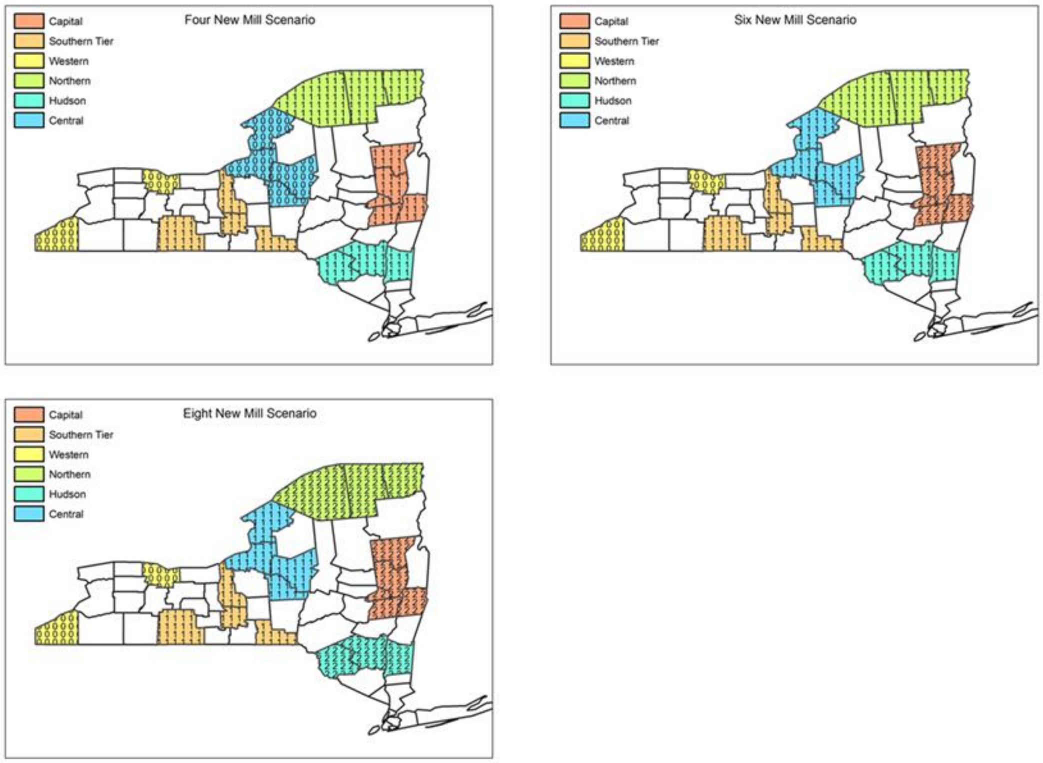
Table 10-15. Direct Inputs by Input Concept (Low Units, Low Technology) for All Regions Analyzed

$ Million

Indicator	2014-18	2019-23	2024-28	2029-33	Total
Residential / Commercial / Institutional, inflow	$195	$634	$903	$956	$2,688
Biomass Sales Margins	$116	$367	$483	$477	$1,443
Thermal Equipment Manufacturing	$121	$165	$0	$0	$286
Thermal Equipment Installation	$29	$34	$0	$0	$62
Plant: Equipment Manufacturing	$14	$14	$7	$7	$41
Plant: In Region Construction	$8	$8	$4	$4	$23
Chipping Equipment Manufacturing	$0	$1	$0	$0	$1
Fuel Oil Sales Margins	-$48	-$143	-$204	-$212	-$606
Residential / Commercial / Institutional, outflow	-$411	-$750	-$527	-$521	-$2,209
Total	$23	$329	$665	$710	$1,728

Figure 10-15. New Pellet Mill Scenario Definitions

Note: The numbers in each shaded region are the total number of new mills built in each region, not county, by pellet mill scenario.



10.7 Direct Economic Modeling Inputs (Concepts)

Once the macroeconomic modeling methodology was established, the direct economic inputs used to conduct the macroeconomic modeling were closely examined. These inputs were summarized in three different ways in order to best illustrate the input assumptions. More specifically, these direct inputs were summarized by economic input concept, by region, and by pellet mill scenario.

10.7.1 Summary of Modeling Inputs by Economic Input Concept

The scale-up analysis developed four scenarios that are described in Section 10.4. The scenarios reflect device deployment at lower and higher rates as well as lesser and more rapid deployment of advanced technology heating devices relative to BAU devices. The tables and figures below reflect the results of two of these scenarios, which bound the range of results for the four scenarios. The following tables and figures present the total value of inputs for all analysis regions under the assumption that the mid-range value of six new pellet mills were constructed in all scenarios.

While the low and high *unit* scenarios vary in the number of total units, the low and high *tech* level assumptions illustrate possible futures in which more advanced BAT technologies are deployed in lesser or greater numbers. While BAT units are widely used in more-developed wood heating markets, they are not typical of the types of units currently being deployed in NYS. As such, it was important to illustrate a range of adoption rates showing different levels of market penetration for advanced heating units. Separate technology adoption schedules were provided for the residential and commercial/institutional sectors, as shown in Figure 10-12 and Figure 10-13. The low and high tech scenarios also distributed conversions across different building and unit profiles. The low and high tech scenarios also distributed conversions across different building and unit profiles. The high tech scenarios also assumed more units would be deployed with thermal storage systems in the later years of the program. The full deployment assumptions for each building and unit profile are included in Appendix G.

Figure 10-12. Residential Technology Assumptions

Residential Cordwood - Low Tech

	BAU	BAT	nBAT
2014	75%	25%	
2015	40%	60%	
2016	40%	60%	
2017	40%	60%	
2018	33%	67%	
2019	27%	73%	
2020	20%	80%	
2021	20%	80%	
2022	20%	80%	
2023	20%	80%	0%

Residential Cordwood - High Tech

	BAU	BAT	nBAT
2014	75%	25%	
2015	10%	90%	
2016	10%	90%	
2017	10%	90%	
2018	7%	93%	
2019	3%	97%	
2020	0%	100%	
2021	0%	100%	
2022	0%	100%	
2023	0%	90%	10%

Figure 10-13. Commercial Technology Assumptions

ICI Chip - Low Tech

	BAU	BAT	nBAT
2014	95%	5%	
2015	95%	5%	
2016	95%	5%	
2017	95%	5%	
2018	90%	10%	
2019	90%	10%	
2020	80%	20%	
2021	80%	20%	
2022	80%	20%	
2023	80%	20%	0%

ICI Chip - High Tech

	BAU	BAT	nBAT
2014	95%	5%	
2015	90%	10%	
2016	90%	10%	
2017	90%	10%	
2018	80%	20%	
2019	60%	40%	
2020	50%	50%	
2021	50%	50%	
2022	50%	50%	
2023	40%	55%	5%

The analysis showed that conversion to wood heating provided substantial savings relative to oil heat in all four commercial/institutional scenarios, despite higher up-front purchase and installation costs, as fuel savings accrued over the lifetime of the units. To illustrate how the economic dynamics change during the period when the units are purchased and installed versus the lifetime fuel savings they provide relative to oil, the analysis quantified total scenario costs for both a 10-year period of installation from 2014 to 2023 and a 20-year period from 2014 to 2033, using the 2015AEO reference and the high oil price cases. In addition to total costs, the aggregate changes in emissions were also calculated for each scenario. Economic and emission results for the different scenarios are depicted in Tables 10-3 to 10-14.

Tables 10-3, 10-4, 10-5. Low Units, Low Tech Scenario Economic and Emission Results

Cost Summary (Millions of 2012$), Ref Oil, Low Wood Price				Cost Summary (Millions of 2012$), High Oil, Low Wood Price			
	C&I 3% NPV	Residential 5% NPV	**Total, NPV**		C&I 3% NPV	Residential 5% NPV	**Total, NPV**
2014-2023	$374.7	$39.6	**$414.3**	2014-2023	$226.5	-$36.1	**$190.4**
2014-2033	$168.9	-$42.1	**$126.8**	2014-2033	-$281.3	-$227.5	**-$508.8**

Emissions Delta Summary (tons per year)									
	C&I PM	Res PM	**Total PM**	C&I CO	Res CO	**Total CO**	C&I NOx	Res NOx	**Total NOx**
2023	239.0	76.3	**315.4**	607.9	2,678.1	**3,286.0**	337.0	2.0	**339.0**

Tables 10-6, 10-7, and 10-8. Low Units, High Tech Scenario Economic and Emission Results

Cost Summary (Millions of 2012$), Ref Oil, Low Wood Price				Cost Summary (Millions of 2012$), High Oil, Low Wood Price			
	C&I 3% NPV	Residential 5% NPV	**Total, NPV**		C&I 3% NPV	Residential 5% NPV	**Total, NPV**
2014-2023	$354.1	$34.3	**$388.4**	2014-2023	$201.2	-$41.2	**$160.1**
2014-2033	$141.1	-$52.6	**$88.6**	2014-2033	-$326.5	-$236.2	**-$562.8**

Emissions Delta Summary (tons per year)									
	C&I PM	Res PM	**Total PM**	C&I CO	Res CO	**Total CO**	C&I NOx	Res NOx	**Total NOx**
2023	205.7	46.6	**252.2**	547.4	1,401.2	**1,948.6**	329.2	-4.0	**325.1**

Tables 10-9, 10-10, and 10-11. High Units, Low Tech Scenario Economic and Emission Results

Cost Summary (Millions of 2012$), Ref Oil, Low Wood Price				Cost Summary (Millions of 2012$), High Oil, Low Wood Price			
	C&I 3% NPV	Residential 5% NPV	**Total, NPV**		C&I 3% NPV	Residential 5% NPV	**Total, NPV**
2014-2023	$664.7	$57.6	**$722.2**	2014-2023	$401.5	-$37.8	**$363.8**
2014-2033	$299.2	-$54.9	**$244.3**	2014-2033	-$497.8	-$303.5	**-$801.3**

Emissions Delta Summary (tons per year)									
	C&I PM	Res PM	**Total PM**	C&I CO	Res CO	**Total CO**	C&I NOx	Res NOx	**Total NOx**
2023	429.8	100.4	**530.2**	1,087.9	3,436.1	**4,524.0**	597.8	7.3	**605.1**

Tables 10-12, 10-13, and 10-14. High Units, High Tech Scenario Economic and Emission Results

Cost Summary (Millions of 2012$), Ref Oil, Low Wood Price				Cost Summary (Millions of 2012$), High Oil, Low Wood Price			
	C&I 3% NPV	Residential 5% NPV	**Total, NPV**		C&I 3% NPV	Residential 5% NPV	**Total, NPV**
2014-2023	$636.0	$56.2	**$692.1**	2014-2023	$364.8	-$39.0	**$325.7**
2014-2033	$263.1	-$60.9	**$202.2**	2014-2033	-$563.7	-$307.2	**-$870.9**

Emissions Delta Summary (tons per year)									
	C&I PM	Res PM	**Total PM**	C&I CO	Res CO	**Total CO**	C&I NOx	Res NOx	**Total NOx**
2023	370.4	75.2	**445.6**	980.3	2,361.8	**3,342.1**	583.9	1.0	**584.9**

10.5.1 State Scale-Up Summary

In all four scenarios, the analysis showed that deployment of wood heating technologies under reference oil prices does not provide cost savings relative to oil over the lifetime of the units. Specific applications in the residential sector, however, do show savings within a 20-year timeframe. Correct sizing, thermal storage and optimized efficiency are required elements in order to achieve a payback under reference oil prices. Under the high oil price scenario, economic paybacks were realized in both the commercial and residential sector within a 20-year timeframe. The greatest difference between the four scenarios is the substantial increase in emissions relative to oil units when using BAU technologies. In contrast, for most building profiles, BAT technologies result in substantial PM and CO emission reductions of more than 90% relative to the BAU units. Over the lifetime of the units, BAT technologies tend to show roughly comparable costs to their BAU counterparts for most building profiles. In some commercial building profiles, the lifetime cost of BAT units is substantially less, due to the significantly lower capital and installation cost of a BAT unit (approximately $400,000) relative to a BAU chip unit with a more expensive fuel handling system (approximately $1.2 million), as illustrated in the previous section. The nBAT technologies, which are only assumed to be deployed in the final year of the program, show a very similar economic profile to the BAT technologies, while providing even greater emission reductions relative to a BAU wood unit.

10.6 Macroeconomic Analysis

Building on the four State scale-up scenarios discussed in the previous section that reflect different projected future trends in the deployment of wood heat technologies, a macroeconomic impact analysis was conducted to assess the effects of the four technology scenarios on employment and gross regional product (GRP) in 21 counties. The analysis evaluated all possible permutations of the four technology scenarios, including three permutations in which the number of projected new pellet mills was varied and two fuel price permutations. This macroeconomic analysis required the establishment of a methodology, the specification of model inputs, and the careful examination of model results.

10.6.1 Methodology

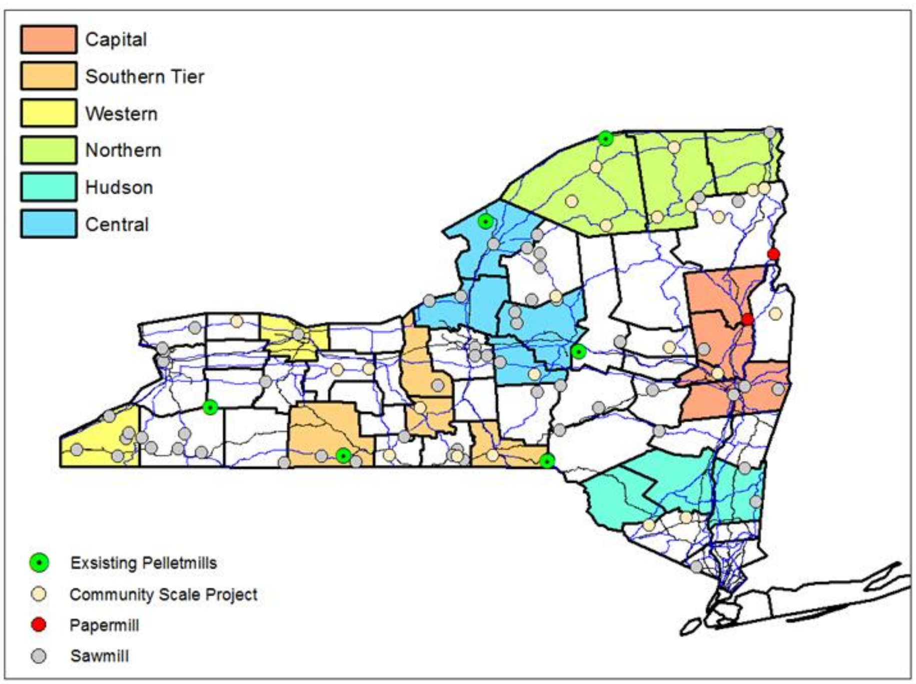
The macroeconomic impacts were estimated using the RIMS II economic impact modeling system, an Input-Output (I-O) accounting framework. The model is comprised of a set of industry multipliers that translate microeconomic impacts associated with a particular scenario into macroeconomic impacts on employment, gross regional product (GRP), earnings, and output.

In order to undertake a regional analysis, the outputs from the four State-level scenario analyses were reorganized by county, technology group, expenditure categories, and timeframe. The scenario outputs included required capital investment and the costs of labor, operation and maintenance (O&M), and fuel. Projecting future trends in NYS' wood fuel manufacturing industry was a key variable in the analysis. Assumptions were made to develop a range of new pellet mill construction and chipping equipment investment scenarios. The outcome of the data reorganization and wood fuel manufacturing scenario assumptions was a set of direct expenditure categories. Before conducting the economic modeling, however, the direct expenditure categories were recast into macroeconomic impact modeling inputs.

Economic impact modeling inputs form an accounting framework used to track how money flows through an economic system. It is possible to do a cost benefit analysis at a household level knowing how much money was spent on heating equipment, fuel, labor, and financing services. To undertake a broader macroeconomic analysis, however, it is important to also attribute those same household expenditures to other in-state economic sectors, such as equipment manufacturers and local equipment installers. Likewise, household expenditures associated with fuel and financing represent income to other sectors of New York State's economy. In other words, the direct expenditures of a household are recast into economic concepts that adequately capture the flow of money, and its impact on NYS' economy, referred to in this analysis as macroeconomic impact modeling concepts. Figure 10-14 displays the regions selected for macroeconomic modeling and indicates existing wood processing facilities.

Following development of the economic impact modeling concepts, the flow of money (inflows and outflows) were mapped into specific industries represented in the RIMS II analysis framework. A detailed mapping is included in Appendix G. Once the industry mapping was established, RIMS II industry-specific multipliers were applied to the full set of impact modeling concepts to estimate effects on employment and GRP.

Figure 10-14. Regions in New York State Analyzed for Macroeconomic Impact



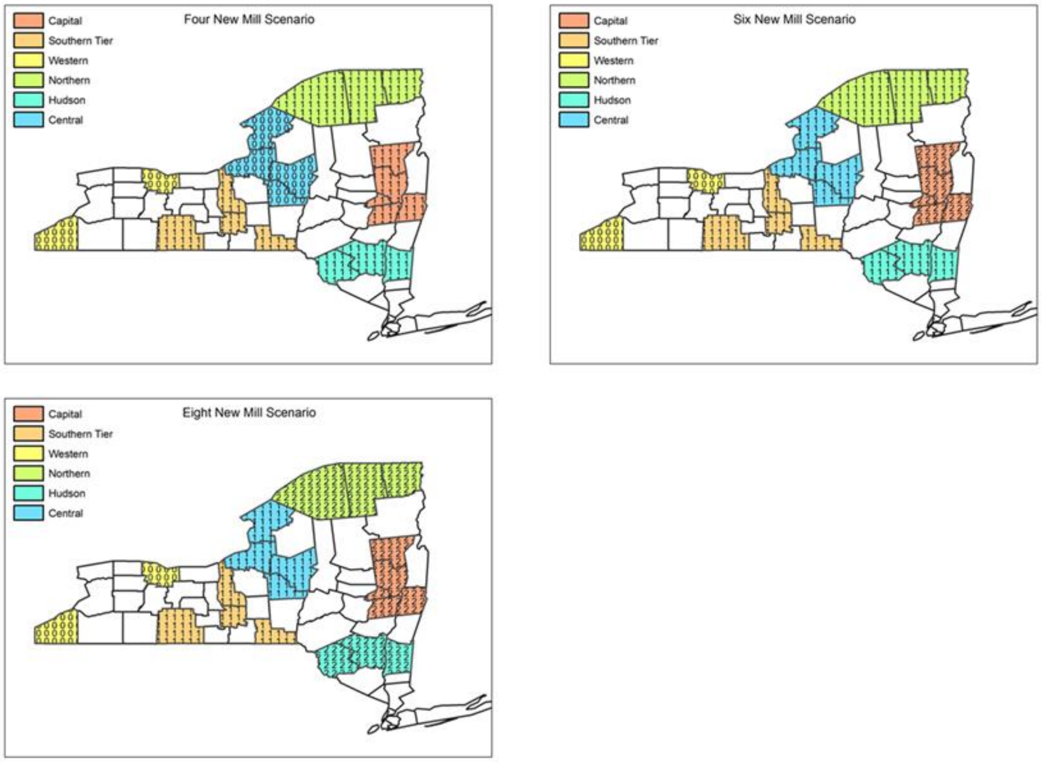
10.6.1.1 Pellet Mill and Chipping Assumptions

The macroeconomic analysis examined three pellet mill construction scenarios. Pellet mill capacity and costs were researched, and this information was then presented to industry experts, who reviewed and revised the data. Based on that analysis, the study assumed that a new pellet mill had an average production capacity of 80,000 thousand tons of pellets per year at a total construction cost of $14.2 million. Total pellet mill construction costs included all plant equipment, site preparation materials, labor, and solid wood transportation machinery. A detailed bill of goods outlining all components of the idealized pellet plant can be found in Appendix G.

A group of industry consultants and pellet manufacturers were convened to review the proposed model scenarios. Based on their input, it was agreed that the analysis would model three scenarios, which would examine the impacts of constructing between four and eight new pellet plants throughout the study regions. In each scenario, the timing of pellet mill construction was distributed differently throughout the timeframe. Figure 10-15 presents how each new pellet mill scenario was defined, with the total number of new mills in a region being represented by a number pattern overlaying the counties that comprise the region. The only region that did not construct a new pellet mill in any of the pellet mill scenarios was the Western region, which also has no existing mills. For these reasons, the positive economic effects associated with hypothetical growth in the wood fuel manufacturing industry are dampened in the Western region relative to the other five regions.

Figure 10-15. New Pellet Mill Scenario Definitions

Note: The numbers in each shaded region are the total number of new mills built in each region, not county, by pellet mill scenario.



10.7 Direct Economic Modeling Inputs (Concepts)

Once the macroeconomic modeling methodology was established, the direct economic inputs used to conduct the macroeconomic modeling were closely examined. These inputs were summarized in three different ways in order to best illustrate the input assumptions. More specifically, these direct inputs were summarized by economic input concept, by region, and by pellet mill scenario.

10.7.1 Summary of Modeling Inputs by Economic Input Concept

The scale-up analysis developed four scenarios that are described in Section 10.4. The scenarios reflect device deployment at lower and higher rates as well as lesser and more rapid deployment of advanced technology heating devices relative to BAU devices. The tables and figures below reflect the results of two of these scenarios, which bound the range of results for the four scenarios. The following tables and figures present the total value of inputs for all analysis regions under the assumption that the mid-range value of six new pellet mills were constructed in all scenarios.

Figure 10-16 and Table 10-15 present the inputs for the Low Units, Low Technology scenario. Figure 10-17 and Table 10-16 present the inputs for the High Units, High Technology scenario. These two technology scenarios represent the low and high ends, respectively, of the possible economic input values.

Figure 10-16. Direct Inputs by Input Concept (Low Units, Low Technology) for All Regions Analyzed

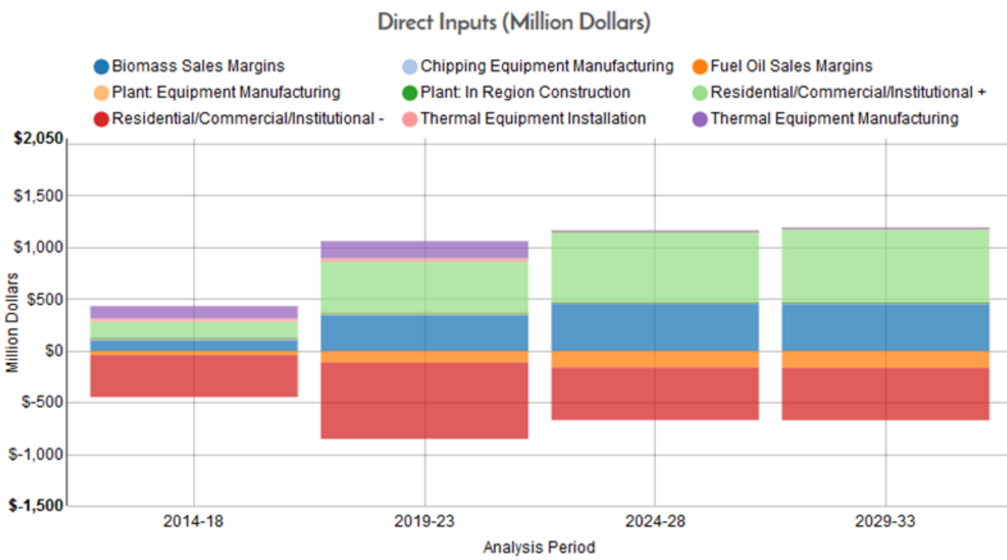


Table 10-15. Direct Inputs by Input Concept (Low Units, Low Technology) for All Regions Analyzed

$ Million

Indicator	2014-18	2019-23	2024-28	2029-33	Total
Residential / Commercial / Institutional, inflow	$195	$634	$903	$956	$2,688
Biomass Sales Margins	$116	$367	$483	$477	$1,443
Thermal Equipment Manufacturing	$121	$165	$0	$0	$286
Thermal Equipment Installation	$29	$34	$0	$0	$62
Plant: Equipment Manufacturing	$14	$14	$7	$7	$41
Plant: In Region Construction	$8	$8	$4	$4	$23
Chipping Equipment Manufacturing	$0	$1	$0	$0	$1
Fuel Oil Sales Margins	-$48	-$143	-$204	-$212	-$606
Residential / Commercial / Institutional, outflow	-$411	-$750	-$527	-$521	-$2,209
Total	$23	$329	$665	$710	$1,728

Figure 10-17. Direct Inputs by Input Concept (High Units, High Technology) for All Regions Analyzed

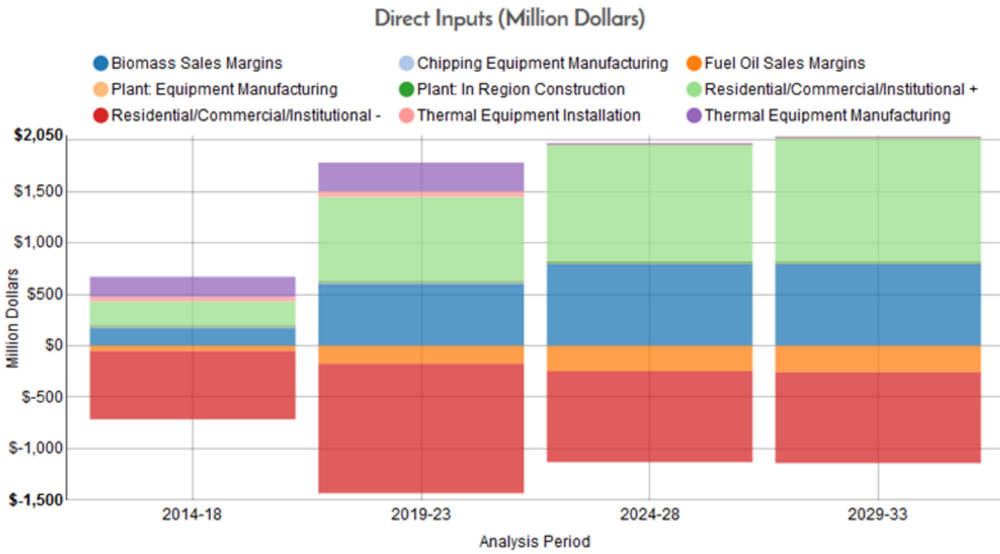


Table 10-16. Direct Inputs by Input Concept (High Units, High Technology) for All Regions Analyzed

$ Million

Indicator	2014-18	2019-23	2024-28	2029-33	Total
Residential / Commercial / Institutional, inflow	$294	$1,058	$1,511	$1,616	$4,479
Biomass Sales Margins	$188	$632	$835	$828	$2,483
Thermal Equipment Manufacturing	$194	$280	$0	$0	$474
Thermal Equipment Installation	$45	$56	$0	$0	$101
Plant: Equipment Manufacturing	$14	$14	$7	$7	$41
Plant: In Region Construction	$8	$8	$4	$4	$23
Chipping Equipment Manufacturing	$0	$1	$0	$0	$1
Fuel Oil Sales Margins	-$65	-$224	-$320	-$339	-$947
Residential / Commercial / Institutional, outflow	-$671	-$1,280	-$913	-$907	-$3,771
Total	$8	$544	$1,123	$1,210	$2,884

10.7.2 Summary of Modeling Inputs by Analysis Region

The economic inputs were also summarized by region. The comparisons in the following figures and tables focus on the Low Units, Low Technology scenario, and the High Units, High Technology scenario. Each of the tables and figures below presents the inputs at the intermediate level of new pellet mill construction, which assumes six new pellet plants. Figure 10-18 and Table 5 reflect the Low Units, Low Technology scenario. Figure 10-19 and Table 10-18 reflect the High Units, High Technology scenario.

Figure 10-18. Direct Inputs by Region (Low Units, Low Technology) Assuming Six New Pellet Mills

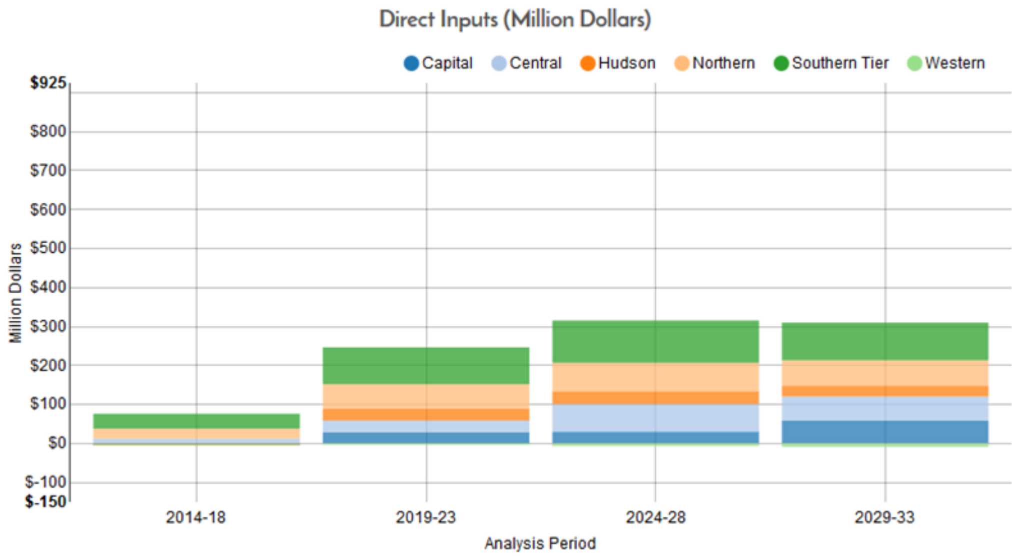


Table 10-17. Direct Inputs by Region (Low Units, Low Technology) Assuming Six New Pellet Mills

$ Million

Region	2014-18	2019-23	2024-28	2029-33	Total
Southern Tier	$30	$97	$157	$151	$434
Capital	$3	$93	$117	$164	$377
Central	$2	$36	$129	$124	$291
Northern	$23	$65	$98	$93	$280
Hudson	-$14	$37	$87	$90	$201
Western	-$21	$1	$77	$88	$145
Total	$23	$329	$665	$710	$1,728

Figure 10-19. Direct Inputs by Region (High Units, High Technology) Assuming Six New Pellet Mills

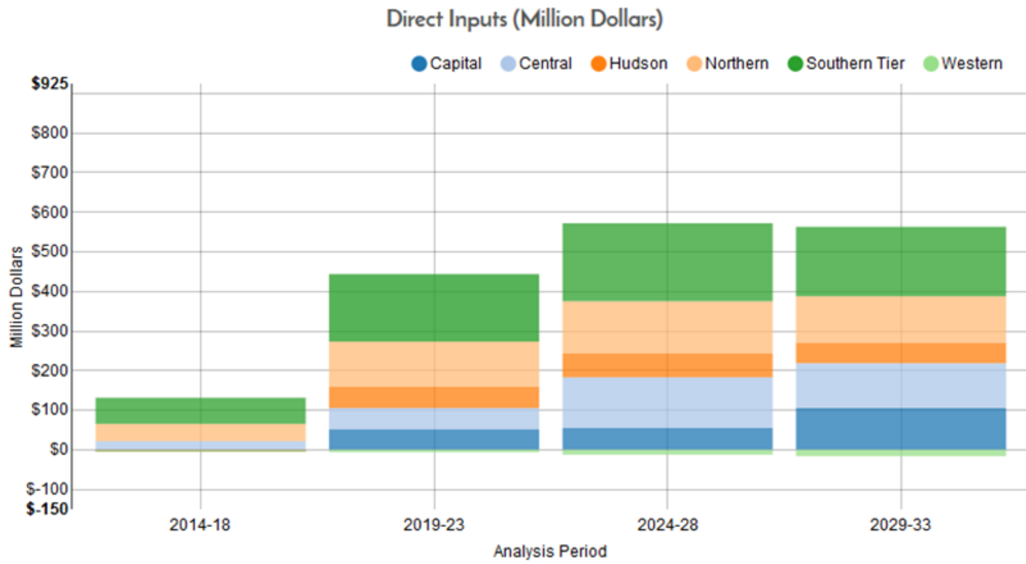


Table 10-18. Direct Inputs by Region (High Units, High Technology) Assuming Six New Pellet Mills

$ Million

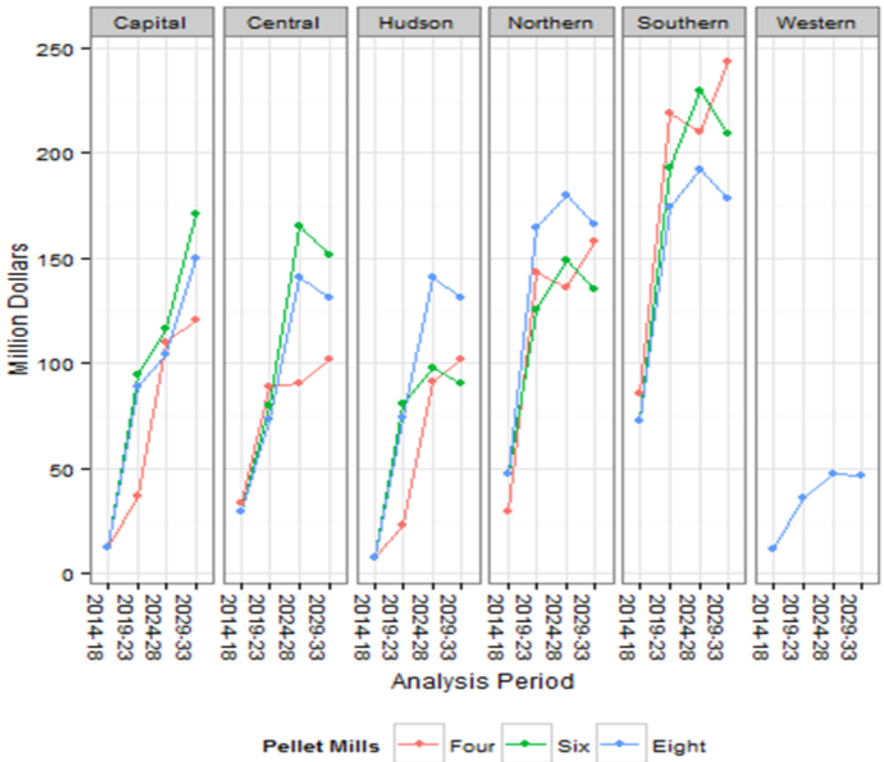
Region	2014-18	2019-23	2024-28	2029-33	Total
Southern Tier	$46	$171	$274	$264	$755
Capital	$1	$148	$193	$275	$616
Central	-$2	$59	$218	$213	$488
Northern	$36	$115	$173	$164	$488
Hudson	-$28	$58	$146	$152	$327
Western	-$44	-$8	$120	$141	$209
Total	$8	$544	$1,123	$1,210	$2,884

10.7.3 Summary of Modeling Inputs by Pellet Mill Scenario

The macroeconomic modeling inputs were also summarized by the pellet mill scenario assumption. In this study, the new pellet mill scenario assumptions are varied to estimate impacts of constructing four, six, or eight new pellet mills. Comparisons focus on the low- and high-end technology scenarios and only examine the impact of these fuels production from new and existing mills. This concept is referred to as the wood fuel sales margin concept. The rationale for isolating this concept is two-fold. First, wood fuel sales are the second largest positive contributor to overall net input expenditures after residential, commercial, and institutional fuel savings, which cause pellet mill construction to have a large influence on the macroeconomic estimates. Second, wood fuel sales are roughly an order of magnitude larger than the other two inputs associated with the pellet manufacturing industry: 1) pellet plant equipment manufacturing and 2) pellet plant labor and site preparation materials.

Figure 10-20 presents the wood fuel sales margins in each region for each pellet scenario based on the High Units, High Technology scenario. Note that in some regions, wood fuel sales margins are lower based on the presumed number of new pellet mills built within the scenario. This difference is particularly apparent in the Southern Tier. This trend is the result of the relationship between new mill construction and pellet sales. When an additional new mill is constructed in a region, that region will capture a larger share of the total in-state demand for pellets because, for a given technology unit scenario, the demand for wood fuel is fixed. If, however, a region builds the same number of new plants in each pellet scenario, then the additional new plants built in other regions will capture an increasingly larger share of that region's pellet sales, and overall wood fuel sales margins in that region will be highest in the four-mill scenario and lowest in the eight-mill scenario. This scenario is the case for the Southern Tier. In the four-mill scenario, the new mill built in the Southern Tier captures a larger share of the pellet market because the environment is less competitive, while in the eight-mill scenario, the one plant built in the Southern Tier is competing with a larger number of pellet suppliers. This outcome is illustrated in Figure 10-15 and Figure 10-20. It is important to note that the analysis only considered sales within NYS, and does not account for pellet mill sales of wood heating fuel to parties outside of the State. These dynamics would be important to capture in a future analysis.

Figure 10-20. Wood Fuel Sale Margins by Pellet Mill Scenario



10.8 Macroeconomic Results

The key metrics for evaluating the macroeconomic effects of the analyzed scenarios are employment and GRP. The following figures and tables represent results for industries in the 21 counties within the six regions. Only the four-mill and eight-mill scenarios are presented in this high-level summary of results, as they bound results for the six-mill scenario as well. Figure 10-21 and Table 10-19 reflect the employment impacts in the four-mill and eight-mill scenarios. In the Low Units, Low Technology scenario, total employment impacts over the 20-year time period range from 5,710 new jobs in the four-mill scenario to 5,890 new jobs in the eight-mill scenario. In the High Units, High Technology scenario, total employment impacts over the 20-year time period range from 8,670 new jobs in the four-mill scenario to 9,850 new jobs in the eight-mill scenario. Note that these employment impact estimates do not imply that each job created lasts for the full 20-year timeframe. In 2013, as a point of reference, the six-region study area had an employment level of 1,552,300 across all sectors.

Figure 10-21. Employment Impacts by Technology Scenario Across All Sectors

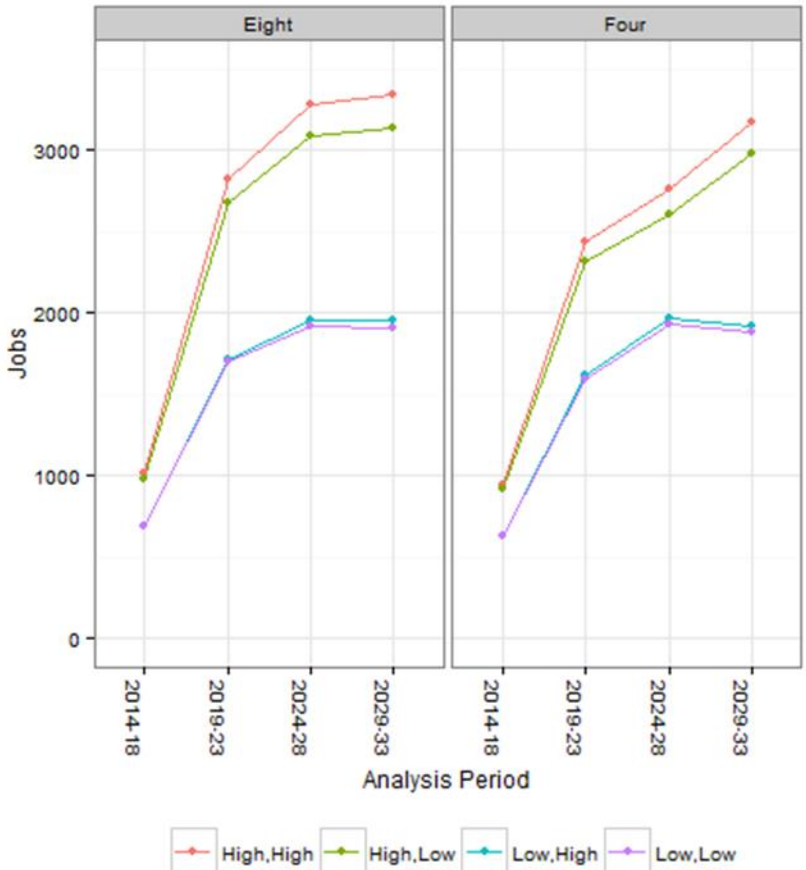


Table 10-19. Summary of Employment Impacts by Technology Scenario[294]

Number of New Plants	Technology Scenario	2014-18	2019-23	2024-28	2029-33	Total
8	High,High	980	2,670	3,090	3,110	9,850
4		910	2,280	2,540	2,940	8,670
8	High,Low	970	2,620	3,010	3,030	9,630
4		910	2,240	2,490	2,870	8,510
8	Low,High	670	1,630	1,840	1,830	5,970
4		610	1,530	1,860	1,800	5,800
8	Low,Low	670	1,620	1,810	1,790	5,890
4		610	1,510	1,830	1,760	5,710

294 Data are rounded to the nearest tenth place; as a result, some data do not sum exactly to the reported total summaries.

Figure 10-22 and Table 10-20 depict the GRP impacts in the four-mill and eight-mill scenarios. In the Low Units, Low Technology scenario, growth in the gross regional product over the 20-year time period ranges from 860 million dollars in the four-mill scenario to 880 million dollars in the eight-mill scenario. In the High Units, High Technology scenario, growth in the gross regional product over the 20-year time period ranges from $1.32 billion in the four-mill scenario to $1.49 billion in the eight-mill scenario.

Figure 10-22. GRP Impacts by Technology Scenario

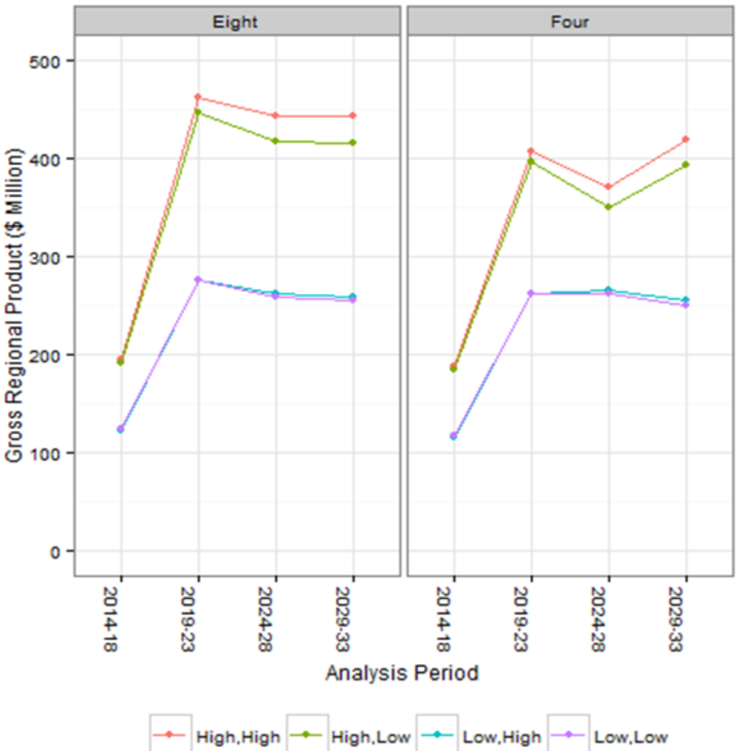


Table 10-20. Summary of GRP Impacts by Technology Scenario ($ in millions)

Data are rounded to the nearest multiple of ten. As a result, some data do not sum exactly to the reported total summaries.

Number of New Plants	Technology Scenario	2014-18	2019-23	2024-28	2029-33	Total
8	High,High	$190	$450	$430	$420	$1,490
4		$190	$390	$350	$390	$1,320
8	High,Low	$190	$450	$420	$410	$1,470
4		$190	$390	$340	$380	$1,300
8	Low,High	$120	$270	$250	$250	$890
4		$120	$260	$260	$240	$880
8	Low,Low	$120	$270	$250	$240	$880
4		$120	$260	$250	$240	$870

10.8.1 Detailed Industry and Regional Results

This macroeconomic analysis did not estimate the impacts on the forestry industry for harvesting, pre-processing, and transporting wood fuel products to pellet mills or chipping operations. This strategy was a departure from the economic analysis conducted in the 2010 Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply for New York State (RFR).[295] The RFR estimated the economic impacts of developing the liquid biofuels market in the State. That analysis explicitly considered the effects on the forestry industry supplying feedstock to biofuel manufacturing operations. The RFR found that agriculture and forestry sector-related employment impacts were the largest.

The economic impact analysis in the RFR indicated that approximately 4,000 to14,000 jobs may be created by a new lignocellulosic biofuels industry, depending on the scenario and assumptions. Most of the jobs were in crop-based, forestry-based, and transportation (trucking) sectors, with a very small share of these jobs (between 275 and 1,320) in the refineries themselves. Agriculture and forestry jobs ranged from 43-49% of the total jobs, transportation-based jobs ranged from 13-29% of the total jobs, and miscellaneous input sector jobs ranged from 17-19% of the total jobs. It is not clear how analogous these results are to the wood heating industry, but growth in either biofuels or wood heating would create jobs in biomass feedstock supply.

In this analysis, the largest positive impacts are in the manufacturing sector. The manufacturing impacts are largely driven by new pellet mill construction, wood heating device manufacturing, and increased sale of wood fuel products by the wood product manufacturing industry. The analysis anticipates that the retail trade industry will experience an overall decline in fuel oil sales that was partially, but not completely, offset by increased biomass sales. Depending on the extent to which the current fuel oil supply industry could assume the new wood fuel product distribution, the negative impacts on them could be mitigated. Industries that fared well in the analysis, such as health care, food and other services, benefited from the indirect and induced impacts resulting from the net savings by households spent on consumption goods.

[295] New York Renewable Fuels Roadmap, http://www.nyserda.ny.gov/Cleantech-and-Innovation/Biomass/Biomass-Reports/Renewable-Fuels-Roadmap.aspx

Macroeconomic impacts were also evaluated by industry at the regional level. The High Units, High Technology scenario with eight new pellet mills had the highest estimated level of economic impact. Table 10-21 summarizes regional employment impacts, and Table 10-22 summarizes GRP impacts.

Table 10-21. Detailed Employment Results by Analysis Region 2015-2035

Data are rounded to the nearest multiple of ten. As a result, some data do not sum exactly to the reported total summaries.

Industry	Capital	Central	Hudson	Northern	Southern	Western	Total
Manufacturing	830	550	0	0	1150	320	2850
Other services	170	130	110	80	110	180	780
Health care and social assistance	120	120	80	40	120	150	630
Transportation and warehousing	20	90	40	180	170	-90	410
Food services and drinking places	80	70	40	20	60	70	340
Real estate and rental and leasing	50	30	20	10	30	50	190
Administrative and waste management services	30	30	10	10	40	30	150
Finance and insurance	30	30	10	0	30	30	130
Professional, scientific, and technical services	30	30	10	0	20	30	120
Educational services	20	20	10	10	20	30	110
Agriculture, forestry, fishing, and hunting	0	70	0	0	20	0	90
Wholesale trade	20	20	10	0	10	20	80
Arts, entertainment, and recreation	10	10	10	0	10	10	50
Management of companies and enterprises	10	0	0	0	30	10	50
Information	10	10	0	0	10	10	40
Construction	10	10	0	0	0	0	20
Accommodation	0	10	0	0	0	0	10
Mining	0	0	0	0	0	0	0
Utilities	0	0	0	0	0	0	0
Retail trade	-240	-180	-220	-100	-140	-380	-1260
Total	**1200**	**1050**	**130**	**250**	**1690**	**470**	**4790**

The largest macroeconomic effects occurred in the Southern Tier, and in the Capital and Central regions (Table 10-22). The largest drivers of regional differences are new pellet mill construction, the ability of a region to manufacture pellet mill equipment or wood heating devices, and how many wood heating devices were purchased by households and businesses. The Southern region's position as the largest beneficiary of the program is a result of new pellet mill construction and increased wood fuel product sales by existing mills located there. The Capital region has the largest capacity to manufacture equipment for a pellet mill and benefits from any new mills constructed throughout the study region. The Western region did not construct any new mills or produce pellets, chips, or substantially increase cordwood harvests; however, the analysis assumed that 20-30% of all new cordwood boilers were manufactured there. As a result, the Western region's manufacturing sector experienced positive economic growth. The Hudson and Northern regions benefit primarily from net household and business savings as a result of purchasing efficient wood heating devices. The Hudson and Northern regions have small manufacturing sectors relative to other regions and as a result played a minor role in manufacturing pellet mill equipment and wood heating devices.

It is also important to note that the largest variation in regional results occurred in the manufacturing and retail trade industries. As previously mentioned, manufacturing sector impacts are primarily driven by a region's capacity to construct pellet mill equipment, wood heating devices, and pellets, chips, or cordwood. The retail trade effects are mainly driven by a region's population. Population was used to determine the number of wood heating devices each region purchased, which as a result, drove reductions in retail fuel oil sales.

Table 10-22. Detailed GRP Analysis Results by Region ($ in millions)

Data are rounded to the nearest multiple of ten. As a result, some data do not sum exactly to the reported total summaries.

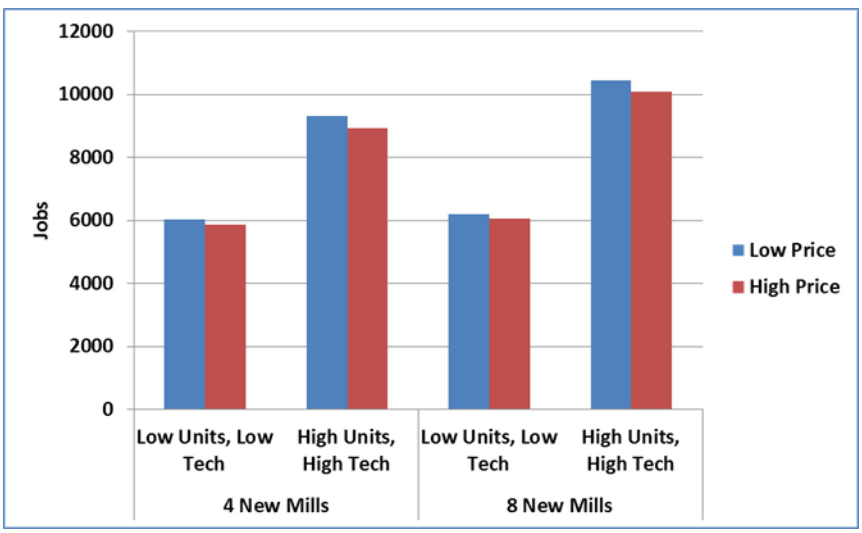
Industry	Capital	Central	Hudson	Northern	Southern	Western	Total
Manufacturing	$70	$50	$0	$0	$60	$20	$200
Other services	$20	$10	$10	$0	$10	$20	$70
Real estate and rental and leasing	$20	$10	$10	$0	$10	$10	$60
Health care and social assistance	$10	$0	$0	$0	$0	$10	$20
Transportation and warehousing	$0	$0	$0	$10	$10	-$10	$10
Accommodation	$0	$0	$0	$0	$0	$0	$0
Administrative and waste management services	$0	$0	$0	$0	$0	$0	$0
Agriculture, forestry, fishing, and hunting	$0	$0	$0	$0	$0	$0	$0
Arts, entertainment, and recreation	$0	$0	$0	$0	$0	$0	$0
Construction	$0	$0	$0	$0	$0	$0	$0
Educational services	$0	$0	$0	$0	$0	$0	$0
Finance and insurance	$0	$0	$0	$0	$0	$0	$0
Food services and drinking places	$0	$0	$0	$0	$0	$0	$0
Information	$0	$0	$0	$0	$0	$0	$0
Management of companies and enterprises	$0	$0	$0	$0	$0	$0	$0
Mining	$0	$0	$0	$0	$0	$0	$0
Professional, scientific, and technical services	$0	$0	$0	$0	$0	$0	$0
Utilities	$0	$0	$0	$0	$0	$0	$0
Wholesale trade	$0	$0	$0	$0	$0	$0	$0
Retail trade	-$30	-$20	-$20	-$10	-$10	-$30	-$120
Total	**$90**	**$50**	**$0**	**$0**	**$80**	**$20**	**$240**

10.8.2 Summary of Macroeconomic Results

The macroeconomic analysis examined the implications of converting conventional fuel oil heating equipment to wood-heating devices using locally sourced wood fuel products (pellets, chips, and cordwood). The methodology used to estimate the economic impacts included sensitivities around technology deployment assumptions, scenarios that varied the number of new pellet mills to be constructed, and fuel oil prices.

Figure 10-23 summarizes the range of macroeconomic employment impacts for the entire study region over the full modeling timeframe across technology deployment, pellet mill construction, and fuel oil price sensitivities. Across all scenario sensitivities examined, the regional economy would generate between 5,700 and 9,900 jobs over a 20-year time period, which corresponds to average job creation that ranges between 285 and 495 jobs per year over the entire study region. For contextual purposes, the total employment level in 2013 in the study region was 1,552,300 jobs. This data means that average annual job creation represented between 0.02% and 0.03% of the 2013 regional employment level. It should be noted that job creation, particularly in feedstock supply (which was not specifically modeled here) is generally expected to occur in rural areas.

Figure 10-23. Summary of Employment Impacts in the Study Region over a 20-year Time Period



The largest driver of manufacturing sector economic impacts was the number of new wood-heating devices purchased by households and businesses and the associated wood product manufacturing required to produce wood heating products. New pellet mill construction had a significant effect on outcomes in the High Units, High Technology deployment scenario, in which case the in-state demand for pellets was great enough to have a marked impact on wood sale margins. Because the variation in oil prices between the oil price scenarios was small, fuel oil prices had only a small impact on overall macroeconomic trends.

The macroeconomic analysis assumed that the market for wood feedstock inputs is an extension of the existing market for sawlogs as described in Chapter 7. As a result, the macroeconomic analysis did not account for any direct economic stimulus to the forestry sector. This is an oversimplification of the market dynamics between the sawlog industry and the solid wood fuel products industry. If the results of the economic analysis were implemented, especially under the higher technology deployment scenarios, it is likely that the forestry industry would require additional labor resources to bring the available wood feedstocks into the solid wood fuel products manufacturing chain. The analysis did not capture this additional labor and thus underestimated the impacts on the forestry sector. This underestimation may vary by region.

The statewide analysis, and by extension the macroeconomic analysis, were primarily designed to estimate the net benefit to households and businesses who purchase wood heating devices and to the industries that manufacture wood heating devices and the associated pellets, chips, and cordwood. The largest contributors to positive economic impacts are derived from new manufacturing operations associated with wood heating devices, wood fuel products, and pellet mill construction.

11 Best Practices for Wood-Heating Systems

Wood-heating units require a systems approach to achieve clean and efficient heating. At all points in the process, from initial analysis through operation, best practices must be used to assure optimum performance. Unit sizing, fuel choice, and system integration require careful design and coordination among the system elements. For space heating, the distribution system must provide adequate heat to each room or building while minimizing heat distribution losses. The following aspects are critical to ensuring proper operation of wood-heating technologies:

- Proper sizing of the boiler based on the heat load needs of the building.
- Analysis of thermal storage needs (based on boiler type, sizing, and the balance of the heating system, including zones, heat emitters, and auxiliary boilers).
- A good match between fuel supply and the technology.
- Analysis of fuel storage requirements.
- Proper installation by an installer experienced with hydronic or biomass heating system.
- Verification of performance through commissioning and measurement.

These sections of this chapter discuss the following best practices:

- Conduct a technical feasibility study or energy audit of the existing building and evaluate historic energy use to determine the conditions and operation of the existing heating system and the actual design-day load.
- Determine the proper sized unit to install to avoid oversizing.
- Identify the appropriate fuel type; learn what is readily available and can be delivered and stored appropriately.
- Identify key system components, such as thermal storage.
- Ensure proper system integration (including flow rates) and control.
- Conduct measurement and verification to confirm that all components are performing as expected.

11.1 Technical Feasibility Study

A key first step when changing to wood fuels in any building is undertaking a feasibility study. The following section details information on key aspects of this analysis for residential and commercial buildings.

11.1.1 Residential Installations

Initial steps in determining the appropriate wood burning technology for a residential application include a heating requirements assessment, analysis of local fuel availability, space and power requirements for the unit, and local terrain conditions. The first step in identifying the correct appliance is deciding whether the unit will provide supplemental space heating (stoves) or will replace a central heating system that will meet all heating needs and possibly also hot water supply needs.

A second step is determining what types of fuel can be obtained locally and stored on-site. Accessibility for fuel delivery and the availability of adequate fuel storage space must be considered. For example, if contemplating the use of cordwood, is there a space to store and season cordwood?

The homeowner should investigate the proposed physical location for the device. Is the space adequate? Will there be adequate clearance between walls and the unit? How will it be vented? Will a new chimney be needed, or modifications to an existing one? All central heating units, and many space heating units, will require access to electricity. A homeowner should ascertain whether there is capacity for new wiring.

Finally, a look at local terrain conditions is essential. The density and proximity of the population in the surrounding neighborhood, the prevailing winds, and topographical features are factors that can determine how, if at all, the unit may affect neighbors.

11.1.2 ICI Installations

Installation of wood-burning heating devices in commercial buildings can be complex and varied. A site-specific energy study should be performed by an independent energy engineering professional. Such a study will inform the building owner about the options for installation of a wood heating system. The technical feasibility study should identify:

- Building heating load and necessary components, sizes, space constraints.
- Operation and maintenance needs.
- Energy efficiency measures.
- Capital, installation, and operation and maintenance costs of a new integrated biomass heating system.
- Measures needed to bring the system into proper operation.

The first step in the assessment is an ASHRAE level II building energy audit by a credentialed energy engineer to identify all of the integrated building energy system components, their condition, and the typical operational cycles. The audit includes interviews with building facility managers and occupants to learn about the thermal comfort of the occupants and reported deficiencies. In some cases when there is a lack of thermal comfort, an existing boiler may be sufficient to provide the required heat to the building, but may not be well controlled or integrated with the heat distribution system. In that case, replacing an older boiler with a new one will not address the thermal comfort issues.

An energy professional should verify that the air conditioning system is not operating concurrently with the heating system. Thermostats should not be placed too close to heat sources that will cause early boiler shutdown, or in cold locations that cause other parts of the building to overheat. The heat distribution system should be inspected to identify any needed repairs. For example, deferred maintenance of steam traps or water conditioning could lead to corrosion and failure of the existing boiler and heat distribution system.

Good energy management controls are necessary to optimize heating system performance and achieve thermal comfort for building occupants. A building in which occupants report uncomfortable conditions may have an energy management system that does not properly communicate with the boiler controls. Control systems are an often overlooked but important component of the heating system. It is possible that significant expense may be required to bring the heating and distribution system into a state of good repair, even before a new biomass boiler is installed. The installation of a new biomass heating system will require good control between the new boiler, the existing back-up boilers, the thermal storage system, and the heat distribution system. Simply adding a new biomass boiler without accounting for the necessary heating system controls may cause the existing oil-fired boilers to cycle too frequently, thereby leading to premature failure.

The technical feasibility study should also measure baseline energy use by metering the fuel use and output of the existing oil-fired boiler(s) during a heating season. Obtaining baseline energy use allows for determination of the peak load and a comparison of that to the installed output capacity of the existing boiler(s). The fuel use and output data will also provide a measure of the actual efficiency of the existing boiler(s) as it has been operated. Actual efficiency can be very different from the rated efficiency depending on whether the boiler is sized correctly for the load, how much of the time it operates at part-load, and how often it cycles. Many commercial buildings have multiple boilers, each sized at less than the peak-load in order to optimize performance and to provide a back-up should one boiler be shut-down for repairs. An evaluation of historical energy bills and operations and maintenance costs is also needed to verify the fuel consumption and economics of the current system and to estimate the payback time for the new biomass system.

A biomass boiler may be properly sized by first determining the peak load for heating application. In most cases for commercial buildings, a biomass boiler will supplement, rather than replace, the existing oil-fired boiler. It is becoming common practice for heating system retrofit projects to size the new biomass boiler at 50-60% of the peak load in order to have it operate under full load (its most efficient operational condition) for greater amounts of time during the heating season. The technical feasibility study should also recommend the volume of thermal storage needed for the system, based on the output rating of the biomass boiler and building-specific information. The following sections discuss these considerations in greater detail.

11.2 Sizing

Proper sizing of the heating device is critical to ensure high-efficiency band low-emissions performance. This section details information on proper sizing of wood heating devices in residential and ICI settings. This section focuses on central heating rather than space heating operations.

11.2.1 Residential Sizing

Wood is commonly used in central, hot water heating systems, which are also known as hydronic heating systems. These systems transfer the heat produced from combustion into water in the boiler pressure vessel via the heat exchanger. Hot water is then circulated through the heat distribution system to heat emitters in each room of the house. These heat emitters may be high-temperature radiators, or they may be low-temperature radiant panels. The temperature of the hot water will be set depending on the type of heat emitter and the heat load of the house. For example, in the U.S., heating systems tend to supply hot water from the boiler (180 °F, and a return 20 °F lower at 160 °F) to large cast-iron radiators, cast-iron base-board, or copper fin-tube radiators. The room will heat properly only if there is a good match between the type and size of heat emitter (radiator, radiant panel, etc.) and the temperature of the hot water. In many cases, a customer may want a new boiler because the house is not warm enough when what is really needed are additional heat emitters. Under those circumstances, a larger boiler will not solve the comfort issues.

Much discussion has focused on European home heating systems. When reviewing installation requirements in Europe, it is important to recognize differences in building stock and unit sizing procedures. Installing a European boiler technology without addressing differences in building practices will, likely, lead to operational issues due to a solid fuel system's inability to cleanly and efficiently respond to rapid load transitions.

Proper sizing is a critical component for proper operation of a wood heating device. Therefore it is important to have a qualified professional conduct a heat load determination using the ACCA Manual J calculation procedure

[296] to determine the proper sizing for a residential device. Guidelines are provided in the next section for energy load determination for residential applications, but these guidelines are intended only for illustration purposes. For analyzing specific loads, ACCA Manual J should be used.

11.2.1.1 Standardized Calculation

A building's thermal heat demand (Q_H) is the amount of heat needed to keep a constant room temperature. The parameter is the mathematical sum of all heat losses minus the usable heat gains. Heat losses include heat leaving the building due to ventilation (Q_V) and transmission (Q_T) through the building envelope. Typical heat gains are due to solar radiation (Q_S) through windows and from internal sources (Q_i), including heat from humans and machinery, including electrical devices and gas appliances.[297] Details on this calculation are in Appendix G.

11.2.1.2 Space Heating Units

Cordwood and pellet stoves will typically be used for area or space heating in combination with a separate central heat/domestic hot water system using a different fuel source. High efficiency, low emission stoves should be used, such as those that meet USEPA's Step 2 compliance standard for the 2015 New Source Performance Standards (NSPS). Space heating units are available in different sizes, capable of heating a single room or an entire home. Space heaters are available in three basic sizes:

- Small stoves appropriate for heating a single room.
- Medium stoves suitable for heating small houses and medium-sized energy-efficient homes.

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[296] ACCA 2001, Manual J residential load calculations, 8th ed. v. 2.1. Air Conditioning Contractors of America, Arlington, VA.

[297] ABC 2008, p. 163.

- Large stoves suitable for larger homes with open floor plans.

A heating professional will be best equipped to assist with determining the right size and placement of a space-heating device.

11.2.1.3 Residential Central Heating

Sizing wood-fired, residential central heaters requires assessing heating demand variability, especially during low load periods. The load factor refers to the load relative to the peak heat demand and can be considered on a seasonal or average basis. Typically, units that operate at loads below their nominal output rating will have reduced efficiency and increased air pollution. One important consequence of low load or idle operation is heat loss. Poor performance at the very low end of the load curve leads to low efficiency and high emissions over much of the year or season. Contributors to poor load efficiency or high idle energy use include:

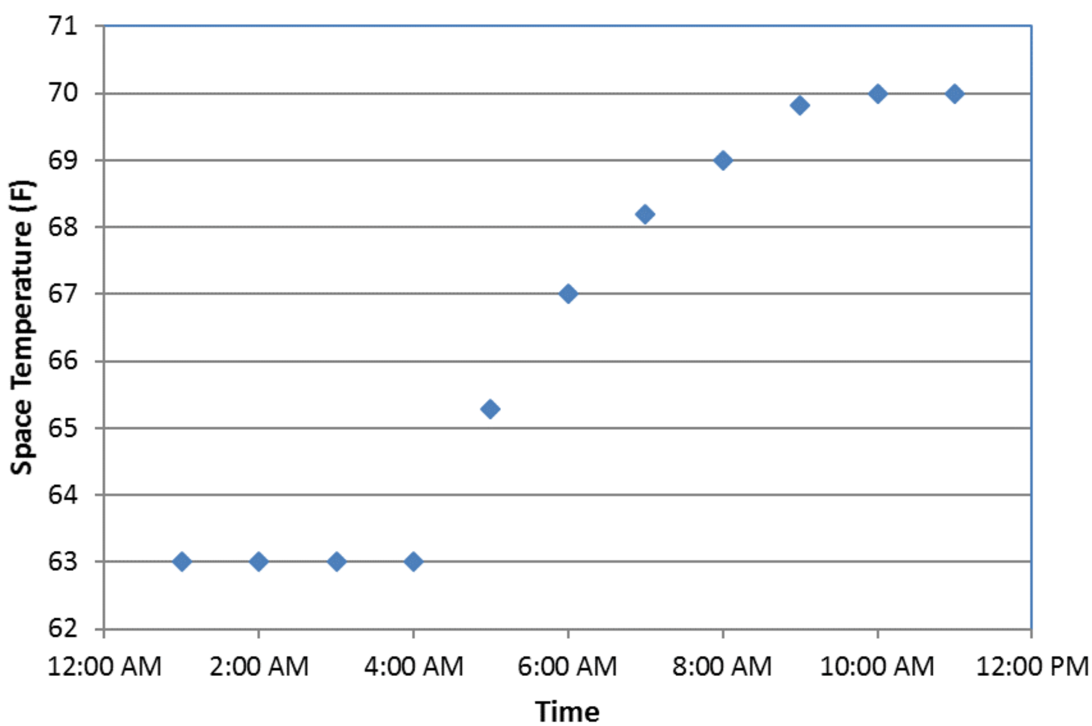
- Lack of thermal storage integration to the heating system
- Poor insulation in the storage tank, boiler jacket, and connected piping and uninsulated sections and openings on the boiler (e.g., loading door).
- High boiler operating temperature at low loads leading to high stack flow and loss.
- Cycling operation where boilers lose energy to the environment during the off (or slumber) cycle.

Controls such as an outdoor reset and a thermal purge control can be effective in reducing low load or idle losses. Outdoor reset controls reduce set point temperatures when the demand is low, and purge controls signal when to transfer residual heat from the boiler to thermal storage after the burn period is complete.

For a given residence at a given location, the maximum space heat demand can be determined through a structure heat loss calculation performed on the coldest expected day (i.e., the “design day”). This level of heat demand occurs only for a few hours (if at all) during a typical year. More typically, a heating system will be called upon to provide its maximum heat output during a recovery from indoor night-time setback temperatures or during a period of high domestic hot water demand. Traditional practice with home heating systems using any fuel has been to oversize the heat source, and an oversize factor of 3 is not uncommon for some wood heating units. In a recent study of oversizing and wood hydronic heaters, it was seen that a typical system is oversized by 3 times and, therefore, operates at less than 25% of its maximum heat output for more than 90% of the time. [298]

Oversizing a system by roughly 20% (an oversizing factor of 1.2) in excess of its peak heat demand is considered acceptable practice. Another approach would be to determine the maximum heat delivery capacity of the heat delivery system, such as baseboard radiators. A pellet-fired hydronic heater should not be installed with a heat production capacity greater than the delivery capacity of the distribution system at a nominal supply temperature of 180 °F. Use of thermal storage minimizes many of the adverse impacts of oversizing a boiler (thermal storage is discussed in other sections of this chapter). To illustrate the oversize and load variability questions, an analysis has been done on a typical (hypothetical) 2,500 ft^2 home located in Syracuse, NY. Figure 11-1 shows the indoor temperature over time (hourly) during the morning recovery period for the overnight temperature setback. This time period is particularly important because it can define the maximum heat load imposed on the boiler system.

Figure 11-1. Indoor Temperature Profile over Time for a Syracuse, NY 2,500 ft^2 Home during Morning Setback Recovery Period



298 Butcher & Russell, 2011.

Figure 11-2 shows the hourly heat load profile for a single January day, highlighting the load on the boiler system and not the heat loss rate of the house. Here, the heat load is highest between 4 and 7 a.m. due to recovery from night setback. The peak heat load on the boiler at this time is limited by the heat delivery capacity of the baseboard radiators. In the afternoon, the heat load drops to a much lower level with passive solar gain. At night, the heat load on the boiler system drops rapidly when the night setback control activates. It should be noted that this heating load profile assumes a daily domestic hot water consumption of 64.3 gallons. This number is based on the national average historically used in water heater efficiency test standards.

The very wide daily load range found in a typical home is a challenge, particularly for cordwood boilers that have a limited range of modulation. Traditional outdoor wood boilers (OWBs) with a large water jacket surrounding the firebox can go into an extended idle, or “slumber,” mode during the low-load periods. During this idle period, the fire smolders and creosote is formed inside the device. Once the fire re-ignites both the wood and the creosote, increased air emissions occur. In a study conducted by the USEPA[299], the emissions produced by cordwood boilers attempting to follow this type of daily load profile were shown to be very high. Boilers that cycle on and off while burning a fuel charge are typically high emitting, low efficiency devices. Delivered efficiency for the January day tested in the study was just 22% for a conventional OWB and 30% for a Phase II OWB.

[299] Gullet, Brian (et al). Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater Technologies. NYSERDA, 2013.

Figure 11-2. Boiler System Heat Load Profile on Selected January Day for Syracuse, NY 2,500 ft^2 Home

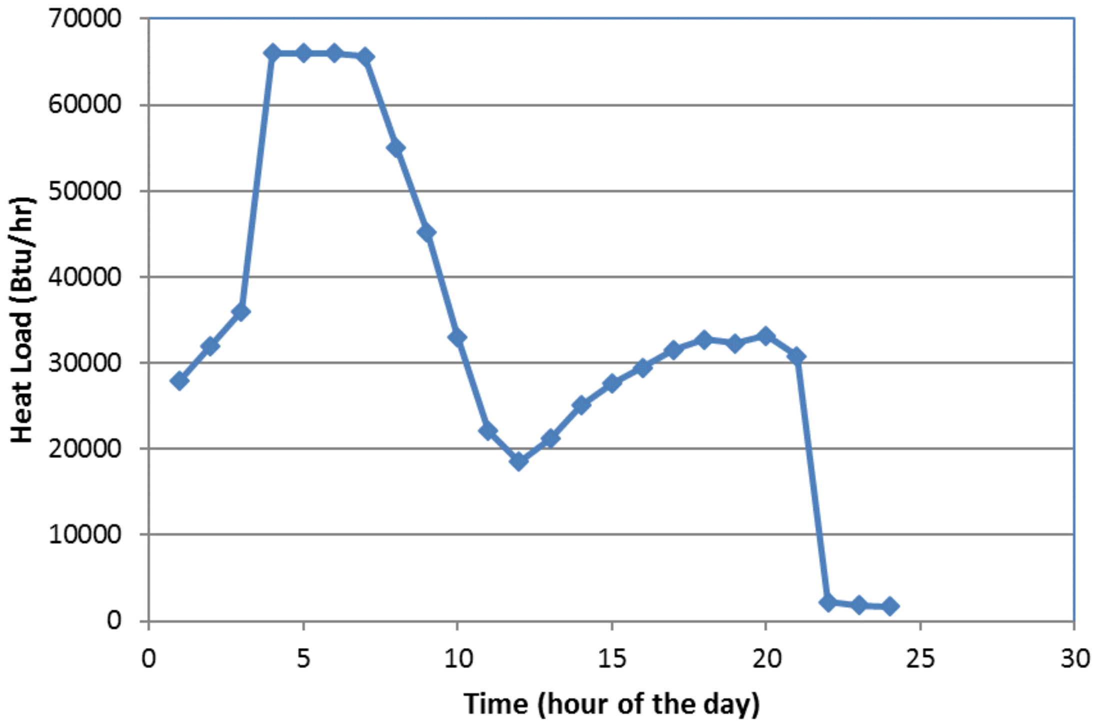


Figure 11-3 shows the variation in the hourly heat load over the entire year for the same Syracuse home. The center of the year is in the summer when the load is completely dominated by the domestic hot water load. This load is much smaller than the peak output capacity of the boiler.

Figure 11-3. Distribution of Heat Demand across the Entire Year, Syracuse, NY 2,500 ft^2 Home

The summer period is roughly hour 3,000 through hour 6,000.

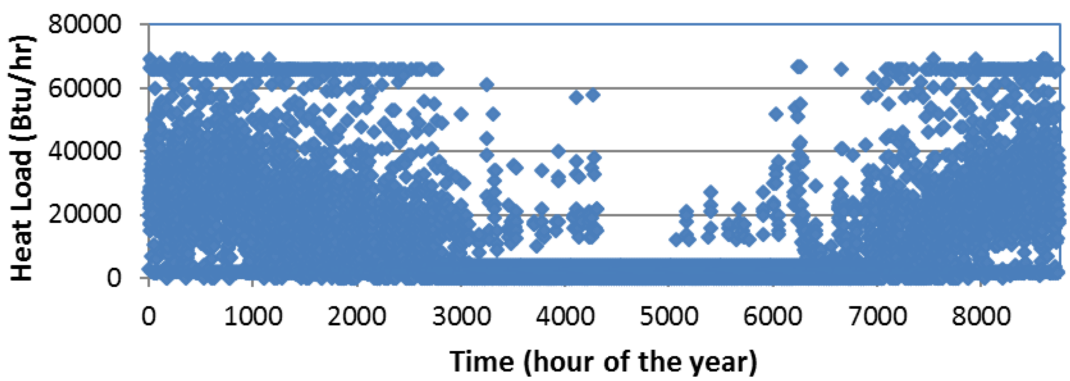


Figure 11-14 shows the distribution of hours and demand for the Syracuse home system for the entire year. The plot shows, for example, that for 90% of the hours during the year, the load is less than 54% of the maximum. For 70% of the hours during the year, the load is less than 25% of the maximum. This data indicates that a perfectly sized heating device would still spend much of its operating time at loads below 25% of maximum heat value. If a unit is oversized, the frequency of low-load operations will increase.

Figure 11-4. Distribution of Annual Hours across Load Profile for Right-Sized Syracuse, NY 2,500 ft^2 Home

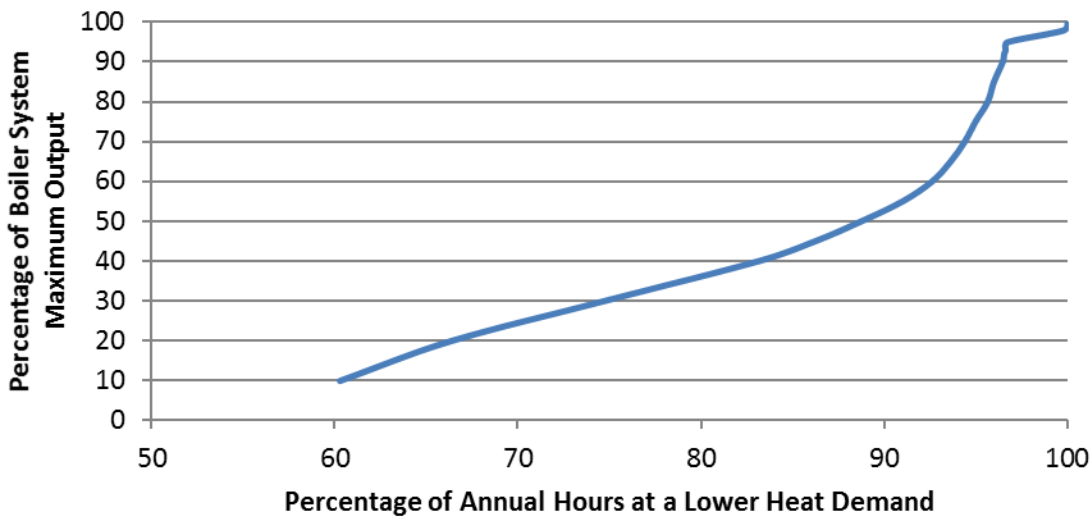
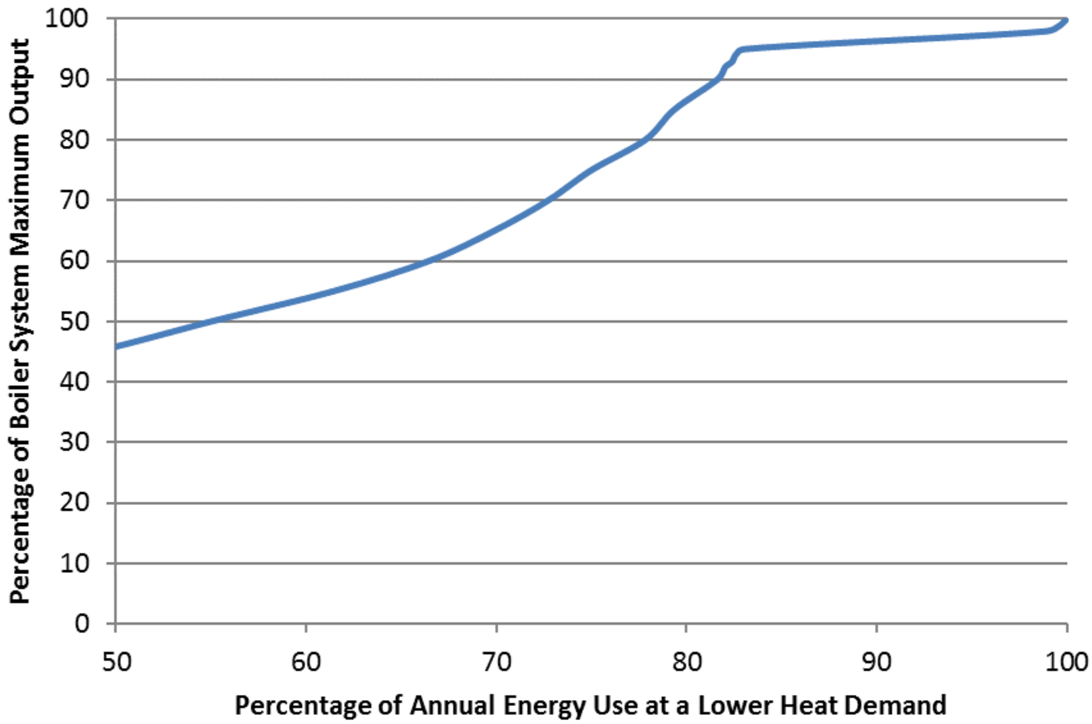


Figure 11-5 shows a similar curve, but in this case the profile has been developed for total annual energy use based on percentages at low load instead of hours. To help interpret this chart, half of the annual energy delivered by the boiler system (50% on the x-axis) is delivered at an output rate of 45% or less of the maximum (y-axis). The high output rate (nearly horizontal line at the top right of the chart) is due to the recovery from night setback behavior, when the system is running at full load to warm the building in the morning. Again, this data does not include effects of oversizing.

Figure 11-5. Distribution of Annual Energy Delivered from Boiler System across Load Profile for Right-Sized Syracuse, NY 2,500 ft^2 Home



11.2.2 ICI Sizing

Appropriate sizing of biomass heating systems is necessary to achieve optimal efficiencies and operating conditions. In buildings with constant running machinery, a portion of the waste heat could be used to heat the room where the machines are located, thus reducing heat demand from the heating system. Proper boiler sizing depends first on determining the heat load for the building as part of a technical feasibility study that includes an ASHRAE level II audit. General information on heat load analysis is provided by ASHRAE (ASHRAE, Handbook of Fundamentals, 2013, Chapters 17 and 18, ASHRAE – Atlanta). Taking baseline measurements for a heating season is better than just modeling. To take baseline measurements, flowmeters and thermocouples are placed on the boiler supply and return. This placement can often be done external to the piping. A flowmeter should also be placed in the fuel supply to the boiler for an accurate reading. This placement will allow determining the efficiency of the existing boiler, its peak-load, and its diurnal loads throughout the heating season. This information is necessary to properly match the new biomass boiler to the heat load requirements of the building. Alternatively, daily fuel-use records may be used and combined with weather data to perform a regression to calculate the peak-load, but this method will not be as reliable. A new biomass boiler should never be selected simply by using the name-plate information of the existing oil-fired boiler. Oversizing of boilers is a common problem that leads to excessive cycling and operations at low loads where boilers are not efficient. This inefficiency is exacerbated when the boiler is fired by a solid fuel such as biomass.

The heat energy rating (HER) parameter is comparable to the fuel economy of a car (e.g., miles per gallon) and is expressed in units relating to energy usage per year and outside surface area of the building. The parameter provides a method for defining the energy quality of dwellings and is a useful metric for comparing energy quality across different buildings and for estimating fuel use. When a building's thermal heat demand is known, the HER can be calculated according to the equation:

$$\mathrm{HER} = \frac{\text{Thermal Heat Demand}}{\text{floor area of the building}} \text{ in } \left(\frac{\mathrm{MBtu}}{\mathrm{ft}^2\ \mathrm{a}}\right) \text{ or } \left(\frac{\mathrm{kWh}}{\mathrm{m}^2\ \mathrm{a}}\right)$$

11.3 Fuel Considerations

Once the proper size of a biomass heating system is determined, one should consider the type of wood fuel to use. Potential fuels include cordwood, pellets, and wood chips. For residential units, typical fuel choices include cordwood and pellets, while ICI units typically employ chips or pellets. Grass pellets or other non-conventional fuel may be used in specific cases, but present significant operational and system compatibility challenges and potential undesirable environmental impacts as well. Once a fuel type is selected, fuel specifications that match the needs of the technology should be obtained to assure proper system operation. The following section provides a more detailed discussion of fuel supply considerations.

11.3.1 Residential

11.3.1.1 Pellets

Wood pellets represent a growing segment of the wood heating market. The most common method to obtain residential wood pellets is purchasing 40-pound bags. In some parts of NYS, however, bulk delivery is available. This fuel has been prone to short-term retail shortages as the supply, demand, and distribution channels continue to adjust in this growing market. Typically, shortages occur for the bagged fuel, not bulk delivery pellets. In NYS, production of residential wood pellets has tripled since 2008;

however, production continues to respond to perturbations in demand. In the 2014-2015 heating season, portions of NYS experienced shortages of bagged pellet fuels. However, the increasing popularity of this fuel, high oil and propane prices during the 2013-2014 heating season, and recent long, cold winters have lead large retail outlets to warehouse bagged pellet inventory during off-season periods. This has led to mills elongating their production season to year-round operation. Bagged pellet fuels tend to be used with space heating; however, when using central heating devices, bulk pellet delivery should be considered, where available. Bulk pellet delivery is widely used in Europe, and is beginning to become available in NYS. Figure 11-6 depicts one of the new wood pellet delivery suppliers currently operating in the State. These systems look much like typical heating oil fuel trucks.

Caution should be taken when planning for bulk storage of wood pellets, or even storage of very large quantities of bagged pellets. Wood pellets emit carbon monoxide (CO),[300] and potential CO emissions must be taken into consideration in designing a pellet storage system. Residential bulk pellet storage systems, although holding smaller volumes of pellets than ICI operations, should be located outside of the building envelope to avoid exposure by sensitive populations (elderly, children, those with illnesses) that may be in the home for extended periods of time. At least two manufacturers in NYS currently supply these residential storage systems: Vincent's Heating and Fuel and MESA Reduction Engineering and Processing, Inc. ASHRAE and LEED recommendations on CO concentrations are the lower of two choices: 9 parts per million (ppm), or no more than 2 ppm above ambient CO concentrations. A more detailed discussion of pellet storage issues is provided later in Section 11.3.3. Carbon monoxide detector systems should be installed in all homes, regardless of the type of fuel used for space heating, and are required in NYS by Amanda's Law.[301]

[300] Hopke, 2013.

[301] Amanda's Law was named in honor of Buffalo, NY, resident Amanda Hansen, a teenage girl who lost her life to CO poisoning. The law went into effect 2010 and requires use of CO alarms in all homes that have a fuel-burning appliance. Information on Amanda's Law can be found at http://amandaslaw.org/

Figure 11-6. Bulk Pellet Delivery Truck

11.3.1.2 Residential Cordwood

Local availability of unsplit wood or seasoned cordwood may often be a significant factor in a homeowner's decision about the use of cordwood. As with pellets, the supply and price of cordwood can vary from year to year. For cordwood, the best performance can be achieved using wood that is dry (under 20% moisture) and properly split. Availability of properly seasoned cordwood can vary from year to year as well – homeowners using cordwood are encouraged to have a two-year supply of seasoned wood on hand. Equipment designs are typically optimized around one specific wood type. Use of wood that is of a different type, size, or moisture content (too high or low) can lead to a lower level of performance. It is poor practice to plan a biomass heating project based on the use of scrap construction materials or other low quality wood. The following list highlights best practices for use of cordwood:

- Wood type - check the Owner's Manual for a given device to determine if it can burn softwood and hardwood. Softwood burns hotter and faster than denser hardwoods. Also make sure wood is free of dirt and other contaminants before it is burned.
- Size -cordwood should be split into pieces no more than six to eight inches in diameter and the length of the wood should fit easily into the device. For woodstoves, typically log lengths are 16 to 18 inches.
- Seasoned wood - burning unseasoned (green) wood or even partially seasoned wood will cause creosote to build-up in the chimney, which creates a fire hazard. The time required to season wood depends on the type of wood. Softwoods can reach the appropriate moisture content in 6 to 12 months, while hardwood typically needs a minimum of 12 to 24 months to reach the appropriate moisture content for use in residential heating devices. Wood can be purchased seasoned or purchased green and seasoned on-site.
- Storage - wood should be stored off the ground, in a covered location and not up against walls. The key to proper seasoning is storing the wood in a manner that optimizes air circulation, as illustrated in Figure 11-7.

Figure 11-7. Storage for Cordwood

If seasoned wood is to be provided by a local supplier, plan to ensure that the wood is properly seasoned hardwood, free from decay or fungus, and of the right size. Moisture meters can be purchased at reasonable cost and used to ensure the supplied wood is properly seasoned.

11.3.2 Fuel Supply ICI

A technical feasibility study (described in Section 11.1) will identify options for biomass boiler and fuel systems to be integrated with the existing heating system. One of the parameters analyzed will be the available space and cost for fuel storage, which is typically a pellet silo or a chip bunker. Evaluating whether there is adequate space for storage, however, is not the only option that should be assessed. Local fuel supply conditions should be reviewed to determine long-term, local availability of chip or pellet fuel. Different types of chip and pellet fuels are discussed in Chapter 7.

Higher quality chips or pellets will be more expensive, but will have lower emissions, reduce equipment maintenance costs, and minimize ash waste. Because they have lower moisture content fuels will burn more efficiently, so they deliver more usable heat than a lower-quality fuel on a cost basis. Whichever fuel is chosen, fuel production quality management and quality assurance practices should be reviewed with potential fuel suppliers to ensure the availability of high quality fuel for the expected life of the project. Implementation of long-term contracts to assure a consistent supply and price for fuel is also advisable, and alternative suppliers of fuel should be identified to ensure continuity of supply in the event of equipment problems or competing market demand situations.

Supplier delivery capacity should be reviewed. For example, one pellet delivery company in NYS has two bulk pellet delivery trucks and is installing on-site storage capacity to ensure pellet availability during periods when supply tightens. Other considerations that should be reviewed include the potential local impact of increased heavy vehicle traffic and waste management protocols for wood ash. Wood ash handling procedures need to be put in place. Ash should be analyzed to ensure that it does not contain elevated levels of metals, which would trigger hazardous waste handling requirements. Fuel storage containers should also require annual cleaning.

11.3.2.1 ICI Wood Chips

ICI wood chip boilers are typically affected by variability in moisture, wood density, species, and size. Such variability can result in increased emissions and lower efficiency. Small- and medium-sized, two-stage combustion ICI boilers using wood chips are available in NYS, but these units require chips with a moisture content of less than 30% to achieve and maintain high efficiency. In cases where air-to-fuel ratios are automatically controlled or where advanced emission control devices such as condensing economizers, ESPs and baghouses are used, the emission impacts of fuel variability are not as great, but efficiency will still be lower. To maximize operations, fuel specifications should be developed. Issues to address in a fuel specification include:

- Bark content - chips from debarked logs versus chips from bole tree or whole tree chipping. Stack test data indicate that wood chips containing bark will have higher emissions than debarked chips and generate more ash.
- 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.
- Fines - excess fines may be of greater concern, as fines have different burning characteristics compared to typical “match-book”-sized wood chips, and fugitive dust can create a safety issue.

In Europe, fuel specifications for wood chips have been in place since 1998 and are referenced in CEN/TC 335 (as detailed in Chapter 7). These specifications include requirements for origin, size, moisture, ash, net energy, chlorine, and nitrogen content. The Biomass Energy Resource Center has developed two helpful documents on wood chip fuel specifications:

- Woodchip Heating Fuel Specifications in the Northeast (available at http://www.biomasscenter.org/images/stories/Woodchip_Heating_Fuel_Specs_electronic.pdf) provides an overview of the different types of wood chip fuels and specifications.

- Woodchip Fuel Specifications and Procurement Strategies for the Black Hills[302] provides an excellent overview of fuel sourcing and specifications that should be undertaken prior to determining which technology to install.

Another issue that should be examined when assessing the use of wood chips is fugitive dust. Sources of fugitive dust include ash piles and dust generated from fuel delivery. Dust also creates worker safety and explosion risks that should addressed along with storage considerations, such as off-gassing and self-heating.

11.3.3 Fuel Storage Issues

Design options for storage facilities depend on whether the use is residential or ICI, the amount of fuel used, the amount of fuel storage required, and the type of biomass fuel used. This section provides information on various fuel storage issues and methods. An excellent overview of health and safety concerns associated with biomass is provided in a recent report published by the IEA.[303]

Storing biomass materials requires minimization of risks. The following list gives an overview of possible problems that can occur from inappropriate storage conditions:[304]

- Self-heating.
- Off-gassing of CO (and other gases).
- Oxygen depletion.
- Loss of substance due to biological processes.
- Growth of fungal spores.
- Nuisance odors.
- Re-humidification, e.g., due to rain.
- Loss of structural integrity and abrasion due to transportation.
- Agglomeration due to frost exposure.
- Explosive conditions due to dust.
- Worker safety, including the hazards associated with confined spaces or potential engulfment in fuel

The follow sections provide information on two significant concerns: self-heating and off-gassing.

302 https://sdda.sd.gov/legacydocs/Forestry/publications/PDF/Black%20Hills%20Wood%20Fuel%20Specifications%205.15.07%20FINAL%20.pdf

303 Health and Safety Aspects of Solid Biomass Storage, Transportation, and Feeding, prepared by IEA Bioenergy Tasks 32, 36, 37, and 40, http://www.ieabcc.nl/publications/IEA_Bioenergy_Health_and_Safety_Report_(final).pdf May 2013

304 Hartmann 2009, p. 289.

11.3.3.1 Self-heating

The phenomenon of self-heating of solid biomass is caused by microbial growth, chemical oxidation, and moisture absorption.[305] This problem is very important for large-scale storage, especially in systems where the fuel storage is in large enough enclosures for people to enter. If, and how quickly, the self-heating mechanism takes place depends on the following parameters:[306]

- Moisture content of the fuel - humidity accelerates biological processes.
- Air supply - ventilation dries and cools the fuel pile.
- Concentration of oxygen in the storage facility - minimum ignition temperature increases with falling oxygen concentration.
- Size and structure of the fuel - small pieces lead to tight bulk density and poor ventilation.

Self-heating can have severe consequences, with the primary consequences listed below in the order of their relative occurrence:[307]

- Release of poison gas emissions, e.g., CO.
- Spontaneous ignition leading to release of pyrolysis/combustion gases.
- Gas and/or dust explosion.
- Surface fire, typically as a result of explosion.

In addition to having the appropriate storage facility for the stored fuel, the following are additional recommendations and safety measures that should be taken to reduce or eliminate the risk of self-heating:[308]

- Avoid storing biomass with moisture content greater than 15% (on a wet basis) in large quantities.
- Avoid mixing different types of biomass fuels in one storage facility.
- Avoid mixing fuel batches with different moisture content.
- Only store high quality fuel, e.g., moisture-damaged pellets should not be stored, but instead directly burned.
- Avoid accumulations of dust and fines in pellet storage.

Persson (2013) provides additional detailed information about self-heating and fire prevention in silos.

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305 Obernberger Thek 2010, p. 144.

306 Hartmann 2009, p. 286.

307 Obernberger Thek 2010, p. 147.

308 Obernberger Thek 2010, p. 147.

11.3.3.2 Off-gassing

In storage, wood pellets can auto-oxidize, leading to consumption of oxygen and production of CO and smaller amounts of other gases. Several laboratory studies have shown that dangerously high levels of CO can be produced in the headspace above pellets in a sealed bin, even at room temperature. To provide some context, Table 11-1 provides a summary of established CO concentration limits used in the health community, which range from 9 ppm over an 8-hr period to 25 ppm for a 1-hr period.

Table 11-1. Summary of Regulatory and Recommended Exposure Limits for CO (Hopke, 2013)

TWA = time weighted average; PEL = permissible exposure limit

Limit/ Level	Type	Organization	Industry/ Area	Sources
9 ppm	8 Hr	USEPA	General	http://www.epa.gov/ttn/naaqs/criteria.html
9 ppm	TWA (8 Hrs)	World Health Organization	General (Outdoor)	http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf
9 ppm	Ceiling	ASHRAE	General (Living Areas)	ASHRAE
25 ppm	TWA (8 Hrs)	ACGIH	General	2004 ACGIH Handbook of TLVs and BEIs
35 ppm	TWA (8 Hrs)	NIOSH	General	https://www.osha.gov/OshDoc/data_General_Facts/carbonmonoxide-factsheet.pdf
35 ppm	(1 Hr)	USEPA	General	http://www.epa.gov/ttn/naaqs/criteria.html
50 ppm	OSHA PEL as TWA (8 Hrs)	OSHA	General	https://www.osha.gov/OshDoc/data_General_Facts/carbonmonoxide-factsheet.pdf
50 ppm	OSHA PEL as TWA (8 Hrs)	OSHA	Construction	https://www.osha.gov/OshDoc/data_General_Facts/carbonmonoxide-factsheet.pdf
50 ppm	OSHA PEL as TWA (8 Hrs)	OSHA	Maritime	https://www.osha.gov/OshDoc/data_General_Facts/carbonmonoxide-factsheet.pdf

Several European studies found high levels of CO in large storage areas. A European study (Gauthier, Grass, Lory, Kraemer, Thali, & Bartsch, 2012) of CO production in enclosed containers found that after 16 days of storage at 26ºC, headspace CO levels ranged from 3,100 ppm to 4,700 ppm. Another study (Tumuluru et al.) measured similar concentrations of 5,000 ppm after 24 days. As temperatures increased, this same study found that CO levels increased. At 50°C, CO levels rose to 17,000 ppm after 24 days. Other studies were conducted in Europe following a fatal accident. One study measured CO and oxygen in store rooms and adjacent stairwells on five ships.[309] This study found CO levels ranging from 2,960 to 21,570 ppm and oxygen levels ranging from 0.8 to 16.9%. Another study[310] also reported two deaths that occurred in Europe due to high CO levels inside of pellet storage rooms.[311] These were larger storage areas in multifamily buildings. In both cases, the person entered the storage area to do service work without venting the space first.

The European studies all measured dangerous levels, but questions remain about how these results translate into concerns for small-scale storage in homes and commercial buildings. More recent studies conducted in NYS attempt to address this issue. Clarkson University analyzed the impacts of wood type, moisture content, and headspace volume on CO levels. The study found that softwood pellets produced more CO than hardwood pellets, and torrified pellets produce lower CO levels than kiln-dried pellets. The maximum headspace CO concentration measured was 900 ppm with softwood following 10 days of storage of 40 pounds of pellets in a 20-gallon container. This study also measured CO levels in storage areas and found 1-hr CO levels in a storage bin and silo of 155 ppm. In a residential basement, the study measured 1-hour CO levels as high as 60 ppm and 8-hr measurements above the ASHRAE 8-hour average guideline of 9 ppm.[312]

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309 Svedberg, Samuelsson, & Melin, 2008.

310 Gauthier et al.

311 Gauthier, et al., 2012.

312 Hopke, 2013.

The issue also continues to be studied in Europe. The Austrian agency Bioenergy 2020+ conducted a field study of CO and oxygen concentrations in pellet storage facilities connected with space heating.[313] In 68% of the sites, CO was found to exceed 30 ppm and in 9% of the sites CO was over 1,000 ppm. This agency continues to study the issue and additional information on CO off-gassing should become available.

11.3.3.3 Storage Best Practices to Address CO and Safety Concerns

Guidance for indoor pellet storage and safety is currently under development. For pellet storage at commercial locations, the Occupational Safety and Health Administration set regulatory standards for maximum exposures as well as requirements for confined spaces. For residential locations, there are no regulatory standards. There is the ASHRAE guidance concentration of 9 ppm over 8 hours. At this time, NYS has not formally established related building codes. Because of concerns regarding potential CO exposure and the absence of a documented effective ventilation strategy for pellet storage, NYSERDA, with guidance from the NYS Department of Health has required all bulk pellet storage to be outside of the residential or commercial building for its RHNY program. Recent data found that the cost for constructing indoor and outdoor storage facilities is similar at approximately $3,000. Discussions with fuel suppliers indicated a preference for outdoor storage, as it makes delivery easier. This area needs additional research, and NYSERDA will continue to pursue the topic.

11.3.4 Residential Pellet Bags

The size of residential-scale pellet storage mainly depends on the nominal power of the combustion unit to be fed. Usually, small-scale applications such as pellet stoves use fuel stored in 40-pound bags. The stoves have this amount of fuel storage space built into the device. This amount of fuel allows the stove to operate from a few hours to several days without refilling. Bagged pellets, at a minimum should be those labeled as meeting the Pellet Fuel Institute (PFI) premium standard; however, previous NYSERDA research indicates that this standard may not identify potential pellet contaminants (Rector 2013). Pellets labeled as certified under the EN-PLUS standard are made without bark and from sustainable wood sources in facilities that have undergone a rigorous certification process; however, currently it may be difficult to obtain EN-PLUS certified pellets in NYS.

[313] Emhofer & Pointner, 2009.

11.3.5 Residential Bulk Pellet

Pellet boilers used for central heating systems are also often equipped with fuel storage tanks to ensure continuous operation over long periods. Residential storage capacities should be sized to store one or one-and-a-half times the system's annual fuel demand.[314] Placement of the storage units is critical to address concerns about potential off-gassing of CO from pellets. Figure 11-8 depicts the use of outside storage of pellets in a residential setting. This arrangement allows easy access for delivery and alleviates exposure concerns from pellet off-gassing.

Figure 11-8. Residential Outside Pellet Storage System

Photo courtesy of Vincent's Heating

11.3.6 ICI Pellet and Chip

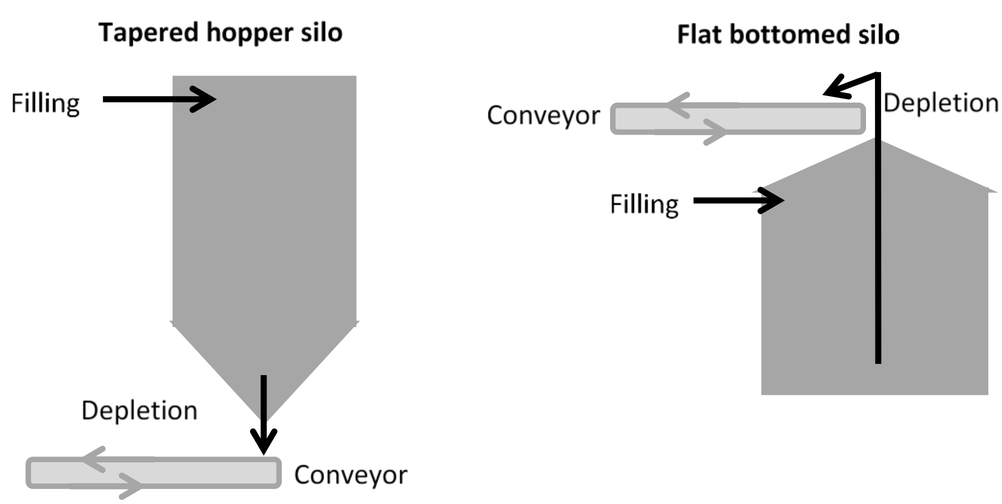
For medium- to large-scale heating systems, the fuel demand increases with the nominal load. Therefore, larger storage systems are needed to ensure continuous operation. These storage units typically are silos, depots, or bunkers.

[314] Obernberger Thek 2010, p. 118.

11.3.6.1 Silos

Silos are typically used for pellet storage, but can be used for chip storage. The silos can be made of concrete or galvanized steel. Tapered-hopper and flat-bottomed vertical silos are pictured in Figure 11-9. Tapered hopper silos are filled by an overhead conveyor and emptied by gravity at the bottom. To take the pellets or chips out of a flat-bottomed silo, a circulating auger is used to remove pellets out of the top. In both cases, the pellets are transported by a conveyor to the combustion facility. Because silos are exposed to the sun, dark paint should be avoided to prevent high temperatures inside the silo. The typical size range of agricultural silos is between 164 and 33,000 ft^3 (50-10,000 m^3).[315] In areas prone to low temperatures, high moisture content fuels such as chips should not be used with unheated silos, as the fuel may freeze. For commercial silos, it is recommended that a hatch at the base of the silo be added with a mechanism to cut off pellet supply. This creates access to the auger to allow for repairs without entering the silo or removing large volumes of pellets. Inclusion of a vertical window allows the facility to see the pellet supply and determine when to re-order pellets without climbing a ladder to look from the access hatch on the top of the silo. Note that these systems are subject to a confined space entry permit issued by the Occupational Safety and Health Administration (OSHA) and its public employment counterpart (PESHA) due to CO, oxygen depletion, and engulfment hazards.

Figure 11-9. Scheme for Two Types of Storage Silos



[315] Obernberger Thek 2010, pp. 123-124.

11.3.6.2 Bunkers

Silos may not be large enough to store large volumes of pellets or wood chips. In that event, storage bunkers with volumes of 33,000 to 330,000 ft^3 can be constructed. Usually the fuel is stored using a telescoping conveyor at the top, and removed by an auger at the bottom for feeding to the combustion unit.[316] The type of fuel selected will affect the decision about storage type. The system configuration will in turn influence the storage space requirement. For ICI applications, it is best to design storage to hold enough fuel to last at least 10 days during peak heating season operation. The design of the storage container and the surrounding delivery area must also take into account the size and type of vehicle that will be delivering the fuel. It is imperative that public health considerations, such as CO exposures, are accounted for to ensure exposures are minimized.

Additional factors to consider when designing fuel storage systems include contaminants, storage time, and climate conditions. The key to maintaining fuel quality is to protect the fuel from the elements and contact with water. If compressed pellets are fully saturated with water, they expand about 3.5 times in size and lose their structural integrity. Not only will they no longer feed into a pellet boiler properly, but expansion forces can also crack the storage container or form an extremely hard and compacted plug that is difficult to remove.[317] Chip quality will also degrade with exposure to moisture. The length of time the fuel is stored can also impact fuel quality. Pellets and chips will degrade over time so it is also important to ensure that the fuel will be used in a timely manner. Finally, protection from overheating and humidification must also be taken into account when designing a fuel storage system. Europe has developed standards and guidelines, such as ÖNORM M 7137 and VDI 3464, which define various requirements for the construction and safety of pellet storage units. A brochure by the German Wood Fuel and Pellet Association (DEPV) also provides information on pellet storage necessities.[318] The Biomass Energy Resource Center has developed a guide for installing wood chip systems,[319] but no U.S. standards have been developed.

11.3.7 District Heating

An alternative to individual heating units is district heating. While not commonly employed in NYS, it is in much more widespread use in Europe. The attraction of a district heating network is that it has the

[316] Obernberger Thek 2010, p. 124.

[317] Obernberger Thek 2010, p. 143.

[318] SavePellets online 2013.

[319] http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf

capacity to utilize a single large automatically fed biomass boiler plant (or multiple boilers in tandem) to heat a large number of homes or buildings with lower emissions and increased efficiency than individual residential devices. The sizing of the combustion boilers and the system network requirements can be evaluated based on the known heat demand and location of each potential end user in a proposed heating district. To assure that the advantages of a district heating network are achievable, there should be a high heat demand within a short network distance from the boilers providing heat. The following two parameters describe these requirements:[320]

- **Thermal transport performance** ($MBtu_{connected}/hr \cdot m$). This is the ratio of the total heat capacity demand of the connected buildings ($MBtu_{connected}/hr$) and the total length of the heating network (m).
- **Thermal connection density** ($MBtu_{sold}/a \cdot m$). This is the ratio of the total annual amount of sold thermal energy ($MBtu_{sold}/a$) and the total length of the heating network (m).

The economic operation of a district heating system is generally achievable when there is a minimal thermal transport performance in the range of about 3.4 MBtu/hr·m to 6.8 MBtu/hr·m.[321]

For estimating the investment costs, energy losses, and economic viability of a district heating system, the thermal connection density is an important economic parameter. In general, the boilers providing system heat should be located as close as possible to the largest consumer, which also provides an anchor client for the system. The economic benefit of the district heating system can increase over time after commencing operation if the network density of its end users also increases.[322]

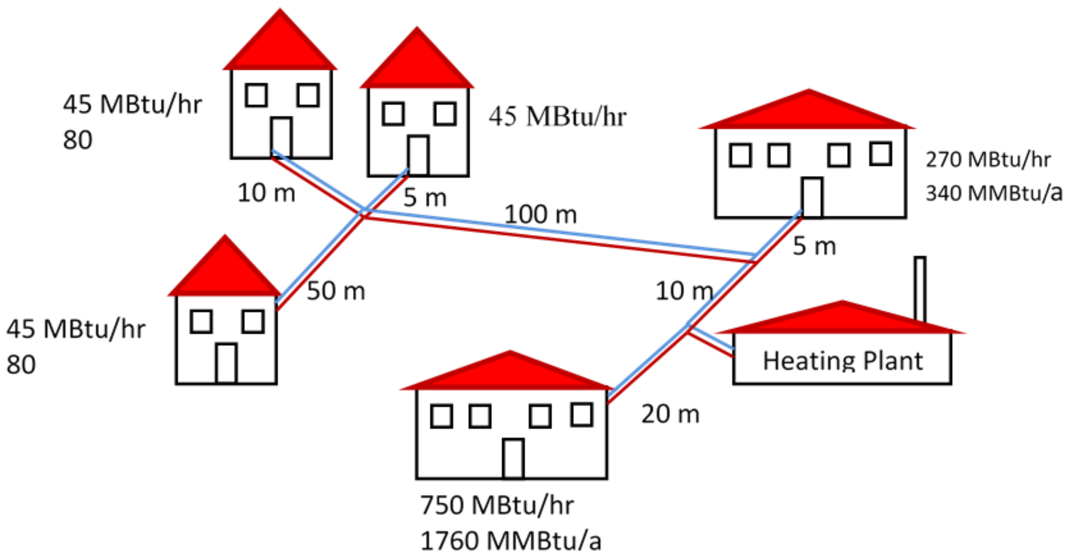
[320] BE2020+ 2011, p. 19.

[321] BE2020+ 2011, p. 19.

[322] BE2020+ 2011, p. 20.

Figure 11-10 is an illustrative scheme of a small district heating network that serves as an example for estimating system viability. Based on the consumers' heat demands, this network would be 200 m long and would have a nominal load of 1.155 MMBtu/hr with a heat demand of about 2,350 MMBtu/a. The calculated thermal transport performance is about 6 MBtu/hr·m and the thermal connection density would be approximately 12 MMBtu/a·m.

Figure 11-10. District Heating Network Scheme



In addition to the previously discussed factors, there are a number of other fundamental elements that need to be considered during the planning process for a district heating network. These elements include the hydraulic design and pipe routing, pressure loss in the pipe network and other operational parameters, the dimensions of pumps for auxiliary energy demand, network transport losses, how the system interacts with existing heating and distribution systems, and construction costs. [323]

[323] BioEnergy 2011, p. 20.

11.4 Thermal Storage

In biomass-fired hydronic heating systems, the incorporation of thermal storage as an engineered part of the system offers the following benefits: [324]

- Output from some biomass boilers, such as cordwood boilers, is often higher than the heating load. Excess heat needs to be temporarily "parked" in storage.
- The heating system can meet intermittent loads without firing the boiler, thereby improving performance and longevity.
- Boiler short-cycling during partial load conditions (for both biomass and auxiliary boiler) is eliminated, leading to cleaner burning and higher efficiency.
- Tempering of the return water at start-up prevents thermal shock to the boiler.
- During periods of high demand, thermal storage supplements boiler output.
- During power outages, thermal storage may act as a heat sink for residual heat.
- At boiler shut-down, thermal storage is able to capture residual heat.
- Thermal storage can also provide mass to stabilize domestic hot water production.
- With proper piping, the storage tank can stratify water at different temperatures in multiple circulator systems.
- The storage tank can also provide storage for solar thermal input.

The benefits of thermal storage include increased thermal efficiency, longer system life, and reduced air pollution. The increase in efficiency and lower emissions are due to increased operation at peak performance rates. Generally, in cyclic on/off operation, air emissions, including particulates, CO, and unburned hydrocarbons, increase. Thermal storage also increases system life by reducing stresses on the system. After the start of a firing period, combustion chamber temperature rises quickly, leading to expansion of metal and, to a lesser degree, refractory components. The different thermal expansion coefficients between physically connected components and the significant temperature gradients within individual components place stress on the components. Reducing the number of hot/cold cycles during regular operation reduces stress failure rates and increases appliance lifetime generally. Of course, the impact of cycling on durability will be appliance-specific.

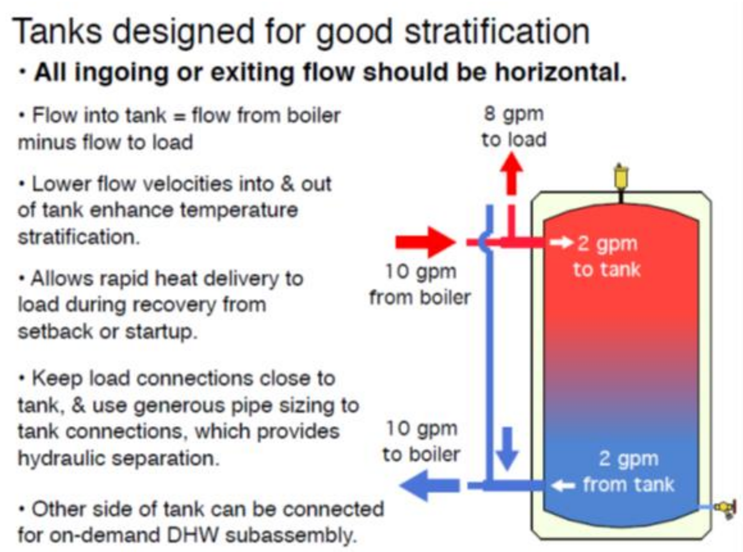
Thermal energy storage uses an engineered tank filled with water, or water plus glycol, to hold excess heat generated from a boiler or furnace. The hot water is held in a thermal storage tank until the next call for heat, when it is circulated through the heat distribution system. Figure 11-11 is a schematic of a pressurized tank. The supply (red pipe) comes into the tank at the top and the return (blue pipe) comes out of the bottom. A thermal gradient or stratification of the heat is maintained in the tank. Depending on

[324] From RHNY Hydronics Training by John Siegenthaler.

whether the system is drawing heat from the tank or the boiler is sending heat to the tank, the thermocline between hot and cold water will move to higher or lower levels in the tank. Care should be given to designing the supply piping in order to maintain stratification. Note that the supply from the boiler is 10 gallons per minute (gpm), but that it enters at 2 gpm because the pipe is widened to slow the flow velocity and prevent turbulence in the tank. Sometimes a diffuser or deflector is also used to maintain stratification.

Figure 11-11. Thermal Storage Schematic

Source: NYSERDA RHNY Training Materials [325]



Thermal storage tanks may be either pressurized (closed), or unpressurized (open). The pressurized tanks may be required to be ASME rated if they are 120 gallons or larger in a commercial application. Open tanks contain an internal heat exchanger, and although covered, they are open to the atmosphere. Because of this, the open systems must be treated to prevent dissolved oxygen from entering the heating system and causing corrosion. The unpressurized tanks also have a high temperature limit that prevents their use with a 180 ºF supply, so more heat emitters may be needed.

[325] http://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/Biomass/biomass-hydronics-training.pdf

11.4.1 Benefits of Thermal Storage with Pellet and Chip-fired Systems

When ignition or recovery from a slumber period occurs in pellet or chip burning systems, the small bed of burning fuel is cold, leading to low burn rates, high air/fuel ratios, low and incomplete combustion, high CO emissions, and reduced thermal efficiency. Similarly, when an automatic feed system is cycled off, the bed becomes cold again, leading to high emissions. Figure 11-12 shows the measured emission transients with a pellet-fired boiler operating in a cyclic mode. Note that during cycling, the CO emissions in the dilution chamber range from a low of 50 ppm to a high of 150 ppm. Hydrocarbon emissions have a similar pattern. The dilution tunnel has a 10:1 dilution ratio, so the values for CO in the stack are 500 to 1,500 ppm. In contrast, the ANSI standard for gas-fired heating systems is limited to 400 ppm in the stack. Therefore, maintaining good combustion conditions for as long as possible is an important health and safety measure as well.

11.4.2 Benefits of Thermal Storage with Cordwood-fired systems

When the temperature reaches the set operating limit in cordwood-fired boilers, the air flow is stopped or reduced to a fixed minimum. In that event, combustion decreases to a near-zero rate with very low oxygen levels (smoldering), leading to a cold bed and high formation rates for particulates, CO, and hydrocarbons. While the formation rates are high, the emission rates are very low due to low air flow. When the air dampers and/or combustion air blowers are activated again, however, there is a period of high emissions as the bed transitions back to active combustion. Figure 11-13 depicts an example of the measured emission transients with a high volume cordwood-fired boiler, operating in a cyclic mode , commonly referred to as an outdoor wood boiler. The CO can reach 4,000 ppm in the dilution tunnel (40,000 ppm in the stack). Particle production follows a similar pattern.

Figure 11-12. Illustration of Carbon Monoxide and Hydrocarbon Emission Transients during Testing, in Cyclic Operation, of a Three-Stage, Downdraft Hydronic Heater

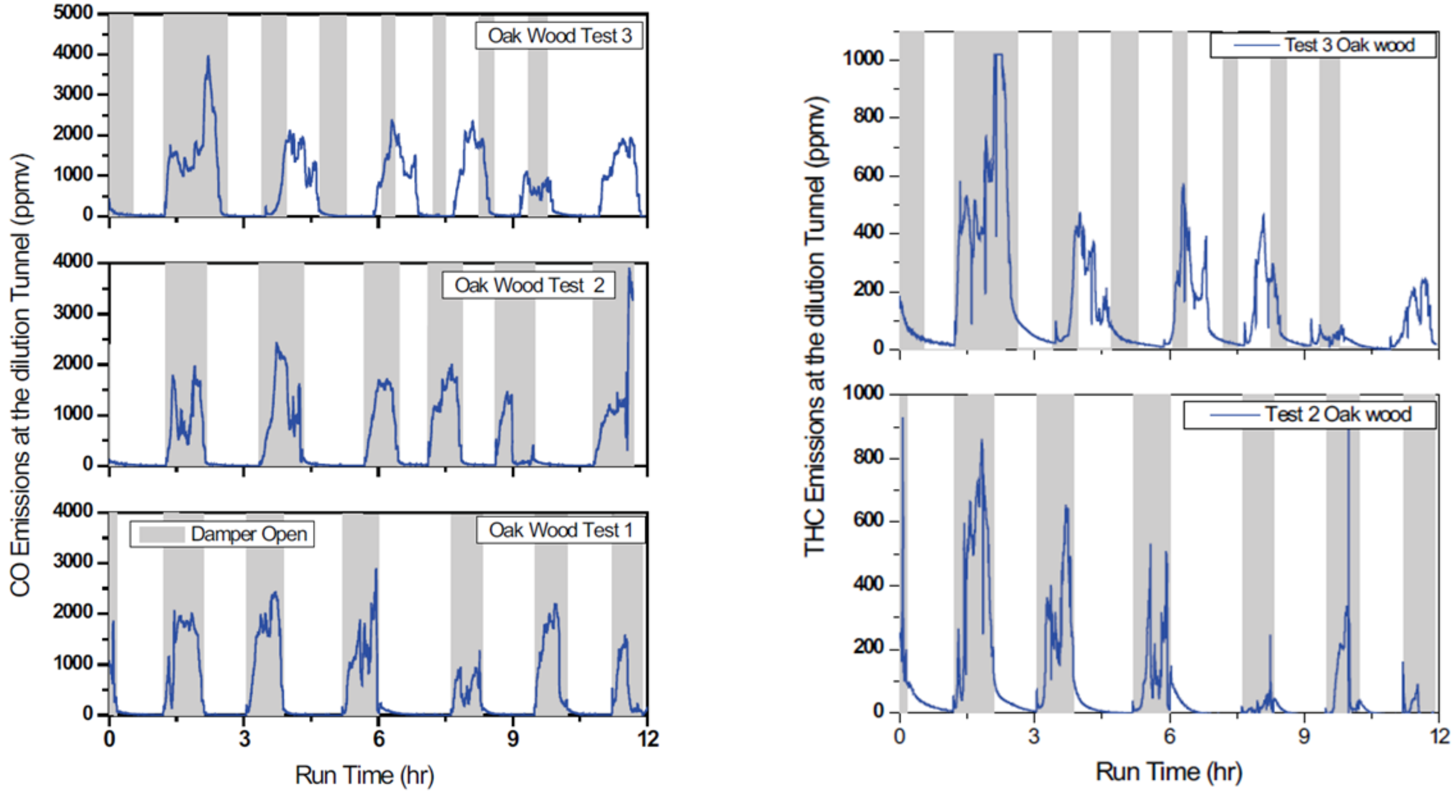
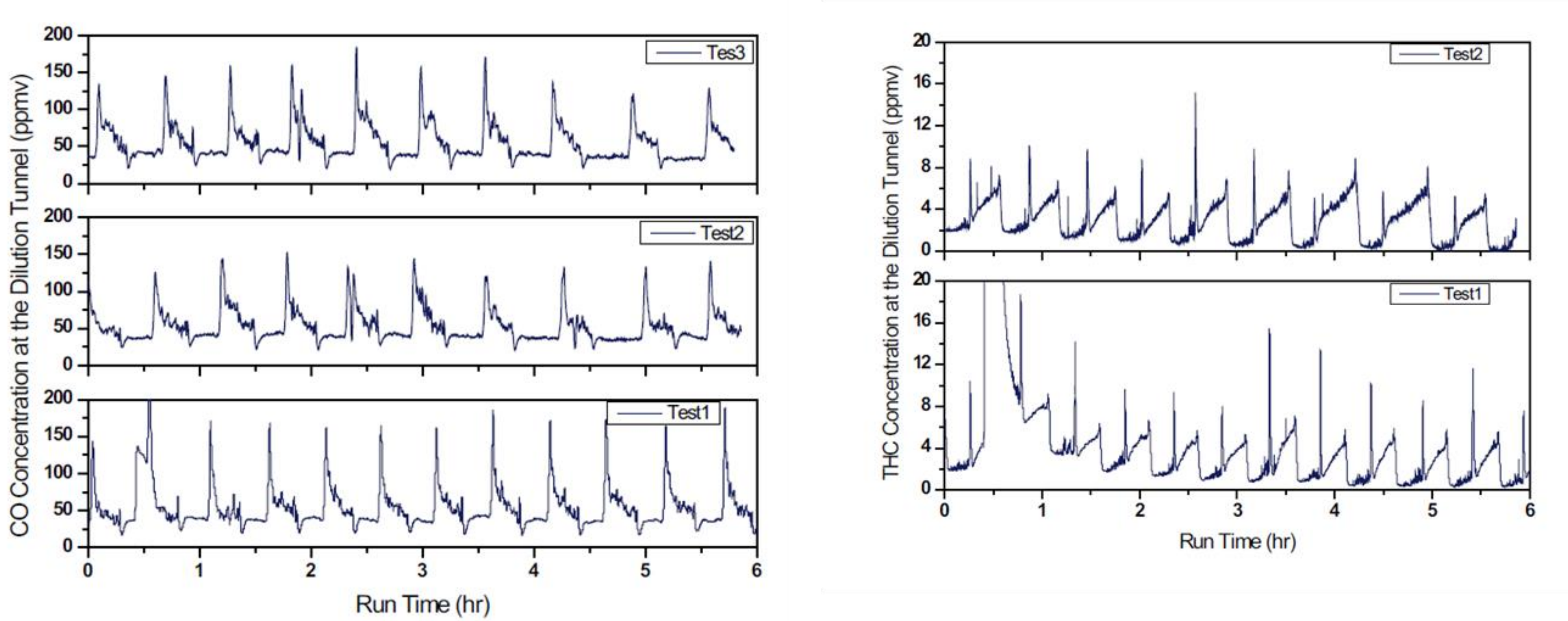


Figure 11-13. Illustration of Carbon Monoxide and Hydrocarbon Emission Transients during Testing, in Cyclic Operation, of a Modern, Pellet-fired Hydronic Heater



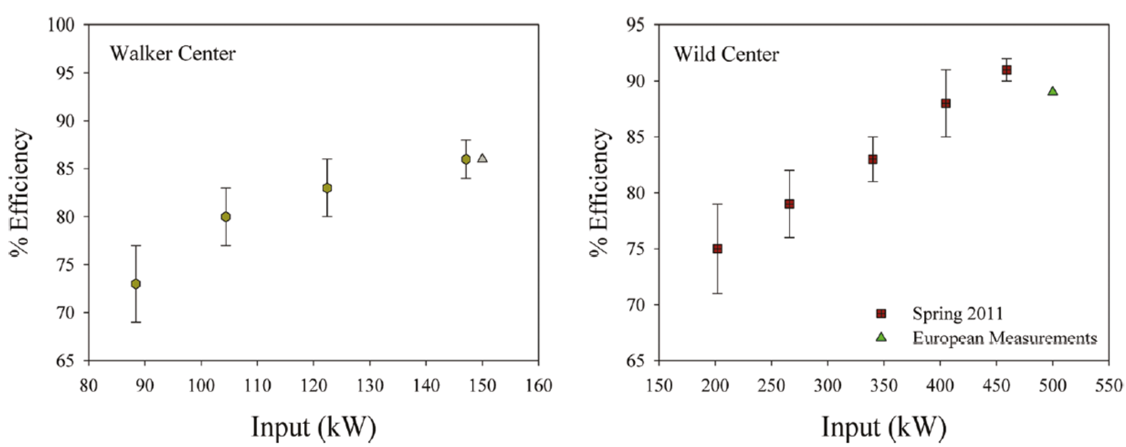
11.4.3 Efficiency Improvements with Thermal Storage

The term efficiency is often used in different contexts, but there are two key efficiency measures: combustion efficiency and thermal efficiency. Combustion efficiency measures the conversion of the carbon in wood to carbon dioxide (CO_2). A high combustion efficiency for these units is typical unless airflow is restricted, which produces char in the ash. Delivered efficiency measures the effective energy delivered for heating purposes. An analysis of the delivered efficiency of a wood heating device is provided in the narrative below. With a system operating in steady state, for example at full load output, efficiency is 100% minus the losses associated with energy in the exhaust gas and the "jacket loss." Jacket loss is heat conducted out through the jacket insulation from the boiler water and hot chamber to the surrounding air. The energy loss in the exhaust gas is roughly a constant percentage of the energy input rate but can change with burn rate as exhaust gas temperature and flue gas oxygen levels change. The jacket loss rate in Btu/hr can be considered roughly constant, therefore as the burn rate changes, jacket losses change accordingly.

During the off period with a system operating in a cyclic mode, the jacket loss continues at a rate that can be close to the steady state level. This off-cycle jacket loss contributes to reduced efficiency when operating in this mode but if there is thermal storage, some of the heat is saved. Figure 11-14 depicts the delivered efficiency as a function of load percentage for two BAT pellet boiler installations in NYS. The efficiency measures taken in situ at these commercial installations highlight efficiency performance at different load conditions and compares those results to measured efficiency under European test methods.

Figure 11-14. Illustration of Decrease in Efficiency of Pellet-fired Hydronic Heaters as Function of Load

Source: Field test data;



Increasingly, biomass-fired heating equipment is being offered with modulating combustion, which can reduce on/off cycling rates. As the load decreases, the thermal efficiency of a pellet boiler decreases, and it does so beginning at higher loads than does an oil boiler. There is a gradual decrease to about 30% of full load, and then a much more rapid decline, especially at 15% of full load, where the decrease becomes steep. Depending on how these boilers are evaluated – whether by the EN 303-5 (tested only at 100% and 30% of full load) or USEPA Test Method 28 WHH (tested at 100%, 25-50%, 15-24%%, and <15% of full load) – the annual efficiency rating will be very different. The use of thermal storage will keep a pellet boiler operating at high loads and reduce cycling, thereby maintaining more efficient operation.

The impact of modulation depends on the details of the equipment and how modulation is implemented. With automatic feed equipment (pellet and chip), modulation may be as low as 30% of the maximum rated firing rate. Modulation can be achieved through changing the fuel feeder screw speed, or by implementing frequent on/off cycling of the feeder screw, effectively feeding the fuel in pulses. Overall or average excess air levels at low firing rates may be higher than at full load, as the air flow is less modulated than fuel flow. At low firing rates, the air velocity is lower, which can lead to poor air/fuel mixing. Combustion zone temperatures are also lower. These conditions typically lead to higher flue gas concentrations of CO, particulates, and unburned hydrocarbons. These factors are very much equipment specific. With cordwood-fired equipment, which is fed in batches, it is not uncommon for modulation rates to be as low as 50% of the maximum rated firing rate. As with automatic-feed systems, at low output, combustion performance may be degraded and emissions higher.

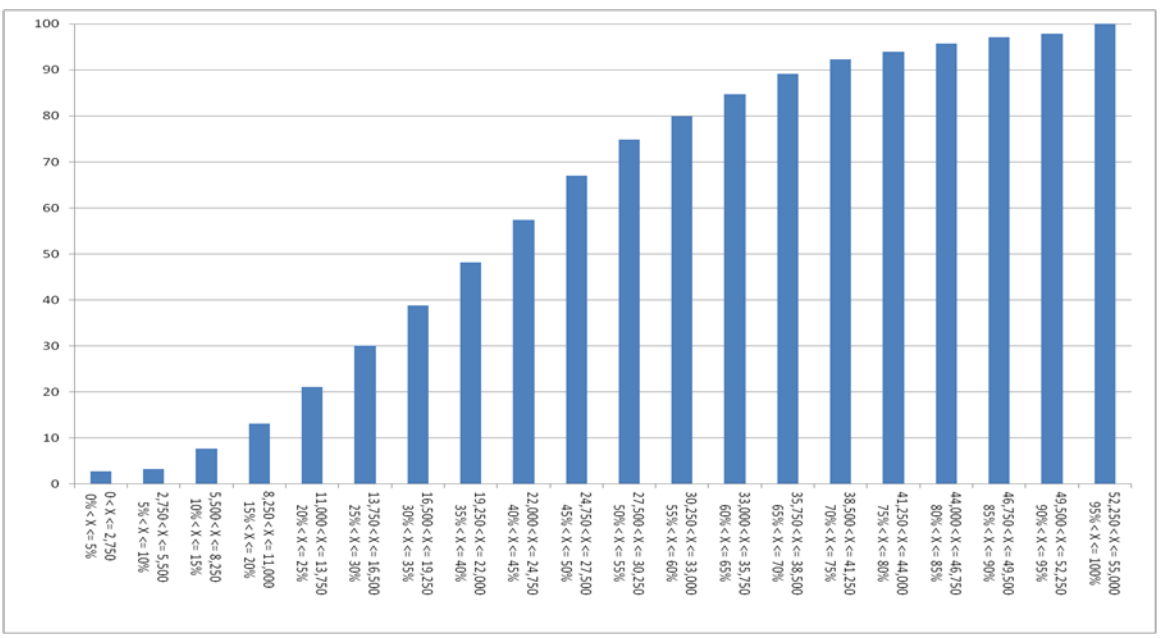
With either cordwood or automatic-feed equipment, the performance under low output will be dependent upon the control configurations and settings. Consider, for example, a cordwood boiler with a set point operating limit of 180 °F. Under very low load, the boiler will fire at full output as the temperature increases from a cold starting point. At some temperature below the set point, the system will start to modulate to lower firing rates. The difference between the operating limit and the temperature at which modulation begins is termed the differential. If the differential is large, e.g., 30 °F, the system will operate for considerable time at low load. With a low differential, e.g., 5 °F, the system will operate at full output until the temperature is nearly at the operating limit, and then modulate briefly before cycling off. A manufacturer will decide on the differential based on performance in a cycling mode versus performance in a low output, modulated mode. Control settings can also affect the rate at which output declines as the operating limit is approached (PID control settings). With thermal storage, a manufacturer might choose a small differential so that the system operates in a good performance, high output mode as long as possible.

11.4.4 Impact of Thermal Storage

The thermal load on any heating system varies over different time scales. Under relatively high and constant building heating loss rate, spaces being warmed cycle under the control of the room thermostat. In residential hydronic heating systems, cycling rates may be 3-5 times per hour. With multiple zone systems, the demand on the heat sources may be more even if the different zones call for heat at different times. With a low mass cordwood boiler or automatic-feed system, even a modest amount of thermal storage can reduce on/off cycling.

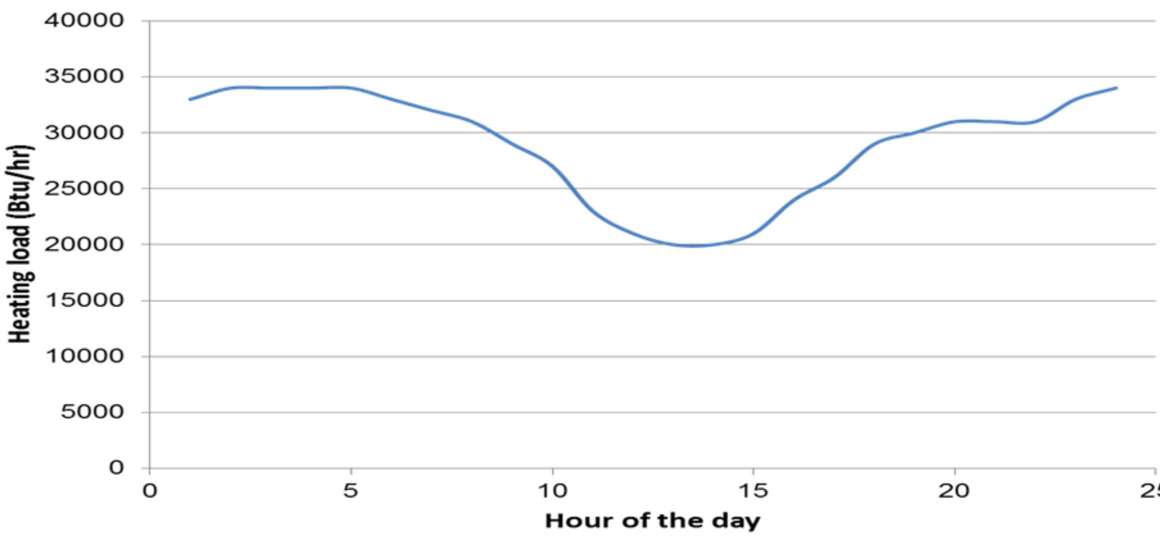
On an annual time scale, heat demand on the heat source varies strongly from the winter peak to the summer domestic hot water-only load. Figure 11-15 shows the modeled heat load analysis for an average sized ranch house of average insulation located in Syracuse, NY. The peak load for the home is 55,000 Btu/hr. However, peak load is the coldest hour of the year. On an annual basis, the boiler operates at loads greater than 70% for 10% of the year. For 50% of the year, heating load is between 35-70%, and for 40% of the year, load is less than 35% of peak load. During times of the year when heating load is very low and intermittent, use of thermal storage is required to avoid rapid cycling and is commonly used even with gas- and oil-fired heat supply systems.

Figure 11-15. Annual Heal Load Analysis, Syracuse, NY 2,500 ft^2 home



A second time scale relates to the daily variation in heat load due to changing outdoor temperature, solar gain, and thermostat setback. Thermal storage can reduce the number of on/off daily cycles that correspond to the daily load variations. Figure 11-16 shows the diurnal heat load for the Syracuse house, but this time just for a January day. The load drops from about 35,000 Btu/hr (64% of peak) to 20,000 Btu/hr (36% of peak) at mid-day due to solar gain. Therefore, even in January, there is a strong variation in demand, and a boiler properly sized to the peak load will operate at low loads in the absence of thermal storage. Because boilers are commonly oversized, this part-load operation in a boiler without thermal storage is exacerbated.

Figure 11-16. Heat Load for Typical Home on Early January Day in Syracuse, NY



In a biomass-fired system, thermal storage designs are either internal or external to the boiler. With large internal thermal storage, as in an OWB, there is the potential for relatively cold storage temperatures to present cool surfaces to the combustion zone and internal gas flow passages during transient operation. This design can lead to poor combustion and deposition of combustion gases on the walls, including heavy hydrocarbons and water. Over time, the condensation of water can lead to corrosion of the boiler and reduced longevity. The build-up of hydrocarbons in the combustion chamber is also indicative of creosote build-up in the chimney/stove pipe that can lead to an uncontrolled fire.

With external storage, the boiler can be low mass, leading to rapid heating of the combustion chamber during cold start or recovery from a temporary idle period. This effect can be mitigated by using return water protection, which tempers the cool water returning from the hydronic distribution system with hot water in the thermal storage tank. A recirculator pump is internal to some biomass boilers to bring hot water back into the water jacket until it meets its set point, significantly reducing the time needed to reach the set point and preventing condensation of combustion gases. With external storage, the efficiency of the system will, of course, be affected by heat losses from the storage tank and, as in the case of the boiler, the external systems should be well insulated to minimize these losses.

Beyond boiler sizing and basic installation, the integration of the entire system is critical in achieving good performance. The key goal of system integration is to avoid low-load, cyclic operation of biomass boilers and idle heat losses from boilers. A hot boiler that is not delivering heat has an efficiency of zero. Many factors affect system integration, and include the following:

- The availability of, and ability to automatically switch-in, a back-up heating source for very low load periods.
- Post-purge of residual heat in the boiler coal bed and/or refractory and steel mass following a firing period, which moves the heat to the thermal storage tank.
- Pre-heating of the storage tank in anticipation of building set point changes and recovery.
- How the firing rate is modulated as the storage tank approaches its set point temperature.
- Information available to the operator about the storage tank condition to facilitate operations planning.
- Set point modulation with current and expected load.

Boilers are typically tested and rated as isolated components, but the actual field performance can be strongly affected by these integration and control decisions.

To illustrate the complex nature of a fully integrated hydronic system, see Figure 11-17 and Figure 11-18. These graphics were provided by John Siegenthaler of Appropriate Design and are part of a biomass hydronic system design course.

Figure 11-17. Illustration of Integrated Hydronic Heating System Based on Hand-fired Gasification Boiler

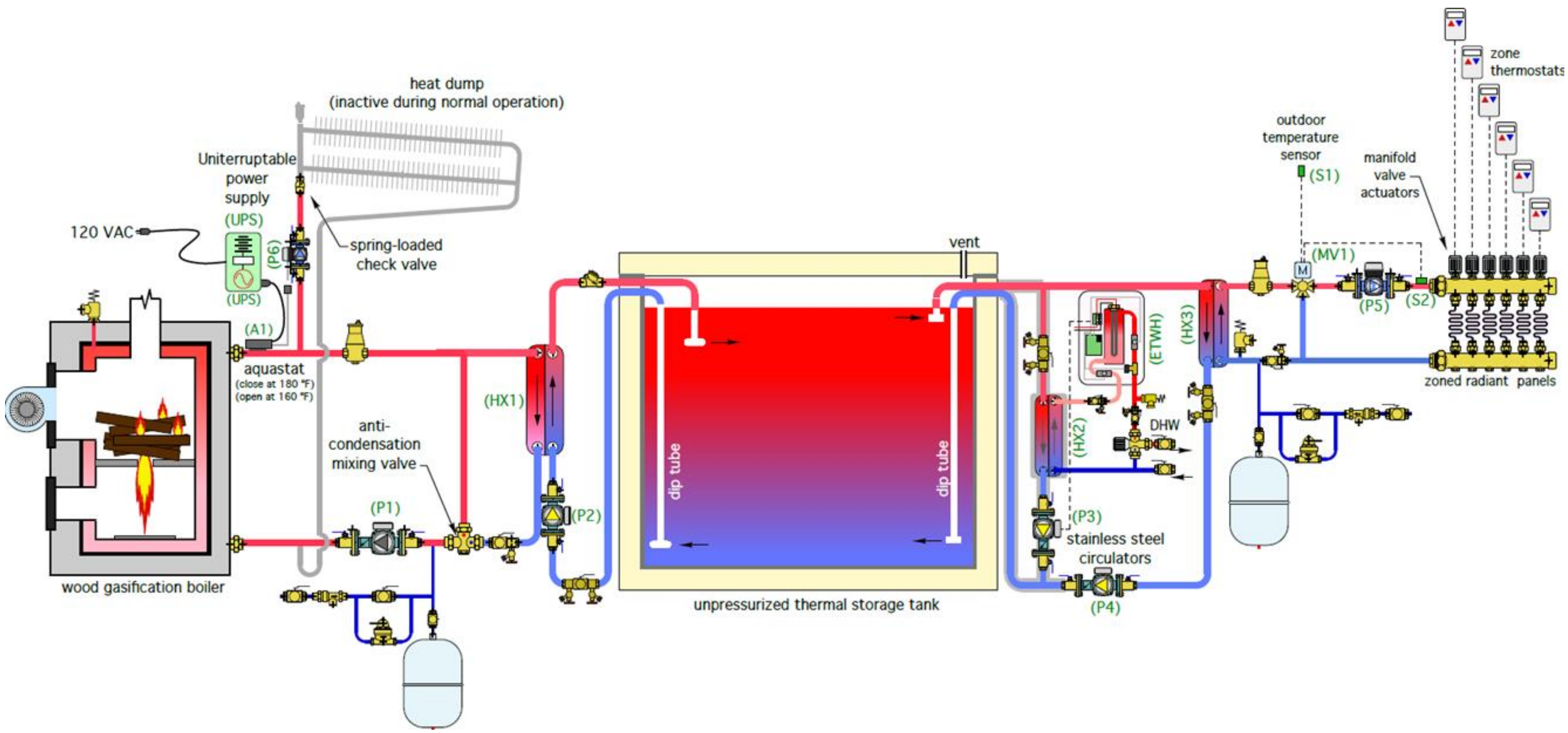
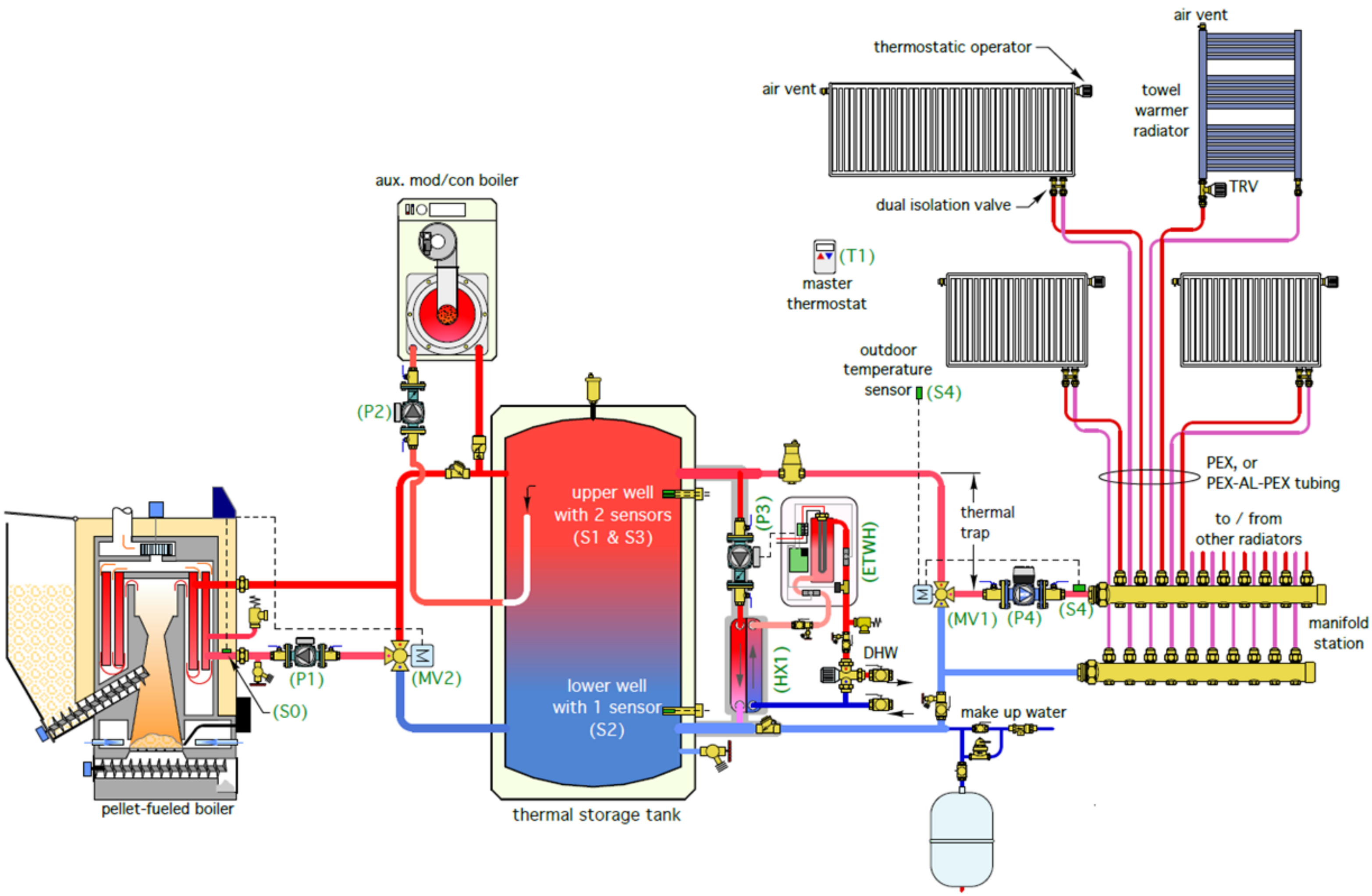


Figure 11-18. Illustration of Hydronic Heating System Based on Use of Pellet Boiler and Gas-fired Backup Boiler



The annual efficiency of a heating system provides a basis for estimating its performance during typical operating conditions. The evaluation includes the heating unit and its distribution system to identify potential losses. To obtain the best estimate of annual heating system efficiency, long-term field measurements over a minimum period of one year should be taken. Several examples of heating system annual efficiency evaluations appear in the literature. The Bavarian Centre of Applied Energy Research conducted in situ measurements on pellet and cordwood boilers to characterize their emissions and performance behavior. The utilization ratio or annual efficiency from these tests was estimated to range from 69% to 74%.[326] Schraube et al. (2010) published average annual efficiencies of 69% based on monitoring data. Efficiency values can be increased by 5% to 10% through proper insulation of pipes and the appropriate design of system components (AEA 2007, p. 3). In general, a heating system is often oversized to ensure it is capable of always meeting heat demand to the consumer's satisfaction. As a result, however, the boiler will operate mainly within a load range below its best efficiency level. A better understanding of the system's heat demand is needed in order to identify the best operating conditions for the heating unit and its components.

11.5 System Commissioning

Commissioning should be undertaken throughout the project development and implementation stages to ensure that a new biomass heating system is designed, installed, and operated as intended. It is also important to determine if the projected cost savings and system benefits are realized. For every ICI installation, a formal step-by-step commissioning plan should be developed. The commissioning plan should include inspections to verify that all components and the integrated system are installed and functioning as intended by design, including building energy management systems. The commissioning plan should also answer the following questions:

- Is the boiler installed correctly and achieving expected output at nominal and partial loads?
- Is there cold water return protection?
- Does the thermal storage tank achieve thermal stratification, or is the flow into the tank too strong and causing mixing?
- Are the previous boilers valved-off, or have they been left on-line? If the latter, do they contain hot water that will function as heat emitters and decrease system efficiency?

[326] Kunde 2007, p. 13.

Central to the commissioning plan is the assurance that there will be proper communication between each of the newly integrated heating system components. Controls must be evaluated to ensure the boiler is able to properly respond to the building heating needs and eliminate or minimize inefficient cycling. In addition, if the system is not well controlled, both the biomass boiler and the auxiliary oil boiler might respond to a call for heat, causing both to energize and cycle frequently. This operation leads to low efficiency and premature equipment failure.

11.6 Measurement and Verification

Measurement and verification (M&V) of a new commercial biomass heating system should take place for at least the first full heating season. NYSERDA has provided M&V training specific to commercial pellet-fired boiler heating systems for technical consultants that will perform M&V review for all of the commercial biomass projects supported through RHNY. An M&V plan outlines all of the measurements and data collection needed (including frequency of collection) and describes the recommended analyses. It is important to develop the M&V plan upfront during system design to be sure the system is capable of measuring the necessary parameters.

Depending on the system, the M&V plan may specify some, or all, of following measurements and data collection requirements:

- Fuel and pellet delivery logs (dates and amounts), periodic fuel tank level measurements or metering to track use over the M&V period (similar to baseline data included in the technical feasibility study).
- Runtime and cycle rate/count data for all the boilers collected at regular intervals (hourly or shorter) over the monitoring period.
- Supply and return temperatures (at hourly intervals) for the individual boilers and overall system, as appropriate.
- Hot water flow readings at hourly intervals over the monitoring period (to calculate thermal output and efficiency).
- Wood pellet auger runtime or speed denoting hourly fuel supply to the boiler.

The measured data should be reviewed to confirm that the boiler is properly sized and system operation and control are consistent with the original design intent and acceptable performance practices. These data will show whether the biomass and back-up boilers are properly responding to the call for heat, or if they are cycling. An analysis of operations on the coldest day when both boilers are operating is recommended. A similar analysis is recommended during early fall and late spring for the auxiliary boiler. For other heating season days, the interaction between the pellet boiler and thermal storage should be apparent. For example, if the tank is hot and there is a call for heat to recover from the nighttime setback, the thermal tank should begin to circulate hot water as the pellet boiler is energized. An analysis of full-load hours will also provide valuable information about the sizing of the pellet boiler and its most efficient operation. The M&V report based on the data collected in the first full heating season will also report total fuel use, fossil fuel displacement, all operation and maintenance costs, and energy cost savings. NYSERDA has developed monitoring and verification procedures for pellet boilers (http://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/Biomass/RHNY-Technical-Guidance-for-Large-Commercial-Pellet-Boilers.pdf).

11.7 Waste Stream Management

Biomass combustion produces ash. The volume of ash and its composition depend on the biomass fuel and the compounds in it. Ideally, the ash should be recycled consistent with environmentally sound management principles, particularly in light of the volume produced by medium- to large-scale combustion units.[327] Given the potential contamination with hazardous substances, however, an appropriate analysis should be conducted to ensure that the ash is not considered a hazardous material under New York State regulations.

Generally, there are three different ash fractions, depending on the combustion facility: (1) bed or raw ash; (2) cyclone ash; and (3) filter ash. In small-scale combustion systems as well as systems without secondary ash removal, only bed ash and ash depositing on the heat exchanger occur.[328] The following options for ash reuse include:[329]

- Fertilizer for agricultural and forestry uses.
- A supplement for mineral construction material.
- As spread material in winter.
- Reuse in industrial processes, such as in the cement industry.
- Raw material in chemical manufacturing processes.
- As a base layer in road construction.
- Landfill cover.

[327] FNR 2007, p. 162.

[328] BE2020+ 2011, p. 21.

[329] BE2020+ 2011, p. 21; FNR 2007, p. 174.

There are practical limitations to the reuse of ash. Industrial applications rarely use this material in processing due to a lack of sufficient quantities and quality. Moreover, the ash quality and composition will vary depending on the fuels used. Ash production is also irregular over time, with the largest volume generated in winter, while the cement and construction industries mainly operate in summer. For these industry applications, the ash would have to be stored during winter, increasing the cost of its reuse.[330]

Due to the lower concentrations of heavy metals compared to fly ash, only the bottom ash fraction is suitable for reuse as a base layer in road construction or for forest roads. While there is interest in these applications, there are similar obstacles as with the cement and construction industries concerning additional costs for ash transport and storage. Currently, the most common option for reusing bottom ash from biomass combustion is its application as a fertilizer in agriculture and forestry because of its high nutrient content. District heating power plants often have contracts with wood chip suppliers to return the bottom ash. Filter ash and fly ash are not suitable for this reuse because of their higher heavy metal content.[331] Whether ash can be used as a fertilizer depends on state regulations related to soil quality, land use, and ash properties. Dust control may also be an issue arising from the dispersion of ash during its application.[332] If the reuse of the ash is not allowed or not economic, the ash has to be properly handled and disposed of as either a solid or hazardous waste.[333]

11.8 Other Information Sources

For those considering the installation of a biomass thermal heating project, there are good sources of guidance published in the U.S. and in other countries. These sources were consulted for this report and can be referred to for additional information. A short review of the most significant of these sources is provided in this section. Note that citation in this report does not imply approval of any recommendations contained in the materials by NYSERDA or the authors of this report. They are included here only in an effort to provide a comprehensive source of information for readers.

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330 BE2020+ 2011, p. 21.

331 BE2020+ 2011, p. 21-22.

332 BE2020+ 2011, p. 22.

333 FNR 2007, p. 176.

For residential applications, the U.S. Environmental Protection Agency (USEPA) BurnWise web site (http://www.epa.gov/burnwise) provides some basic guidance, as well as information on appliance types and the results of standard emission qualification tests for specific products. Useful information for residential applications is also provided by Wood Heat Organization, Inc. through its website (www.woodheat.org/) and by the Hearth, Patio, and Barbeque Association (www.hpba.org). For larger non-residential systems, the Biomass Energy Resource Center (BERC) (a program of Vermont Energy Investment Corporation) (www.biomasscenter.org) has published a series of downloadable guideline reports that address specific aspects of biomass heating. Related guidance has also been published by the US Department of Energy Federal Energy Management Program.

The Biomass Thermal Energy Council website includes a series of downloadable publications on biomass heating. One of these is a report published by the Carbon Trust, which includes very detailed technical and implementation guidance for non-residential applications. While this is specific to installations in the United Kingdom, the general guidelines are useful for consideration in the U.S.

The USEPA's BurnWise website provides information on certification test results for specific stoves. All stoves require regular maintenance to ensure that vent systems are clear and safe, gaskets and seals are correctly balancing air flows for low emissions, and catalysts are operating. Wood stoves, and particularly cordwood stoves, have levels of exhaust carbon monoxide that are much higher than gas- and oil-fired heating systems. It is critical to ensure that the combustion gases are safely vented to the outdoors.

11.9 References

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12 Key Findings

Wood, under favorable conditions, can be competitive with oil as a replacement heating fuel. NYS has sufficient local wood supply to support approximately 5% of the State’s total residential heating needs with wood, assuming there is little growth in the ICI wood heating and biofuel production sectors. How growth occurs using wood heating will have long-term ramifications for NYS. Under all circumstances, moving from fossil fuels to wood will result in emission increases to the airshed, but the extent of the increase will be dependent upon the types of wood burning technologies deployed.

Analysis of the existing regulatory framework indicates that there are no requirements in place to ensure proper installation of clean wood burning devices. Emission standards alone will not address the problem. Key factors, such as wood fuel standards, system sizing, system testing, and technology integration issues must be addressed to ensure optimal results. Regardless of how the policy and technology trajectory develops, NYS can realize economic benefits by fostering increased use of woody biomass, but those benefits could ultimately be offset by increased air pollution and costs associated with health and safety impacts. Key findings from the analysis include the following:

- Converting from oil and propane to wood heating saves consumers’ money over time due to lower fuel costs.
- Using Best Available Technology (BAT) wood-burning units yields greater lifetime cost savings due to higher efficiencies, lower maintenance costs, and significantly reduced emissions compared to Business As Usual (BAU) technologies.
- Large segments of the existing fleet of wood heating devices are high emitting units that disproportionately impact air quality and health.
- Emission and health impacts will likely be significant in local communities if the use of BAU units continues and/or increases. Generally, these emissions will not be noticed in statewide air monitoring emissions or the regional airshed, as dispersion is local and not likely to impact regional air quality monitors.
- Installing correctly sized equipment to meet actual heating needs is critical to ensure proper unit operation.
- Lack of expertise in appropriate sizing, installation, and proper design (including optimal stack heights and controls) of biomass units leads to greater costs, reduced efficiencies, and increased emissions and air impacts.
- Standardizing fuel and creating wood fuel specifications to match equipment will lead to improved efficiency and emissions performance.

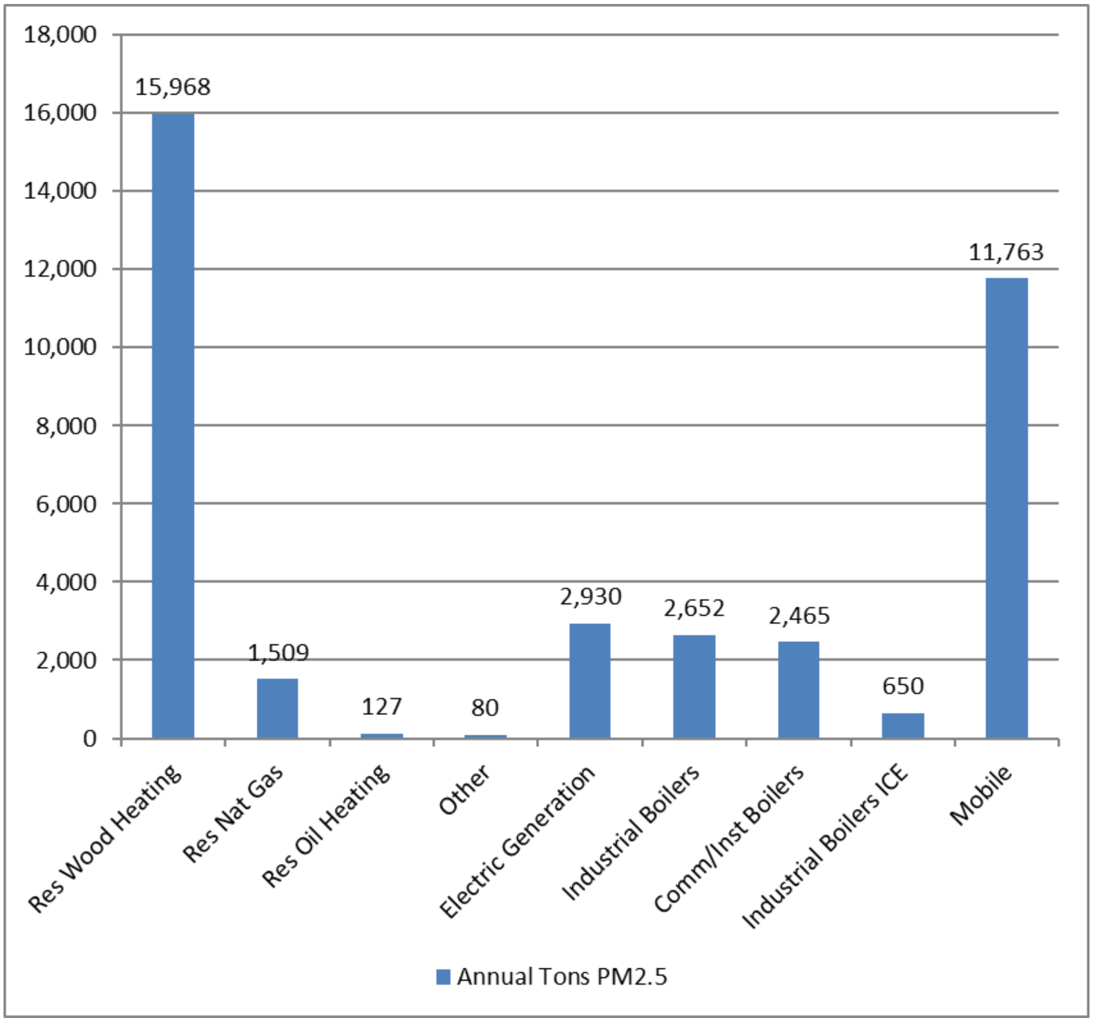
- Sale and installation of high-emitting BAU technologies will continue unless there are new regulatory controls put in place.
- Proactive government policies and practices will be needed to ensure installation of clean and efficient technologies, at least in the near-term, to stimulate growth in the advanced thermal biomass market. Reducing emissions from the existing fleet of wood heating devices should also be considered to improve community air quality.

12.1 Trends and Patterns

NYS is the second largest market for residential wood burning devices in the country, and use of wood burning devices continues to grow. The lack of data on device sales and cordwood harvesting, however, makes it impossible to precisely characterize what segment of the residential heating market is growing, and if the growth is occurring in cordwood, chip, or pellet fuels. The use of wood heating in the ICI sector is insignificant and primarily found in wood processing operations, with a few NYS schools also heating with wood. BAU and some BAT ICI wood heating applications installed in locations near sensitive populations (hospitals and schools) are of significant concern as the emission increases in these locations are more likely to result in adverse health impacts.

While the overall use of wood for heating purposes is minimal compared to other fuels, its impact on NYS' air quality is significant, as the current fleet of wood-heating devices consists primarily of high-emitting, low-efficiency devices. This point is illustrated with data from one pollutant, $PM_{2.5}$, but wood also emits a variety of pollutants at higher levels than liquid heating fuels such as CO, NO_x, SO_2, and PAHs. Figure 12-1 highlights the $PM_{2.5}$ contributions by source category. While residential wood heating provides less than 5% of NYS' overall heating needs, the sector contributes more than 90% of the fine particulate ($PM_{2.5}$) emissions in NYS. To put this number in perspective, wood heating currently contributes 275% more $PM_{2.5}$ than all ICI heating emissions combined, 550% more $PM_{2.5}$ than the electricity generation sector, and 35% more $PM_{2.5}$ than the transportation sector. High emissions from the residential wood heating sector are attributable to the large inventory of unregulated devices in NYS.

Figure 12-1. Annual Tons of $PM_{2.5}$ Emissions in 2012 by Sector [334]



12.2 Regulatory Framework

A review of State and federal regulations indicates that regulation of this sector has been primarily through a patchwork approach. Currently, only a limited subset of residential devices and a few large ICI devices are subject to emission standards that reflect best performing equipment. In NYS, small ICI boilers and most residential devices are not subject to any emission standard, and emission standards for medium-sized units allow emissions that are 20 times higher than in neighboring Vermont.

334 NEI 2012.

Without further regulation, high-emitting, low-efficiency devices in ICI applications can be legally sold and installed in NYS. For residential units, BAU devices can be legally sold and installed in NYS until the Step 2 standards of the 2015 NSPS for residential wood heaters take effect. This rule, however, will have no impact on the secondary market (resale market) for all wood-burning devices but OWBs and does not address the significant emission issues surrounding the existing inventory of devices.

Compounding this problem is the lack of mandated fuel specifications. Regulations prohibit the burning of hazardous waste, however problematic waste wood feedstocks such as pressure-treated and pentachlorophenol-treated wood may be difficult to completely segregate and eliminate from clean wood waste streams. Low-emitting, high-efficiency devices will not work properly if used with improper fuels. Analysis of European regulations demonstrates that a comprehensive regulatory framework, combined with fuel standards matched to proper technology, can foster a robust clean wood heating sector.

12.3 Incentive Programs

Incentive programs present an opportunity for states to move the market to better performing units by setting standards for efficiency, emissions, oversizing, and installation. State environmental regulations and building codes do not address all necessary aspects of biomass installations, such as proper sizing. Incentive programs should establish guidelines to ensure the proper installation of clean systems. Most commercial and many residential biomass heating systems will be added to an existing heating system and heat distribution system. These retrofits must be carefully integrated so the wood heating system operates optimally. Performance verification is a critical step to assure that incentivized units meet the efficiency and emissions targets set by these programs. Incentive programs for wood heating should include requirements that ensure quality installation, correct sizing, best emissions performance, appropriate fuel use, and monitoring.

Incentive programs can be categorized into the following four categories:

- **Rebate programs** reduce a key barrier to installation of wood heating devices, namely the high upfront costs. These programs can be effective in expanding the market for more efficient and cleaner-burning units. Successful programs typically incentivize top performers, require appropriate sizing, and set requirements for proper installation. Setting the appropriate rebate level is critical, as setting it too high or too low can reduce program effectiveness. Typically, incentive levels are set to reduce the higher initial capital costs of high-efficiency, low-emitting equipment compared to BAU technology. Rebate programs are often targeted at bringing new consumers to the technology, but can be targeted to helping existing customers make better choices when it comes time to buy a new unit.

- **Changeout programs** help current wood device owners purchase new equipment. These programs can promote the removal of nuisance units and older central heating devices, and enable low income households to enter the market for cleaner devices. Changeout programs build on the rebate programs, but add an additional incentive for those who currently own high-emitting equipment. Changeout programs typically have high administrative costs.
- **Bounty programs** pay owners of high emitting units cash to turn in and destroy the device. These programs are directed as a cost effective program to eliminate high emitting devices from the market.
- A **Thermal Renewable Portfolio Standard (TRPS)**, alone, will not address key market barriers. Regardless of type and design, any thermal biomass incentive program will need to consider the cost of the technology, the cost of alternative technologies and fuels, and the current state of the market. TRPS programs are complex to implement and operate, and will likely have the highest administrative costs.

12.4 Training

NYS must overcome several challenges, if proper installation of woody biomass units is deemed a priority. NYSERDA has developed a Renewable Heat NY (RHNY) training program to address some, but not all, installation issues. These challenges can be viewed as opportunities to develop education programs and promote green jobs. Work under the roadmap developed the following training recommendations:

- **Establish minimum technical qualifications for installers.** NYS could establish minimum technical qualifications for installers, which could be tailored to the different types of units, i.e., separate criteria for installers of cordwood and pellet stoves and installers of biomass boilers and ICI applications. This certification process could be enforced through the establishment of a statewide registry and through State and local permitting and inspection practices. Consideration should be given to requiring New York State-issued professional licenses; such state licensing is required in Oregon and Maine.
- **Promote coursework on commercial system design, sizing, and integration.** Continue and expand training opportunities, such as those developed for NYSERDA's RHNY program, on the design and sizing of commercial systems, and the integration of these systems with new or existing heating systems. Coursework on this subject should include consideration of thermal storage, thermostat and system controls, heat distribution systems, commissioning, and monitoring and verification.
- **Work with New York State vocational schools, community colleges, and state universities.** Vocational schools, community colleges, and New York State universities may be interested in providing coursework on biomass heating units and systems as part of plumbing, HVAC, or other relevant programs. Schools may be able to certify installers, which could help to professionalize the field.

- **Encourage the practice of accepting continuing education units for biomass boiler courses.** Coursework offered by trade organizations, often for continuing education units (CEUs), is currently a major source of information transfer to those in the wood heat industry. By accepting biomass coursework for State-managed professional licenses, NYS could encourage the practice of offering CEUs for biomass boiler courses. NYS could also make CEUs a condition of installer participation in programs that provide incentives.

12.5 Outreach

Analysis completed for this report found that consumers need education on key issues when considering the purchase, installation, and use of wood heat units. Public awareness of safety issues such as the dangers of exposure to wood smoke or CO is low. Consumers should be educated on the role they can play in minimizing emissions and adverse health impacts through the proper installation and operation of biomass units and fuel use. Recommendations include:

- **Develop outreach and education partnerships.** Partner with other agencies in the State and with local municipal governments to design and execute an consumer education and outreach plan. Include local groups, such as low-income assistance organizations, that have an understanding of local consumers' needs, constraints, and market entry barriers. These organizations may also have established outreach and education platforms that are trusted by constituents. Involve consumers in the planning effort. An engaged group of consumers could help determine what will resonate with a larger audience.
- **Create general and targeted outreach and education.** General outreach and education is beneficial, and can itself be a strategy for increasing the use of efficient biomass stoves and boilers. However, a targeted outreach and education strategy and plan tied to a specific policy or incentive program may produce greater results. The education and outreach plan should be developed early in the planning process for any policy or incentive program, and should be adopted before the policy or program is rolled out to the general public. This strategy will help maximize program benefits by combining the dissemination of information with clear opportunities for consumers.
- **Provide tools and materials to help consumers and decision-makers.** In addition to educational opportunities, education and outreach plans should include materials and tools that help consumers and decision-makers understand all of the steps needed to make informed choices, including consulting with a design professional. This strategy is particularly important for larger biomass boiler systems.
- **Measure against a baseline.** Conduct a baseline analysis, to establish, for example, the prevalence of high efficiency biomass units, the number of public buildings or private businesses with biomass systems, the number of attendees at local heating fairs, website hits, and media coverage statistics relevant to the biomass field. Set goals against this baseline and revisit it periodically. Review the results, re-evaluate the outreach and education plan, and adjust accordingly.
- **Establish a local presence.** Work with local organizations and individuals, including low-income assistance groups, health officials, hospitals, and firefighters to bring outreach

and education to local communities. Work with these organizations and individuals to speak at local events and provide information on websites and other media outlets. Make sure messages are clear, instructions are simple, and administrative processes are streamlined. Increase education and outreach efforts during the heating season when consumers are thinking about heating options. Make events accessible to all consumers by holding them in the evenings or on weekends. Include experts that have personal experience with biomass heating. Focus the message on what consumers can do to increase the efficiency of their current practices, and encourage upgrades to more efficient units by providing demonstrations. Include information on preventing the spread of invasive insects as appropriate.

12.6 Fuel Supply

Wood dominates the solid biomass market in NYS. Non-woody biomass fuels, such as pelletized fuels made from grass, corn, or other agricultural residue, are not ready for the market. Because the technologies to burn these non-woody biomass fuels are not developed and emissions from these alternative fuels are poorly understood, the fuel focus for this report was on wood. More than 10 million tons of green wood is estimated to be available in NYS. Of that amount, 5.25 million tons of green wood could be used for thermal applications. By way of comparative examples, if a 5.25 million ton harvest level could be achieved, the volume would be capable of providing feedstock for any one of the following three heating scenarios:

- 437,500 homes using wood pellets (assuming 2 green tons of feedstock per 1 ton of wood pellets, and 6 tons of wood pellet use per home per year), representing 3.8% of New York's residential thermal heating needs. A similar number of homes could be heated using cordwood instead of pellets.
- 10,500 schools or similarly sized community-scale facilities (assuming 500 green tons of fuel used annually).
- 262 college campuses or similarly sized district energy facilities (assuming 20,000 green tons of fuel used annually).

These numbers also assume little to no growth occurs in other sectors that might use this feedstock, such as production of cellulosic ethanol. It is unlikely, however, that thermal markets alone can provide a sufficient financial incentive for harvesting. In order to be cost-effective, harvests must include both low- and high-quality wood, and wood intended for a variety of uses. The most critical of these materials is sawmill logs, as they represent the highest value product. Concerns about fragmented forest ownership, competing uses for wood, and long-term availability of fuel exist. Much of this wood supply may not be accessible for use, as it is in small-scale private ownership where owners may have goals that do not include wood harvests. Compounding the supply issues is the lack of reliable estimates for current or future harvests of cordwood, which might reduce industry growth estimates above. Finally, regulations are inadequate to assure no use of waste wood from construction and demolition activities as well as treated waste wood products.

12.7 Air Quality Assessment

While NYS was in attainment for the $PM_{2.5}$ NAAQS as of March 2015, there may be areas of the State without ambient air monitors that experience $PM_{2.5}$ concentrations above the current NAAQS. In these areas, the results of this analysis indicate that where current conditions show elevated background pollutant levels, technology selection is of great importance; a single polluting boiler or stove can lead to exceedances of the health-based air quality standard in the immediate vicinity of the source. Increased air pollution is causally associated with adverse health outcomes.

For areas in compliance with the $PM_{2.5}$ NAAQS, the modeling performed to assess local air impacts suggests that installation of some technologies have potential to degrade local air quality. This particular concern exists in areas with sensitive populations such as people with cardiovascular and respiratory conditions at homes, schools, or hospitals, and illustrates the importance of proper installation with adequate controls and emission limitations. It should be noted that neither air quality monitoring nor stack testing is typically performed at these installations.

The neighborhood level analysis demonstrated that choice of technology (and associated emissions) when adding wood heat to a large institution in a neighborhood has a demonstrable effect on local air quality, especially in areas where wood burning is not already widespread. In areas where wood burning is already widespread, existing BAU wood units at homes may lead to health-relevant concentrations, even when the institutional unit is controlled with nBAT level technology. In neighborhoods where wood burning is already widespread, impacts from an institutional source can be exacerbated by the neighborhood impacts, and vice-versa. The effect of changeouts in neighborhoods is noticeable, but results also indicate that aggressive changeout regimes will be necessary to fully address potential problems. This conclusion is consistent with the experience of Libby, Montana, where extremely aggressive changeout programs resulted in large (50%) reductions in wood smoke levels, but did not entirely resolve the air quality problem.[335] While changeouts were successful in areas with significant wood-burning levels, changeout of BAU wood units did not appear to have a pronounced effect on air quality in neighborhoods where there was not a significant density of BAU wood units.

The influence of surrounding terrain on dispersion of stack emissions also must be assessed. These results suggest that proper siting and stack design must go hand in hand, and that technologies must be designed to disperse smoke above trapping terrain features. For homes, terrain influences may dramatically increase concentrations, and adjustments to chimney design to improve dispersion may not be feasible. Therefore, highly polluting technologies should be avoided in areas where terrain may contribute to adverse air quality impacts.

For institutional settings, BAU stoker chip boilers may produce unacceptable levels of fine PM that may be health-relevant at hourly, daily, and even annual timescales. BAT and nBAT units produced significantly lower concentrations but BAT units with insufficient stack height may produce levels potentially above similar BAU wood units due to the limited dispersion of pollutants and the potential for wood smoke intake by building HVAC systems. In comparison to all wood-burning installation types analyzed in this study, oil boilers burning ultra-low sulfur heating oil had lower potential impacts. Given these findings, $PM_{2.5}$ emissions from BAU, and potentially BAT, wood unit installations should be carefully reviewed and assessed for potential health impacts.

In residential settings, the modeling indicates that BAU technologies have among the highest potential impacts, including the potential for exceeding $PM_{2.5}$ health standards at homes with phase II outdoor wood boilers or BAU cordwood stoves.

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[335] Bergauff et al. 2009.

The most significant decision in controlling air impacts resulting from installation of a wood-fired heating unit is the choice of technology. Higher emissions from dirtier units may be mitigated through higher stacks, proper sizing, thermal storage, and improved fuel quality, but choosing an advanced technology with advanced emission controls is likely the most effective strategy for reducing air impacts. Not surprisingly, selecting units with higher emission rates leads to greater air pollution impacts. When comparing installations in a particular setting, impacts were generally highest from BAU wood units, followed by BAT wood units, and then nBAT wood units. In those same settings, impacts from oil-fired units burning ultra-low sulfur heating oil were the lowest. Modeling results indicate that the nBAT units produce air emission levels much closer to those produced by oil boilers using ultra-low sulfur heating oil, but these units are not currently available in the U.S. market.

Proper sizing to meet actual heating needs can significantly mitigate the air impacts from wood units. It is clear from the impact levels of the BAU units, which are oversized by two or three times their required size based on thermal demand, that proper sizing would significantly reduce the overall air quality impacts. Fuel choice is another key factor in mitigating air quality impacts. Devices burning clean wood pellets operate more efficiently and have reduced emission rates when compared to chip or cordwood units. Cordwood technologies at residential installations produced the highest maximum potential impacts.

The air quality impact assessment highlighted the benefits of installing thermal storage with heating systems. By allowing the unit to fire less often, and at maximum efficiency, thermal storage may reduce maximum air quality impacts by a factor of 5 to 10, based on the type of residential central heating unit. ICI boilers with thermal storage studied in this analysis (i.e., RHNY-qualified boilers at the large school) had lower 24-hour average $PM_{2.5}$, annual $PM_{2.5}$, and 1-hour NO_2 levels compared to other BAT and BAU wood boilers). For ICI units with storage in this analysis, the thermal storage allowed for a significantly smaller unit size, which resulted in much lower emission rates. Therefore, this analysis indicates that thermal storage is an important strategy for reducing impacts from wood-fired heating at residential and institutional settings.

12.8 Current Deployment Technology

The statewide economic analysis of four different technology deployment scenarios demonstrated that wood-heating units provide substantial cost savings relative to oil over the lifetime of the units. The greatest difference between the four scenarios is the substantial increase in emissions relative to oil units when using BAU technologies. By contrast, BAT technologies emit substantially lower emissions relative to the BAU units, providing upward of a 90% reduction in PM and CO emissions for most building profiles. Over the lifetime of the units, these technologies tend to have costs that are roughly comparable to their BAU counterparts for most building profiles. The nBAT technologies, which were assumed to be used only in the final year of the analysis, have an economic profile that is similar to the BAT technologies, while providing even greater emissions reductions relative to a BAU wood unit.

The statewide analysis, and by extension the macroeconomic analysis, were primarily designed to estimate the net benefit to households and businesses who purchase wood heating devices and to the industries that manufacture wood heating devices and the associated pellets, chips, and cordwood. The largest contributors to positive economic impacts are derived from new manufacturing operations associated with wood heating devices, wood fuel products, and pellet mill construction.

The macroeconomic analysis examined local implications of converting conventional fuel oil heating equipment to wood heating devices using locally-sourced wood fuel products (pellets, chips, and cordwood). Across all scenario sensitivities examined, the regional economy would generate between 5,000 and 10,000 jobs over a 20-year time period, which corresponds to average job creation that ranges between 285 and 495 jobs per year over the entire study region (not including numerous jobs related to feedstock supply). The analysis anticipates job growth in the fuel and device manufacturing sectors. For contextual purposes, the total employment level in 2013 in the study region was 1,552,300 jobs. This means that average annual job creation represented between 0.02% and 0.03% of the 2013 regional employment level. The largest driver of manufacturing sector economic impacts was the number of new wood heating devices purchased by households and businesses and the associated wood product manufacturing required to produce wood heating products. New pellet mill construction also had a significant effect on outcomes.

12.9 Study Limitations

This analysis was constrained by a number of limitations in scope, data availability, and methodology. These limitations and uncertainties were described in context in this chapter, and are presented here in a consolidated list:

- In-use data for a wide variety of technologies analyzed in the study were not available.
- Fuel use, specifically cordwood use data, does not exist. Data on residential units and ICI units smaller than 1 MMBtu/hr are difficult to obtain.
- Direct observations of air impacts were not available therefore impacts were modeled. Uncertainties associated with simulations apply to the results from the air modeling. Model performance within a factor of two is generally regarded as adequate, and thus the results may be uncertain.
- This analysis examined maximum and typical emissions scenarios for a range of wood burning technologies of particular sizes; emissions at actual installations may differ somewhat from those evaluated in this study.
- For most of the technologies and pollutants described in this analysis, appropriate stack testing data were not available so average unit performance data, including emission factors, were used instead of directly observed emission rates at the specified operating conditions. This limitation hampers direct comparison between the few technologies for which direct emission rates were available and those for which emission factors were used.
- This study did not analyze costs or public health impacts associated with increased use of wood for thermal purposes.
- This study does not take into account ozone impacts, climate impacts, or impacts from specific compounds other than those explicitly listed (e.g., individual VOCs).
- This analysis did not address health impacts resulting from the air impacts described in the analysis.

12.10 Research Needs

Based on this study, following additional research needs were identified:

- Actual stack testing data under typical, low load, and maximum firing conditions. These data would include stack flow characteristics, and, most critically, emission rates for all relevant pollutants, specifically NO_x and air toxics. These observations would replace calculated values based on theoretical performance of the units.
- Measured, rather than estimated, unit delivered efficiency.
- Analysis on the health impacts of sub-daily exposure to wood combustion impacts.

List of Appendices

Appendix A. Supplemental Training and Outreach Materials

A.1 Sample Course Information for Continuing Education Credit


THE AMERICAN INSTITUTE OF ARCHITECTS

User: Anonymous - User Area

Course Directory

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Course Directory Search

Building Science & Performance Course Directory » Energy: Energy Conservation & Efficiency enhanced by the architectural design Topic » Renewable Energy Technology Applications - Biomass Technologies Course » Course Information

Renewable Energy Technology Applications - Biomass Technologies

Description:	Biomass energy technologies can help Federal sites meet agency goals and legislative mandates, improve energy security, and reduce environmental impact while efficiently providing electricity, heating, cooling, and other applications. The course covers sourcing and selecting cost-effective biomass energy technologies and common implementation considerations.
Course Information Link:	http://www.wbdg.org/education/femp26.php
Learning Units:	1
Delivery Provider Name:	National Institute of Building Sciences (Show More)
Credit Designations:	LU|HSW
Course Format:	No instructor – computer based
Contact Us:	Whole Building Design Guide, National Institute of Building Sciences (NIBS), 1090 Vermont Avenue NW, Suite 700, Washington, DC 20005, Tel 202-289-7800, Fax 202-289-1092 or you can send us an email by completing the form here
Learning Objective 1:	Understand geographic/climate considerations biomass energy technology capabilities and constraints, and evaluation of various technology options;
Learning Objective 2:	Select the best biomass energy technologies for building and site needs, considering the latest best practices and technical considerations;
Learning Objective 3:	Understand operating principles for direct combustion, gasification, and pyrolysis conversion technologies; and
Learning Objective 4:	Assess factors to integrate biomass energy into larger energy systems.

Sessions	Start Date MM/DD/YYYY	End Date MM/DD/YYYY	City			
-FEMP26 A	12/19/2014	12/19/2017	TBA		More Info	

A.2 Fundamental and Installation Knowledge Requirements for the National Fireplace Institute Woodburning Specialist Certification[336]

Woodburning Category 1: Combustion

1. Knowledge of principles of combustion
2. Knowledge of consequences of incomplete combustion

336 National Fireplace Institute Website. Woodburning Hearth Exam Description.

Woodburning Category 2: Heat/Heat Protection

1. Knowledge of heat transfer principles
2. Knowledge of heat distribution methods
3. Knowledge of required clearances to combustibles
4. Knowledge of required clearances to noncombustibles
5. Knowledge of floor protection

Woodburning Category 3: Safety Guidelines/Consequences of Action

1. Knowledge consequences of improper installations
2. Knowledge of the causes and effects of carbon monoxide (CO)
3. Knowledge of hazardous materials
4. Knowledge of safety guidelines for installation

Woodburning Category 4: Construction Fundamentals

1. Knowledge of basic home construction
2. Knowledge of techniques for protecting client property in the work area
3. Knowledge of construction factors that affect installation
4. Knowledge of chase construction and weatherization

Woodburning Category 5: Regulation and Instructions

1. Knowledge of the relationship between codes, standards, and manufacturer
2. Knowledge of jurisdictional roles and responsibilities

Woodburning Category 6: Appliance Requirements

1. Knowledge of appliance types
2. Knowledge of acceptable modifications to appliance
3. Knowledge of factors affecting the choice of an appliance selection
4. Knowledge of factors affecting the choice of an appliance location
5. Knowledge of appliance installation procedure
6. Knowledge of appliance installation requirements for mobile homes
7. Knowledge of installation requirements for inserted appliances into prefabricated fireplaces
8. Knowledge of existing masonry fireplace construction details and requirements
9. Knowledge of installation compatibility for aftermarket add-ons

10. Knowledge of solid fuel appliance categories
11. Knowledge of clearance reduction methods for solid fuel appliances and connector pipes
12. Knowledge of solid fuel code requirements and standards
13. Knowledge of installation requirements for unlisted solid fuel appliances
14. Knowledge of factory-built fireplace components

Woodburning Category 7: Draft and Ventilation Principles

1. Knowledge of ventilation and indoor air quality
2. Knowledge of draft principles
3. Knowledge of resistance to flow in chimney/venting systems
4. Knowledge of factors exterior to the house affecting draft
5. Knowledge of house characteristics contributing to negative pressure problems
6. Knowledge of ventilation principles

Woodburning Category 8: Woodburning Venting Requirements

1. Knowledge of installation procedures for outside air system
2. Knowledge of UL 1777, Standard for Chimney Liners, as it pertains to installation of solid fuel lining systems
3. Knowledge of chimney termination requirements for solid fuel appliances
4. Knowledge of solid fuel chimney/venting system types
5. Knowledge of solid fuel liner systems
6. Knowledge of chimney/vent connectors (stovepipe) for solid fuel appliances
7. Knowledge of sizing requirements for solid fuel chimney/venting systems
8. Knowledge of installation procedures for lining/relining chimneys for solid fuel appliances
9. Knowledge of purpose, use, and compatibility of chimney/venting components
10. Knowledge of chimney/venting installation procedures
11. Knowledge of inspection and cleaning requirements for chimney/venting systems

Wood burning Category 9: Post Installation Inspection and Service

1. Knowledge of appliance break-in procedures
2. Knowledge of operating procedures for appliances
3. Knowledge of solid fuel characteristics
4. Knowledge of maintenance requirements for cordwood appliances and venting systems
5. Knowledge of causes and solutions to common solid fuel appliance performance problems
6. Knowledge of troubleshooting procedures for testing solid fuel appliances and venting systems

A.3 Fundamental Knowledge and Installation Requirements for the National Fireplace Institute Pellet Specialist Certification[337]

Pellet Category 1: Combustion/Fuel

1. Knowledge of principles of combustion
2. Knowledge of consequences of incomplete combustion
3. Knowledge of air-to-fuel ratio and consequences of an inappropriate ratio
4. Knowledge of pellet fuel characteristics
5. Knowledge of pellet stove fuel types

Pellet Category 2: Heat/Heat Protection

1. Knowledge of heat transfer principles
2. Knowledge of required clearances to combustibles
3. Knowledge of required clearances to noncombustibles
4. Knowledge of floor protection

Pellet Category 3: Safety Guidelines/Consequences of Action

1. Knowledge of consequences of improper installations
2. Knowledge of the causes and effects of carbon monoxide (CO)
3. Knowledge of hazardous materials
4. Knowledge of safety guidelines for installation of a pellet appliance

[337] National Fireplace Institute Website. Pellet Hearth Systems Exam Description, http://nficertified.org/pages_industry/descrp_6.html

Pellet Category 4: Construction Fundamentals

1. Knowledge of basic home construction
2. Knowledge of construction factors that affect pellet installation
3. Knowledge of techniques for protecting client property in the work area

Pellet Category 5: Regulation and Instructions

1. Knowledge of the relationship between codes, standards, and manufacturer's instructions
2. Knowledge of jurisdictional roles and responsibilities
3. Knowledge of pellet appliance installation requirements for mobile homes
4. Knowledge of pellet appliance code requirements and standards

Pellet Category 6: Appliance Requirements

1. Knowledge of pellet appliance types
2. Knowledge of factors affecting pellet appliance selection
3. Knowledge of factors affecting the choice of a pellet appliance location
4. Knowledge of pellet appliance components
5. Knowledge of pellet appliance installation procedures
6. Knowledge of installation requirements for pellet inserts in factory-built fireplaces
7. Knowledge of procedures for starting-up appliance for first time
8. Knowledge of electrical requirements for pellet appliances
9. Knowledge of wiring diagrams
10. Knowledge of basic electricity
11. Knowledge of purposes and uses of tools needed for pellet appliance installation and service
12. Knowledge of purposes and uses of gauges needed for pellet appliance installation and service

Pellet Category 7: Draft and Ventilation Principles

1. Knowledge of natural draft principles
2. Knowledge of mechanical draft principles
3. Knowledge of resistance to flow in chimney/venting systems
4. Knowledge of the effect of horizontal runs on pellet appliance performance
5. Knowledge of factors exterior to the house affecting draft
6. Knowledge of house characteristics contributing to negative pressure problems
7. Knowledge of ventilation principles
8. Knowledge of ventilation and indoor air quality

Pellet Category 8: Venting Requirements

1. Knowledge of pellet chimney/venting system types
2. Knowledge of pellet fuel liner systems
3. Knowledge of purpose, use, and compatibility of chimney/venting components
4. Knowledge of chimney/vent connectors (stovepipe) for pellet appliances
5. Knowledge of sizing requirements for pellet fuel chimney/venting systems
6. Knowledge of equivalent vent length (EVL) calculations for pellet vents
7. Knowledge of horizontal venting limitations
8. Knowledge of installation procedures for pellet vents
9. Knowledge of installation procedures for lining/relining chimneys for pellet appliances
10. Knowledge of inspection and cleaning requirements for chimney/venting systems
11. Knowledge of methods for venting pellet appliances into existing solid-fuel chimneys
12. Knowledge of pellet vent termination requirements
13. Knowledge of installation procedures for outside air system

Pellet Category 9: Post Installation Inspection and Service

1. Knowledge of operating procedures for pellet appliances
2. Knowledge of principles of operation for pellet appliance components
3. Knowledge of pellet appliance safety systems
4. Knowledge of functions and compatibility of emergency backup equipment
5. Knowledge of maintenance requirements for pellet appliances and venting systems
6. Knowledge of troubleshooting procedures for testing pellet appliances and venting systems
7. Knowledge of causes and solutions to common pellet appliance performance problems

A.4 Webpage Text Describing the Chimney Safety Institute Training Agenda for Installing and Troubleshooting Woodburning[338]

A.4.1 Installing & Troubleshooting Woodburning

NFI Woodburning Specialist Certification Exam Included with registration!

[338] Chimney Safety Institute website. Installing and Troubleshooting Woodburning training description, http://www.csia.org/education/Installing_Troubleshooting_Woodburning.aspx#sthash.6IxtzyUn.dpuf

This session is subject to minimum attendance requirements. A 50% refundable deposit is required when registering for the Installing & Troubleshooting Woodburning Hearth Appliances seminar. If there are fewer than 10 registrants 30 days prior to the start of the seminar, this seminar will not be held. CSIA is not responsible for non-refundable airline tickets and other travel commitments.

Topics included in this weeklong course are energy efficiency, appliance selection and sizing, installation of factory-built woodburning fireplaces and wood stoves and troubleshooting woodburning systems, among many others. Each day will conclude with testing, to confirm a solid knowledge base is established in preparation for the NFI Woodburning Hearth Specialist certification exam session at the conclusion of the week.

This is an intensive week of training for those with a working knowledge of woodburning hearth systems. Hands-on training will be conducted in the CSIA Technology Center's technical lab. This is not a vacation! Sessions are likely to run into the early evening!

On Monday, we'll cover the basics of burning wood, energy efficiency, factors affecting efficiency, categories of woodburning appliances, codes and standards, emissions, woodburning venting systems, principles of draft, flow and ventilation, chimneys and wood stove connectors. And that's all before lunch!

Tuesday brings installation planning, including appliance selection, sizing, location and practical applications, into light. Then we'll cover venting system requirements and installation of factory-built woodburning fireplaces, fireplace support and floor protection, firebox and chimney installation and add-on appliances and accessories.

Wednesday morning will start with wood stove installation, including freestanding appliances, insert and hearth stove installations. We'll cover built-in high efficiency fireplaces, factory-built chimneys and masonry chimneys too!

Thursday will be spent on communicating with homeowners, system operation and maintenance and troubleshooting woodburning systems. You'll also learn to calculate hearth extension material requirements, make-up air systems and which tools are best for the job.

Friday morning, we'll wrap up with a review of subjects covered throughout the week and will prepare for the NFI Woodburning Hearth Specialist exam (to be administered in the afternoon).

Afternoon sessions will be spent on additional lecture and hands-on training in the CSIA Technology Center's technical lab.

Installing and Troubleshooting Woodburning Hearth Appliances is held exclusively at the CSIA Technology Center in Plainfield, IN, just minutes away from the Indianapolis International Airport.

Lunch and dinner Monday - Thursday are included with registration fee. NFI's Woodburning Hearth Specialist manual and exam are also included with registration fee. Please note that you must supply your own NFPA 211.

A.5 Austrian Biomass Association Training Description

A.6 Bioenergy Training Schedule[339]

Training week materials

From 3rd to 7th October 2011 two training weeks on establishing woodfuel supply chains were organised by VTT in Jyväskylä (Finland) and BIOENERGY 2020+ Wieselburg (Austria). In total 27 forest owners, wood fuel users and forest managers from France, the UK and Slovenia attended the Austria training and gained inside knowledge in the field of woodfuel harvesting, processing and supply as well as sustainable combustion technologies and successful business models for utilising biomass. Meanwhile, a group of 15 forest owners and forestry professionals from Latvia and the UK attended a similar training period in Jyväskylä region, Central Finland.

Below the training material for both the Finnish and Austrian training can be downloaded:

Session 1: Welcome and Introduction

Introduction of training week, Erwin Rotheneder and Franz Figl, BIOENERGY 2020+ GmbH
Bioenergy in Finland, Martti Kuusinen, Tapio
Forestry in Finland, Petri Kilpinen, Forestry Centre Central Finland

Session 2: The biomass production chain

Overview on harvesting technologies and related costs, Erwin Rotheneder, BIOENERGY 2020+
Overview on conversion technologies, Franz Figl, BIOENERGY 2020+
Harvesting technologies, Matti Virkkunen, VTT
Processing applications, Martti Kuusinen, TAPIO
Wood fuel measuring, Martti Kuusinen, TAPIO
Wood fuel transportation, Martti Kuusinen, TAPIO
Sustainable Woodfuel Harvesting - Environmental and Silvicultural Aspects, Martti Kuusinen, TAPIO
Quality control, Martti Kuusinen, TAPIO
Biomass storage, Martti Kuusinen, TAPIO

Session 3: Business concepts

Investment calculation for biomass heating plants, Christa Kristöfel and Rita Ehrig, BIOENERGY 2020+
Investment calcualtion for biomass heating plants - Austrian example, BIOENERGY 2020+
Case studies of wood fuel supply businesses in Austria
Forest management and wood fuel supply – from forest to biofuel, Martin Schober, Machinery Service Austria
Planning and operation of biomass heating plants, Herbert Leichtfried, regional heating plant operator in Gresten
Forestry associations as PFO umbrella organisations for wood fuel supply, Forest management association Päijänne
Introducing Vakkalämpö co-operative and Ekowatti heating enterprise, Jyrki Raitila, (VTT)
Co-operative models, case Eno energy, Urpo Hassinen, Forestry Centre North Karelia
Contracting to create steady demand for wood, case Vapo, Jyrki Raitila, VTT
Economy of woodheat business, Jyrki Raitila, VTT
Woodfuel supply contracts, Jyrki Raitila, VTT

Session 4: Developing business ideas

Project planning and do's and don'ts for implementing district heating facilities, Franz Figl and Erwin Rotheneder, BIOENERGY 2020+
Input presentations from Austrian experts:
Josef Petschko, Project development company Agrar Plus GmbH/ Bioenergie NÖ GmbH
Ferdinand Köberl, Engineering company Riebenbauer GmbH

339 AFO website (www.afo.eu.com).

Session 5: Woodfuel projects in the target regions

Face-to-face presentations:
Approvisionnement «local» de la chaudière de Nègrepelisse (Midi-Pyrenée)
Feasibility study on Wood biomass district heating system in Bovec (Slovenia), Vito Komac, Cezsoca Agri Association
Wood fuel supply and demand situation in South Yorkshire (UK), South Yorkshire stakeholder group
Summary of working groups' results (Finland)

Other materials:

Fact Sheets on study tours in Austria, BIOENERGY 2020+

Operating figures and investment costs for district heating systems, Rita Ehrig, Christa Kristöfel, Christian Pointner, BIOENERGY 2020+

Wood biomass conversion calculator in English, Austrian Energy Agency
Wood fuel supply model contract, Erwin Rotheneder and Rita Ehrig, BIOENERGY 2020+

Appendix B. Training Materials

B.1 Examples of Manufacturers' Print Media Campaigns and Links to Radio and Television Campaigns

B.1.1 Maine Energy Systems

Videos: http://www.maineenergysystems.com/videos/

B.1.2 Econoburn

Print Brochure:

B.1.3 Burn it Smart

Poster:

Appendix A. Sample poster

Burn it Smart!

In your wood stove, fireplace or furnace

A free workshop to help you burn wood better

Monday, February 23, 2004
Germania Hall, Pembroke
15 Bennett Street

Burn display 6:30 pm
Workshop 7:00 pm to 9:30 pm

How to buy firewood and get what you pay for.

Find out if your wood burning system is up to date.

Trained experts on hand to answer your questions.

A non-commercial, educational event for people who burn wood at home. Presented by some of Canada's most experienced wood heat specialists

- Learn things you didn't know about wood burning
- Take home loads of great wood heat publications
- See a dramatic burn display comparing an old "airtight" to a new technology stove

Get your questions answered

www.burnitsmart.org

This series is made possible by a contribution agreement from Environment Canada
Project coordinated by The Wood Heat Organization Inc. ***www.woodheat.org***
Burn it Smart! is a trademark of Natural Resources Canada. Used with permission.

Press Release:

Wood Burning Workshop

Burn it Smart in your wood stove, fireplace or furnace
Free workshop to help people burn wood better

__day, February __, 2004
Venue name
Address
The workshop starts at 7:00 pm and concludes at 9:30 pm, sharp.
People are encouraged to arrive at 6:30 pm so they can view the outdoor burn display.

_______ area householders who burn wood for heat and enjoyment will be invited to attend an evening *Burn it Smart* workshop to be held in the city on __day, February __. The workshop at the Venue*** will be delivered by trained wood heat specialists offering useful insights and tips on effective wood burning. Those attending will be treated to a dramatic technology demonstration and a range of free publications on wood burning to take home.

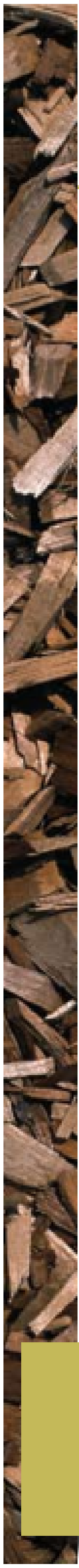
The Burn it Smart campaign was initially developed by Natural Resources Canada to promote the more efficient, safe and healthier use of wood for home heating and enjoyment. The Eastern Ontario Burn it Smart workshop series is being organized by the Wood Heat Organization Inc., a non-profit group that promotes the responsible use of wood fuel at home. Cal Wallis, one off the organizers says, “People will be amazed how much practical knowledge useful information they’ll pick up at this workshop. No one who burns wood at home should miss it”.

For more information visit www.woodheat.org/bis/
Or call Mr. Local Organizer at (613) ___-____

- - -
230 words

B.1.4 Vermont Fuels for Schools

Brochure:



VERMONT Fuels For Schools

About
Vermont Fuels For Schools

A statewide biomass energy use initiative promoting a plentiful local natural resource to provide reliable heat for Vermont schools

An initiative of
Biomass Energy Resource Center

in collaboration with the
Vermont Superintendents Association's School Energy Management Program

and cooperation with the
Vermont Department of Education

Vermont Department of Public Service

Vermont Department of Forests, Parks and Recreation

with funding from the
US Department of Energy

through the support of
Senator Patrick Leahy

Vermont Fuels For Schools (VFFS) provides schools with the information and support needed to evaluate and successfully implement biomass-based heating systems that replace expensive fossil fuels with locally supplied biomass fuel.

VFFS will help schools navigate the steps in both the pre- and post-bond processes—from the preliminary site assessment to system installation—providing tools and expert guidance to ensure a successful biomass heating system.

What is biomass? Any biological material that can be used to produce heat, energy, electricity, or fuels, including woodchips and pellets, low-grade wood wastes, agricultural crop residues, and farm animal wastes.

Why use biomass for energy? It makes sense to use forms of sustainably produced biomass to replace conventional fuels (oil, gas, and coal) for a number of reasons, such as:

Increased economic development
Biomass comes from local resources and keeps energy dollars close to home. When a community uses biomass it creates forestry and agriculture jobs in the surrounding region.

Better for the environment
- Biomass use reduces greenhouse gases that cause climate change.
- Biomass heating has a positive impact on acid rain because, unlike fuel oil, biomass contains virtually no sulfur.
- Biomass heating systems help keep forests strong by providing a productive use for low-grade cull wood.

Cuts fuel bills
Since 1986, biomass heat in Vermont schools has always been at least 30 percent less expensive than oil and 75 percent less expensive than electricity. Now, oil, propane, and natural gas heating costs roughly two-to-three times as much as heat from biomass.

For more information on Vermont Fuels For Schools, contact:
Biomass Energy Resource Center
802-223-7770, contacts@biomasscenter.org

Where does wood fuel come from? From three local markets:

HARDWOOD MILL CHIPS are high-quality fuel at a reasonable price. It is the preferred choice for schools, however, supplies are limited so schools compete with other users.

BOLE CHIPS are made by putting the main trunks (boles) of low-quality trees through a chipper working in the woods as part of a timber operation.

WOOD PELLETS are small, compressed, symmetrical bits of wood that are generally manufactured from mill and agricultural residue.

What are the parts of a woodchip system?

Storage Bin	Equipment	Boiler	Controls	Chimney	Building
for fuel	to transport fuel from bin to boiler	to burn fuel and create hot water for building heat	to ensure efficient, clean combustion	to exhaust combustion products	to house equipment and storage bin

What if the wood system is too expensive to be cost effective?

Large schools usually find the combined costs of installing fully automated wood systems, the bond payment, and the wood fuel far less than what they were paying using oil, gas, or electric heating. Smaller schools with relatively modest heating bills can opt for a semi-automated system that uses significantly less-expensive equipment and can be housed in a significantly less-expensive building.

- ***Not only are woodchips by far the least expensive fuel available to schools, their use keeps energy dollars in the local economy and help improve overall forest health.***
- ***School districts with new wood-energy systems often reduce annual heating expenditures within the first year of use.***
- ***Using wood to replace fossil fuels is the most powerful action a school can take to address global warming and climate change.***

How much work is it for school maintenance staff?

Modern school woodchip systems are easy to take care of—30 minutes average per work day for automated systems and up to 60 minutes per day for semi-automated systems. Most of the work involves removing a few shovels full of ash into a trash can each day.

What Are the Next Steps?

For a free school site assessment and more information:
Vermont Superintendents Association
802-229-5834, www.vtvsa.org

For information on state aid to help pay for a biomass-heating system:
Vermont Department of Education
802-828-5402, www.education.vermont.gov

For information on wood-fuel supply for schools:
Vermont Department of Forests, Parks and Recreation
802-241-3678, www.vtfpr.org

For technical assistance in organizing and implementing a wood-heating project:
Biomass Energy Resource Center
802-223-7770, www.biomasscenter.org

For general information on energy efficiency and renewable energy:
Vermont Department of Public Service
802-828-2811, www.publicservice.vermont.gov

B.1.5 NEFF/ INRS[340]

Flier for non-wood burners: Version 1.

The benefits of heating with wood…

Cost Effective

Wood fuel is about ½ **the cost of heating oil** per unit of heat output and has a history of more **stable and predictable pricing** than volatile fuel oil prices.

Fuel Type	Price	$ per Million BTU*
#2 Fuel Oil	$3.65/gallon	$31.74
Wood Pellets	$250/ton	$18.38
Dry Cordwood	$250/cord	$16.34

** BTU (British Thermal Unit) is a measure of the heat value (or energy content) of fuels.*
** Values from USDA Forest Service, Fuel Value Calculator*

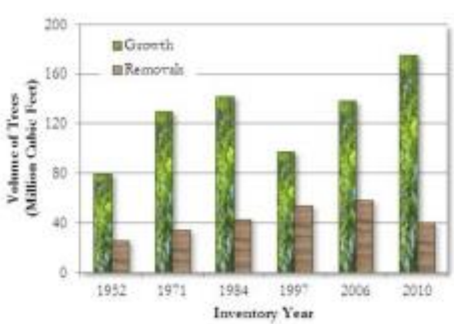
Local

Wood for energy is produced locally within our region, which helps the local economy by…

- Enhancing markets for low-grade wood & promoting small-scale forestry.
- Increasing the economic viability of working forests & helping to protect forests from development threat.
- Keeping dollars spent on fuel in the local economy.

Renewable

Wood is a renewable resource that regenerates naturally in our forests after harvesting. Wood for energy is produced as part of existing timber harvests, which are at sustainable levels – each year our forests grow more volume than we cut. The chart to the left shows this trend in Massachusetts.



Source: USDA Forest Service, Forest Inventory & Analysis Data

This information is provided as part of a project funded by the USDA Forest Service and carried out by Innovative Natural Resource Solutions, LLC for New England Forestry Foundation, in collaboration with the LIHEAP and HEARTWAP fuel assistance programs in Massachusetts.

New Technology = Cleaner Burn

Wood stoves manufactured after July 1, 1988 must comply with new EPA air quality regulations. Better insulation and improved air flow allow these stoves to burn the wood material and smoke more completely, resulting in improved energy efficiency and much lower emissions.

Modern wood-burning boilers and furnaces for central heating can also achieve efficiency ratings of 85–90%+.

Do you already meet some of your heating needs with wood? Are you using a woodstove manufactured before 1988?

If so, you may qualify to have your older woodstove replaced with a newer, EPA-certified wood or pellet stove at NO COST. Contact Community Action at energyprog@communityaction.us or (413)376-1140 for more information.

Replacing an inefficient wood stove can*:

- Improve energy efficiency by 50%, using 1/3 less wood to produce the same amount of heat.
- Reduce fine particle and toxic air pollution by 70%.

*Source: US Environmental Protection Agency

New England Forestry Foundation

Innovative Natural Resource Solutions, LLC
(603) 784-5004
www.inrsllc.com

340 Provided by Jennifer Hushaw.

Flier for non-wood burners: Version 2.

The benefits of heating with wood…

Cost Effective

Wood fuel is about ½ **the cost of heating oil** per unit of heat output and has a history of more **stable and predictable pricing** than volatile fuel oil prices.

Fuel Type	Price	$ per Million BTU*
#2 Fuel Oil	$3.65/gallon	$31.74
Wood Pellets	$250/ton	$18.38
Dry Cordwood	$250/cord	$16.34

** BTU (British Thermal Unit) is a measure of the heat value (or energy content) of fuels.*
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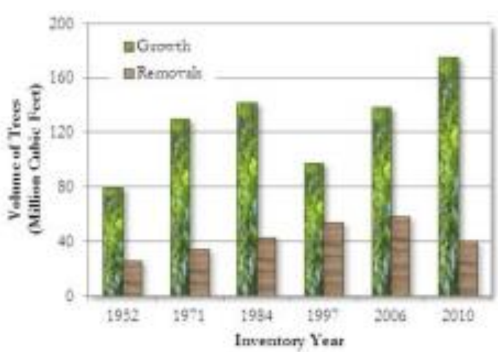

Source: USDA Forest Service, Forest Inventory & Analysis Data

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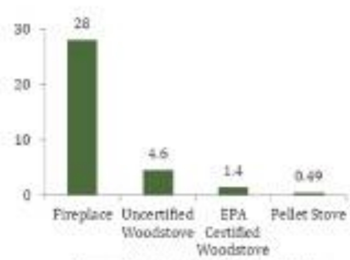


Average Emissions of Fine Particles
(lbs/MMBtus of heat output)*

Modern wood-burning boilers and furnaces for central heating can also achieve efficiency ratings of 85–90%+.

*Source: US Environmental Protection Agency

New England Forestry Foundation

Innovative Natural Resource Solutions, LLC
(603) 784-5004
www.inrsllc.com

This information is provided as part of a project funded by the USDA Forest Service and carried out by Innovative Natural Resource Solutions, LLC for New England Forestry Foundation, in collaboration with the LIHEAP and HEARTWAP fuel assistance programs in Massachusetts.

B.1.6 EPA Burnwise

Educational Materials:[341]

Burn Wise

Program of U.S. EPA

BURN THE RIGHT WOOD, THE RIGHT WAY, IN THE RIGHT WOOD-BURNING APPLIANCE

Did you know that by changing the way you burn wood you can save money, reduce air pollution and protect your health?

Here are a few simple tips to make your fire burn hotter, keep your wallet fatter and keep your local air cleaner and healthier.

Season all firewood. All firewood should be split, securely covered or stored, and aged for at least six months. Seasoned wood burns hotter, cuts fuel consumption and reduces the amount of smoke your appliance produces.

Choose the right firewood. Hardwoods are the best. Never burn trash or treated wood which can emit toxic air pollutants.

Start it right. Use only clean newspaper or dry kindling to start a fire. Never use gasoline, kerosene, charcoal starter, or a propane torch.

Don't let the fire smolder. Many people think they should let a fire smolder overnight. But reducing the air supply does little for heating and increases air pollution.

Clean ashes from your wood-burning appliance. Excess ashes can clog the air intake vents reducing efficiency. Be sure to dispose of ashes in a metal container away from the house or any flammable material to reduce the risk of fire.

Keep your chimney clean. A clean chimney provides good draft for your wood-burning appliance and reduces the risk of a chimney fire. Have a certified professional inspect your chimney once a year.

Be a good neighbor. Follow best practices for burning wood. Always remember to comply with state and local codes and check your local air quality forecast.

Follow instructions. Operate your wood-burning appliance according to the manufacturer's instructions and follow all maintenance procedures.

Upgrade to cleaner equipment. EPA-certified wood stoves and fireplace inserts burn cleaner and burn wood more efficiently emitting less particle pollution than older models.

Size matters. Choose the right-sized appliance for your needs. If your wood-burning appliance is too big for your room or house, the fuel will smolder and create more air pollution.

EPA For more information on how to burn wise, go to www.epa.gov/burnwise

EPA-456/F-09-004

PSAs: http://www.epa.gov/burnwise/psas.html

341 http://www.epa.gov/burnwise/burnwisekit.html

B.1.7 Libby, Montana Changeout

Press Release:

Hearth, Patio & Barbecue Association

Suite 600, 1901 North Moore Street
Arlington, VA 22209 USA
Phone: (703) 522-0086 • Fax: (703) 522-0548
Email: hpbamail@hpba.org
Web Site: www.hpba.org

News Release
For Immediate Release
January 31, 2008

CONTACT:
Leslie Wheeler or Deidra Darsa
(703) 522-0086

New Report: Stoves & Fireplace Inserts Save Money, Clean the Air

Pilot Project Demonstrates Effectiveness of Wood Stove Changeouts;
Nationwide Tax Incentives Proposed

Arlington, VA – Consumers who install new wood stoves this winter not only will enjoy warmer homes, but also can save money and help clean the air, according to a new report released today by the Hearth, Patio & Barbecue Association (HPBA). The report, *Clearing the Smoke*, unveils results from a pilot program to replace every outdated woodburning stove in Libby, Montana, with new, cleaner units certified to strict U.S. Environmental Protection Agency (EPA) standards.

"Replacing older, inefficient wood stoves with cleaner-burning EPA-certified models can reduce pollution by 70 percent per stove, on average," said Robert J. Meyers, principal deputy assistant administrator for EPA's Office of Air & Radiation. "In areas such as Libby, where most of the fine particle pollution comes from wood smoke, a community-wide changeout can make a tremendous difference."

The Libby changeout replaced or repaired 1,130 old, polluting stoves with new wood, pellet, gas or electric heating appliances. HPBA, its member companies, EPA and other Montana partners provided direct grants, equipment donations and in-kind support worth more than $2.5 million to finance the program.

Based on preliminary data, Libby residents are now breathing significantly cleaner air both outdoors and inside their homes. Average wintertime fine particulate levels in the outdoor air decreased by 28 percent in 2007 – the first year following completion of the changeouts. The results are even more dramatic for indoor air quality with initial research by the University of Montana finding the air 72 percent cleaner inside homes with new, EPA-certified stoves.

"Today's stoves and inserts produce almost no smoke and require less firewood than earlier models," noted Jack Goldman, HPBA's president. "Consumers have more choices than ever to provide their homes with ambiance and heat, including a variety of renewable fuel options like wood, pellets and corn."

Home experts estimate that stoves and inserts can reduce annual heating costs by 20 to 40 percent. To help consumers approximate the cost-saving benefits of various options, HPBA has developed an online guide (www.hpba.org/hearthconsumerguide) and fuel efficiency calculator (www.hpba.org/fuelcalculator) highlighting the differences between appliance options, fuels, approximate efficiency and estimated costs for purchase and operation. Some 55 million households in the U.S. have at least one fireplace or freestanding stove, and the industry shipped nearly 3 million hearth appliances in 2006.

The Libby experience demonstrated that a wood stove changeout can significantly and cost effectively reduce particulate emissions, and other communities have begun to benefit from similar initiatives. Since 2005 when the Libby program began, at least 24 changeout campaigns across the U.S. have replaced more than 3,300 outdated wood stoves and fireplaces. EPA estimates that these changeouts have removed approximately 135 tons of particulates from the air annually and yielded $16 million in health benefits.

To help expand changeout programs nationwide, Rep. John Salazar (D-CO) and Sen. Mike Crapo (R-ID) have introduced the Clean Stove Act. This is a bipartisan bill that would authorize a $500 tax credit to consumers who replace old stoves with the new technology of EPA-certified wood stoves. "This important legislation encourages cleaner air, healthier homes, renewable energy and greater fuel efficiency," added Goldman.

Clearing the Smoke details the unique history, topography, economy and air quality problems that made Libby the ideal location for this pilot program. The report includes first-hand accounts from the local residents who led and benefited from the changeouts, as well as details on how the program worked, lessons learned and advice for other communities. It is available for download at www.woodstovechangeout.org.

"For consumers coast-to-coast, this study confirms that cleaner burning stoves offer great potential to warm their homes, help reduce spending and clean the air in their neighborhoods," Goldman concluded. "The hearth industry hopes that leaders in other areas can learn how to make their communities cleaner, safer and healthier from the Libby project."

###

About Hearth, Patio & Barbecue Association (HPBA)
The Hearth, Patio & Barbecue Association is an international trade association first established in 1980 to represent and promote the interests of the hearth products industry in North America. In 2002, the Hearth Products Association (HPA) merged with the Barbecue Industry Association (BIA) to form HPBA. The association includes manufacturers, retailers, distributors, manufacturers' representatives, service and installation firms, and other companies and individuals - all having business interests in and related to the hearth, patio and barbecue products industries. For more information, please visit www.hpba.org or www.woodstovechangeout.org.

B-Roll Satellite Feed Dates and Coordinates
Thursday, January 31, 2008 -- 2:30-2:45 PM ET
Galaxy 26C/17 Downlink 4040V

Wednesday, February 6, 2008 -- 2:00-2:15 PM ET
Galaxy 3C/4 Downlink 3780V

Thursday, February 7, 2008 -- 2:00-2:15 PM ET
Galaxy 3C/4 Downlink 3780V

Education materials:

Video: https://www.youtube.com/watch?v=lF2Hd3snvvM

Final Report: http://www.woodstovechangeout.org/fileadmin/PDF/Libby_Report-Final.pdf

Appendix C: Non-Timberland Feedstocks and Processing

Non-forest biomass fuels are not included in the report as these fuels and associated combustion technologies are not fully commercially available and their emission impacts are not fully characterized.

C.1 Feedstocks

C.1.1 Short Rotation forestry

The quality and amount of fuel that can be harvested from short rotation forestry is dependent upon the amount of precipitation, the clone, and the cultivation. Between 3 and 7 tons dry matter/acre can be harvested under ideal conditions.[342] The cultivation of short rotation forestry is positively influenced by:

- Good choice of the clone regarding the location and soil conditions.
- High quality cuttings (cool and moist storage).
- Sufficient water supply.
- Weed control.
- Protection against pests and diseases.

The following sections provide information on specific short rotation forestry crops.

C.1.1.1 Salix (Willow)

Willow is a perennial and fast growing shrub. It is planted as cuttings during spring and early summer (April-June). It is important to cultivate willow in areas that are easily accessible by winter-proof roads, and fields should not be too small (larger than 5 acres is recommended). To start a short rotation forest, one year old shoots are planted by machine at 5,200-6,000 shoots per acre.

[342] Hinchee, Maud et al. "Short-Rotation Woody Crops for Bioenergy and Biofuels Applications." In Vitro Cellular & Developmental Biology 45.6 (2009): 619–629. PMC. Web. 4 Mar. 2016.

Willow cultivations must be cared for, including weed control and fertilization, to be profitable. Although often planted on soils that are not prime, for good yields willow needs fertile growing soil and sufficient water supply, and the plantation must be fertilized with nitrogen after planting.

Willow cultivations are usually harvested for the first time 3-4 years after plantation. The harvest occurs from November to April, when the yearly growth is completed and the leaves have fallen off. This practice helps retain nutrients. After harvest, new shoots protrude from the stumps, and the next harvest is ready 3-4 years later. Willow cultivations give returns for about 20-30 years.

C.1.1.2 Poplar

Poplar displays more apical dominance (i.e., buds at top of plant) than willow and is therefore less ready to develop multiple stems following coppicing. Poplar tends to develop fewer, thicker stems than willow, and consequently has a lower bark to wood ratio. Individual shoots can reach up to 8 m by the end of the first three-year rotation.

Poplar is planted in spring from cuttings. These cuttings must have an apical bud within 1 cm of the top of the cutting. Therefore, it is difficult to use equipment developed for planting willow. Poplar planting density is also lower than for willow, typically 4,000-4,800 cuttings per acre.

Average yield on a suitable site is likely to be about 3.2 dry tons per acre per year. Poplar responds well to harvesting cycles of around 4 or 5 years. This is because growth in the year following a cutback or harvest is generally not as rapid as in subsequent years. Because poplar has a very upright growth habit, the crop may not develop a closed canopy, and hence maximum light interception, until the second or third year. In addition, weeds must be controlled until the canopy closes. Harvesting requires similar equipment to that used for harvesting willow, but because of the tendency of poplar to form fewer, heavier stems, the equipment must be slightly more robust. In addition, removal of a poplar crop at the end of the useful life of the plantation can be more difficult than for willow as poplar often forms a large taproot that will generally require either a large excavator to remove it or more time to decay naturally.

C.1.2 Harvesting of Short Rotation Crops

One of the key challenges when growing Short Rotation Crops (SRC) for the energy market is to develop an efficient and sustainable fuel supply chain that is profitable for the grower and processor, and is competitive with traditional fuels. Harvesting represents one of the major costs in SRC production, and must be carried out efficiently for low-cost production. To meet this need, many harvesters have been developed, mostly in Europe, specifically for willow plantations (Picchi et al., s.a.). The main functional difference between harvester types is the number and the type of operations that they can perform. The availability of drying and or storage facilities, the requirements of the customers, site conditions, and other factors will determine the most efficient choice. The sections below describe three harvesting approaches.

C.1.2.1 Direct Chip Harvesting

Direct chip harvesting uses adapted forage harvesters, followed by immediate transport to the end user or to a drying facility. It is an efficient harvesting operation and has been the most widely used system to date in several European countries, and is the harvesting system currently most utilized in the United States. In Sweden, this method is practiced with high moisture chip (50%) being delivered to the end user. For some users, the chip needs to be dried to a specific moisture content, typically 25-30%.

The system for direct chip harvesting has been developed over many years. When conditions are favorable, harvest is done at large capacity and low cost. Under less favorable conditions, however, the harvesting has challenges. One challenge is weather, which sometimes makes the harvest difficult to implement due to poor ground conditions for the equipment. Another challenge can be regulating the fuel supply to end users; like wood chips, the fuel can be difficult to store due to high moisture content. In addition, the harvesters do not cut trees larger than 6-7 cm in diameter. With new clones that grow rapidly, a one-year delay in harvesting may lead to failure of the harvesting machine to handle a willow stand.

C.1.2.2 Billeting

Billeting cuts the crop into 5-20 cm billets or chunks, followed by transport to a storage/drying facility or end user. Billet harvesting of SRC was introduced into Sweden by Henriksson Salix AB and was used during the 1990s. Because the market for this product in Sweden was limited, billet harvesting subsequently ceased in that country. Billet harvesting has since been further developed in the UK, with the same harvester as used in Sweden, Austoft 7700, and its successor, Case IH 7700. Billet harvesting is currently carried out in England by two different companies (Henriksson 2011, Caslin 2010). This system is not currently utilized in the United States.

The billet harvesting method has several advantages. It produces a storable fuel that can be readily handled with existing machinery. The billet storage heaps are porous enough to dry without creating heat. This maintains the fuel's maximum quality and calorific value. A recent study showed that the costs of harvesting billets with the latest model CASE IH 8000, the successor to Austoft 7700, were more or less equal to those of chip harvesting with a forage harvester for the entire supply chain from cutting in the field up to and including delivery to the end-user or terminal (Henriksson 2011). According to Henriksson, the capacity of the machine has a significant impact on the efficiency.

Another aspect of billeting is the ability to make cuttings directly with the billet harvester for planting as lying cuttings. The advantage of lying cuttings is that the cost for the cuttings can be considerably lower than the cost of conventional cuttings. In addition, the planting may be slightly cheaper than the planting of cuttings.

C.1.2.3 Whole Rod Harvesting With or Without Bundling/Baling

Whole rod harvesting consists of harvesting (either with or without bundling/baling), transport to a drying area, followed by chipping and transport to the end user. The whole-rod harvester cuts the stems, laying them in windrows or heaps. Cut stems are then collected by a separate unit, which delivers them to a chipper. As an alternative, a chip forwarder can be used to collect, chip, and extract in one pass. A whole-rod harvester with bundling/baling cuts the stems and collects them in bales/bundles. The bales/bundles are dropped on the field, and later collected by a separate unit. Whole stems, bundles, or bales can be easily stored in the field and within a few months the stems lose a variable percentage of water content with limited reduction of biomass. A disadvantage is that the harvested rods must be handled a second time when they are chipped prior to use. The whole-rod harvesting system has recently gained new interest as it enables delivery of fuel when demanded, therefore better security of supply. The method also has an advantage of using conventional farm machinery, such as tractors. There are, however, higher costs for handling and transport compared to direct chipping.

Parts of the agricultural land in Europe are of low quality and consist of small fields within the range of 0.4-2 acre. In countries like Austria and Germany this land is the most interesting for growing SRC, but it is not economical to use direct chip harvesting for these fields. Development of machine and logistic systems that are adapted to smaller fields are needed in order to lower production costs. The harvesters also need be more flexible and powerful to be able to cut thicker stems so the harvesting frequency can be decreased, lowering costs for small fields. Table C-1 summarizes the advantages and disadvantages of the different systems.

Table C-1. Advantages and Disadvantages of Different Harvesting Systems

Source: BioEnergy 2020

Decision criteria for choice of system	Direct chip harvesting chain	Billeting chain	Whole-rod harvesting chains
Harvest (capacity)	Yes	Yes	No
Harvest (cost)	High	High	Low
Suitable for large areas	Yes	Yes	No
Suitable for small areas	No	No	Yes
Adaption of machine for other purposes	No	No	Yes
Field transport (cost)	High	High	Low
Fuel quality (moisture)	High	High	High
Chipped material on demand	Yes	No	No

C.2 Fuel quality

The logistics to meet end user requirements for fuel quality are important. Users often require wood fuel in the form of wood chips. The users may prefer the chip to have specific moisture content; in Europe, this is often 25–30%, however in the United States it is often delivered “as harvested.” Newly harvested SRC in New York has a moisture content of 45%, which is similar to a timberland harvested chip. Another important fuel specification is the chip size (Garstang 2002).

Whole rods, bundles, bales, and billets can be easily stored and dried naturally. Direct-harvested chips require immediate drying and active drying facilities are often needed. Storage and handling of willow chips should be done carefully and consider chip size, time of year, size of pile and weather, among other factors. Willow chips are somewhat finer than timberland chips, which can restrict air circulation in a pile. Garstang (2002) reports that natural air drying can reduce wood chip moisture content to acceptable levels without unacceptable chip degradation, but only in the core of a pile where the chips are insulated from the effects of the weather by a surface layer.

C.3 Pellets from Herbaceous Biomass and Farm Residues

The following two sections are based on the reports from Kristöfel and Wopienka (2012) and Zeng et al. (2012), which describe results of the IEE project “MixBioPells.”

C.3.1 Miscanthus

Miscanthus (Figure C-2) is a perennial crop with a low demand for fertilizer. It requires good agricultural soils with a sufficient water supply. Cultivation of Miscanthus starts with the planting of rhizomes (underground offshoots). Approximately 4,000 plants/acre can be grown, with weed control necessary in the first two years of cultivation. Afterwards, Miscanthus can be harvested for up to 20 years (LK Österreich 2006).

With sufficient water and soil conditions, a harvest of 8 tons of dry matter per acre is possible. On average, however, the annual harvest amounts to 6 tons of dry matter per acre. One acre of harvested Miscanthus corresponds to 62 loose cubic meters (bulk density of 500 kg/m^3). After the second year, Miscanthus can be harvested annually in April with a moisture content of about 14 wt.-%.

Figure C-2. Miscanthus Stock in the Second Year (left: spring, right: autumn)

Source: Thomas Rieger, ARGE Elefantenwärme

Miscanthus can be harvested as whole plant if it will be processed for material utilization (e.g., fiber production, building material, backfill) or chaffed if it is used for energy purposes. For pelletizing or briquetting, a corn chopper is usually used for the harvest (Figure C-3). Because of its low water content, Miscanthus is suitable for storage. A specially designed conveyor belt wagon is used for the delivery.

Figure C-3. Miscanthus Chopper in Combination with a Baling Press

Source: Luxemburger Miscanthus-Energie) URL: www.Miscanthus.lu

C.3.2 Reed Canary Grass

Reed canary grass (Figure C-4) is an easily grown perennial reed-like grass that reproduces by rhizomes and can grow up to 2 meters in height. Under good conditions, it yields up to 2.8-3.2 tons of dry matter per acre. A spring crop of reed canary grass has low water content and can be processed into briquettes or pellets without drying.

Figure C-4. Reed Canary Grass

Source: http://www.bioenergiportalen.se/

The grass is durable, winter hardy, and can be grown on most soils. Greatest yields, however, occur when harvested on humus and peat lands. Soil has a strong impact on both yield and combustion characteristics. Annually yields on heavy clay soils are lower (2.4 t dm/acre) and contain higher ash content (8-10 wt.-%). Mull soils (mixed organic matter and mineral soils) result in higher yields per year (3 t dm/acre) and lower ash content (2-3 wt.-%).

Reed canary grass develops slowly and should be sown shallow during spring or early summer. The seedlings are susceptible to dehydration and the first season requires some weed control.

It takes two years before the grass can be initially harvested. As soon as the grass is established, however, it can give good yields for up to 10-12 years. Fertilizers and machine costs are the main expense in the cultivation of reed canary grass. A fertilizer ration of 16 kg per acre is sufficient for the first year according to most studies. For the following 2 years 20-40 kg per acre is recommended depending on soil texture and humus content. From year three, it is possible to reduce the fertilizer ration.

Reed canary grass can be harvested either as round or square bales using conventional reapers (Figure C-5). The grass can be harvested during autumn and stored in windrows in the field for use in winter, or harvested in spring. Harvesting in spring can start as soon as the frost is gone and the soils are dry. Spring harvest requires the grass to be stored until needed in winter. Indoor storage is preferable because reed canary grass is sensitive to moisture, and the risk of mold is relatively large for outdoor storage. In addition, if the grass is cut in spring, it is important to do before the green shoots grow too high, as regrowth will be impaired if the annual shoot is cut off. The green shoots also increase water and ash content in the harvest.

Figure C-5. Combined harvester and bale compactor of reed canary grass

Source: Paapanen et al. 2011

C.3.5 Residues from Agriculture

C.3.5.1 Straw

Straw is a general term for an agricultural by-product made of dry lignocellulosic materials (stalks, leaves) and derived from different cereal plants, such as rice, wheat, oats, and barley. Depending on the kind of crop, the annual production can range from 1.2 to 2 tons per acre of dry matter. Traditional forage harvester equipment is used to pick up the product, which can be stored in different sized bales. Bulk densities range from 100 to 250 kg/m^3, depending on the kind of harvest machinery.

Straw is used for multiple purposes; not all harvested straw can be used for combustion. Straw is needed, for example, as bedding on farms. In addition, some straw must be plowed back into the fields to maintain humus formation. When too much straw is removed from the fields, it reduces the humus content of the soil, making it less porous. The harvested straw also removes nutrients from the soil. It is therefore recommended to harvest straw only once per rotation to maintain soil capacity. If the humus content is too low, straw should not be harvested at all. Ash disposal on the land can balance some of the nutrient losses. However, some of the nitrogen content is lost during combustion (Motola 2009).

The harvesting and storage technologies for straw are well established. Usually the harvested straw will be compressed into bales (Figure C-6). Weather limits how much straw can be used as fuel. Rainy conditions during straw collection affect its moisture content, which is crucial for fuel quality. The moisture content should not exceed 20 wt.-% to avoid mold growth. Moisture content needs to be even lower for production of pellets and briquettes (about 10 wt.-%).

The ash content of pure straw is quite high. Thus, soil uptake during harvest and compacting should be avoided to minimize additional potential for ash generation. Outdoor storage is much cheaper than indoor storage, but exposure to weathering increases the risk of decay and lowers the quality of the straw. On the other hand, outdoor storage can lead to better combustion characteristics due to reduced concentrations of potassium and chlorine from leaching of the straw (Motola 2009).

Figure C-6. Large round straw bale (left) and round hay baling machines

Source: http://macchinetrattori.wordpress.com

C.3.5.2 Corn Cobs

Corn cobs are residues of corn production that typically are left in the field by automatic harvesters. The water content of corn cobs is usually higher than the water content of corn kernels, and depends on the maize species, its ripeness, its habitat, and the weather. Corn cobs are storable when the water content is below 25 wt.-%, and therefore usually have to be dried prior to storage. Corn cobs can be harvested with modified harvester threshers that leave the straw on the field.

Figure C-7. Modified Harvester Thresher

Source: Handler, FJ-BLT

Figure C-8. Unloading of Corn Cobs

Source: Handler, FJ-BLT

Figure C-9. Harvested Corn Cobs

Source: Source:FJ-BLT

C.3.5.3 Cereal Spillage

Cereal spillage consists of damaged grains and seeds, chaff, hulls, weed seeds, and other residue recovered from the distribution and processing of grain, oilseeds, grass seed, and other crops. A large part of cereal spillage is used as fuel for grain drying; some is used as animal feed. Cereal spillage has high ash content and contains relatively large amounts of chlorine and sulfur. From an energy point of view, cereal spillage is a by-product of the processing of cereal, so no additional energy is needed to produce the raw material.

C.3.5.4 Low Grade Hay or Landscaping Residues

Landscape maintenance is sometimes used to preserve the ecology of the area. There are obstacles, however, in commercially using the harvested biomass from these areas. Because mowing times occur late in the year, the harvest from abandoned or protected meadows has poor feed quality, so is unsuitable for livestock. It has been investigated for use as an energy crop in biogas or combustion plants.

For extensively cultivated meadows, the annual harvest amounts to 1.2 – 1.6 tons/acre with a water content of about 15 wt.-% at harvesting time.

As with most herbaceous fuels, it has a low ash fusion temperature and high ash content. Therefore, modifications in the combustion chamber and the ash removal system are necessary to avoid slagging and fouling.

C.4 Combustion Properties

Compared to woody biomass, non-woody biomass feedstocks show considerable differences with regard to fuel properties. In general, the ash content of non-woody biomass is higher while ash fusion temperatures are lower. Lower ash fusion temperatures result in the formation of slag and clinkers when combusted. Consequently, improved grate systems are required when using these fuels. In addition, variable combustion conditions can cause higher pollutant emissions (e.g., carbon monoxide (CO), volatile organic compounds (VOCs), or hazardous air pollutants (HAPs)) due to incomplete combustion. High levels of nitrogen, sulfur, potassium and chlorine in alternative biomass feedstocks can increase emissions of NO_x, SO_2, and HCl, as well as particulate emissions. Moreover, sulfur and chlorine play a major role in corrosion. Table C-2 gives an overview of the fuel properties relevant for the combustion of selected raw materials. If available, the data range is given; other table entries are average values except where indicated as single values.

The calorific value is closely related to water and ash content. For the selected raw materials, it falls in the range of 16-20 MJ/kg dm. Ash content varies from below 1 wt.-% up to 17 wt.-% dm. Cereal spillage has particularly high ash content. Strong variations are also found for elemental concentrations of nitrogen, sulfur, and chlorine. Cereal spillage also has relatively high concentrations of all three elements.

Table C-2. Combustion-relevant fuel properties

Kind of biomass	Net calorific value	Ash content	Water content	Ash fusion	N	S	Cl
	MJ/kg db	% db	%	°C	% dm	% dm	% dm
Miscanthus	17.5-17.9	1.6-3.0	7.5-14.0	820-1172	0.20-0.43	0.02-0.09	0.02-0.13
Reed canary grass	17.5-19.0	4.5-6.0	10.0-15.0	1150-1650	0.30-0.60	0.07-0.08	0.03-0.04
Hemp	19.1-19.6	1.6-2.3	56.6	1200-1250	0.30-1.40	0.06-0.10	0.02-0.30
Straw	17.0-19.0	4.4-7.0	9.0-15.0	800-900	0.30-0.80	0.06-0.12	0.03-0.05
Corn cobs	16.5	1.0-3.0	6.0-7.0	1100	0.40-0.90	0.03	0.02
Corn stalks	16.6-17.5	11.0-17.0	15.0-18.0	1250	0.70-0.90	0.08-0.10	n.a.
Cereal spillage	16.5	9.8-10.0	10.0-12.0	1055	1.20-1.70	0.20	0.16-0.3
Residues	18.3	5.5	15.0	820-1150	1.60	0.04	0.09

Table C-3. Main ash forming elements

Kind of biomass	Al	Ca	Fe	K	Mg	Na	Si	Ti
	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)	mg/kg (dm)
Miscanthus	79[1]	1600-1790	92-120	3410-7200	300-600	31.5[a]	3930[a]	4-40
Reed canary grass	200-600	900-2000	13849	2300-4330	600-730	200-350	22280-22800	360
Hemp	111	13400	120	15400	2000	130	2100	0
Straw	60-130	2950-3300	120	7120-10000	630-1030	100-120	9000-19300	0
Corn cobs	60[a]	400[a]	70[a]	8500[a]	290[a]	<50[a]	1100[a]	250[a]
Corn stalks	140	7390	680	8190	500	800	14200	70
Cereal spillage	700	2050-5000	500	5380-1340	1170-1400	300	26100	10
Residues	200	5600	60	14000	1740	1000	15000	0

[a] Single value

Table C-4. Heavy metals.

Kind of biomass	As mg/kg (db)	Cd mg/kg (db)	Cr mg/kg (db)	Cu mg/kg (db)	Hg mg/kg (db)	Ni mg/kg (db)	Pb mg/kg (db)	Zn mg/kg (db)
Miscanthus	<0.17	0.03-0.09	0.81-6.85	1.4-2.0	<0.03	2.0-3.3	0.16-0.95	1.0-25.5
Reed canary grass	2.10	0.30	3.40	9.1	0.03-0.10	1.0	0.10	11.7[1]
Hemp	0.86	0.11	1.21	4.9	0.03	n.a.	n.a.	2.5
Straw	0.31	0.17	6.56	2.1	0.02	2.2	0.18	1.4
Corn cobs	n.a.	<1[a]	4.00[a]	<4[a]	n.a.	2.0[a]	<1[a]	11.0[a]
Corn stalks	n.a.	0.80	8.00	10.0	0.1	3.3	n.a.	n.a.
Cereal spillage	0.10	0.10	4.60	2.2	0.02	7.0	0.00	1.7
Residues	5.40	0.90	6.40	6.2	0.20	1.2	2.00	6

n.a. = not available

[a] Single value

C.5 Properties of alternative biomass pellets and briquettes

Alternative biomass raw materials have several properties that can create handling problems (Table C-5).

Table C-5. Properties of alternative biomass raw materials and potential problems

Property	Potential Problems
higher ash content	abrasion during the pelletizing process reduced lifetime of pellet dies
structural properties (e.g. stalks)	problems with the feeding system (e.g., blocking)
hardness of the material	higher energy demand and wear during cutting and milling
different elemental composition	different compacting properties requiring different pellet dies
varying fuel characteristics and inhomogeneous structural features	handling of these variations requires experience that is rarely available
low energy density	higher storage and transportation requirements

Converting these fuels into pellets or briquettes can reduce issues related to transportation costs, storage degradation and fuel feeding problems. These processes increase the density of the fuel by compressing them. Binders are often used to reduce abrasion of pellet dies and to lower the energy consumption during the compacting process. The conditioning of the raw material for the pelletizing process itself can be done in several ways; 1) changing the water content of the raw material, 2) adding binders, additives, and other raw materials, and 3) pre-heating and steam addition. Depending on the composition of the raw materials, the optimal moisture content for the pelletizing process is different. Based on the experience of producers, the optimal moisture content of the raw material for standardized wood pelletizing is about 12%. Material that is too dry can cause problems with bonding during the compacting process. For herbaceous biomass, the optimal moisture content is slightly higher. The addition of binders, such as starchy residues, can also increase the stability of herbaceous pellets. Additives such as lime, dolomite, kaolin, and talcum powder can be added during the pelletizing process to improve the combustion properties of biomass by increasing the ash melting temperature of the pellets. However, the addition of these substances can lower the mechanical durability of the produced pellets, as well as the energy value.

Certain fuel properties, such as ash content, pelletizing properties, and concentrations of critical elements, can be set by mixing different raw materials together in optimal proportions. This mixing can help control the concentrations of nitrogen, sulfur, and chlorine in the raw material mix, thus reducing formation of harmful emissions formed during combustion.

At present, the most common methods for mixing different biomass raw materials are manual mixing on the ground with a bulldozer (which has the potential for soil contamination) or by using rotating mechanical mixers. Mixing of raw materials could also be done with two parallel feeding systems. With parallel systems, the rotation speeds, and hence the proportion of the mixes, can be controlled easily.

C.6 Pelletizing Technologies

Pressure densification processes like briquetting and pelletizing can be used to improve the mechanical and physical properties of solid biomass fuels. Usually, increasing the biomass fuel density helps create uniform fuel mechanical properties and improves fuel transporting and handling properties, while keeping fuel chemical properties unchanged, despite the thermal-mechanical processing involved in the densification. Specific advantages of increasing fuel density include:

- Improves the combustion properties of the material.
- Increases fuel bulk density, thus improving transportation economics.
- Reduces risk of solidification and bridging of fines during transport and storage.
- Decreases dust in the bulk storage area; thus reducing dust explosion risks.
- Decreases material loss and prevents product losses during long-term storage by reducing oxidation and microbiological decomposition.
- Stabilizes and homogenizes heterogeneous mixtures of materials, e.g. to enable the development of blended pellets.
- Improves thermal and combustion properties.

Briquetting is a common process for improving the physical properties of biomass whereby milled and often fine particle biomass is compressed under high pressure. The friction between the material and the press mold releases heat, which activates particle binding. The feasibility of briquetting depends on the plasticity of the biomass. For harder and more brittle material, additional binding agents are needed to form material bridges between the particles. However, this is rarely required for wood briquetting.

Another process for the densification of biomass is pelletizing, where ground biomass is compacted into pellets. Similar to the briquetting process, the material to be pelletized needs to be formable.

Pelletizing is a well-studied process with established technical equipment developed by the animal feed industry. The process has more recently been adapted and commercialized for the production of wood pellets. Alternative biomass raw materials such as herbaceous bioenergy feedstocks, however, are characterized by different handling properties from either wood or animal feed as well as their own unique physical and mechanical characteristics. As a result, the production technology for fodder pellets is not directly transferable to alternative biomass fuels, and some modifications are needed.

C.6.1 Pelletizing and Briquetting Processes

Harvesting technologies and transport logistics for straw and hay are well developed. Baling for heating applications requires no or only minor adaptions to current methods. Raw materials with high moisture content must be dried to ensure stable storage conditions. Depending on the raw material, water content in feedstock should be in the range of 10 – 15% is needed to achieve the required physical fuel properties. The bulk density of herbaceous raw materials, e.g., grass and straw, is < 100 kg/m^3, requiring short transport distances.

Usually straw and grass are not dried prior to processing. Some other raw materials need mechanical drying, which increases fuel costs. At small scale, either a batch perforated-floor technology using heated air, or a simple band conveyor using exhaust gas or heated air, are commonly used. At medium scale, a rotary dryer is commonly used, while a band dryer is a possible alternative. In stand-alone applications, a preference for lower investment options often results in less energy-efficient solutions, like flue gas dryers (drum dryers) or band dryers. In large scale pellet factories, several sophisticated solutions for raw materials drying are used. Usually, the process is integrated with another process, or drying stages are separated across several phases.

C.6.1.1 Torrification

In recent years, several special pre-treatment technologies such as torrification have been developed. Torrification involves the thermochemical treatment of biomass at 200 °C to 300 °C carried out under atmospheric conditions in the absence of oxygen. The development status of various torrification technology options ranges from pilot-plant to demonstration-scale. Combining torrification with densification processes increases the energy content of the pellets or briquettes as much as 50%. The torrification process also increases water resistance and durability. Given the emerging nature of this technology, there is little public information available on the costs associated with this process and the chemical and combustion characteristics of the resulting material.

C.6.1.2 Grinding

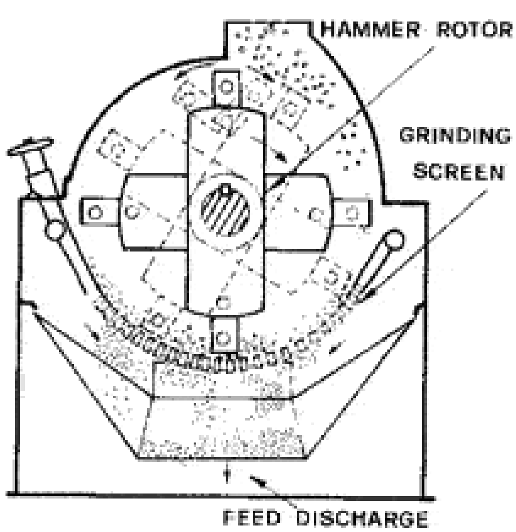
Before pelletizing, biomass raw material needs to be ground, which can be accomplished by different mill types. The type of mill (roller or hammer mill) and the milling grade of the raw material have a large influence on the pelletizing process. For example, with increasing pellet diameter, a coarser grinding may be sufficient for pellet production. Achieving smaller particle sizes of the raw material requires higher energy consumption in the grinding process, but beyond a certain point, finer particles result in negligible improvements in pellet durability.

Grinding with a roller mill has been found to be unsuitable for pelletizing. While the energy consumption of a roller mill was lower than for a hammer mill, the mechanical durability of the produced pellets was significantly poorer.

Hammer mills (Figure C-10) are the most commonly used mills for grinding. For pellet production, baled material is first debaled and chopped. The length of the chopped stem particles is between 25 to 75 mm. The bigger the press, the coarser the raw material can be. A hammer mill at the end of the feeding system grinds the raw material into finer particles. The grinding machine contains a screen, which controls the particle size of the material passed on to the pelleting process. In hammer mills, the openings are usually 4 – 10 mm. If the raw material is too wet, the openings of the screen can become blocked.

Figure C-10. Hammer mill.

Source: http://www.feedmachinery.com/glossary/hammer_mill.php



C.6.1.3 Compacting

Increasing the density of ground biomass raw materials takes place by applying external forces to particles using different shaped dies to form enlarged agglomerates. This process can be categorized by the pressure and press mold or the tool configuration:

- Ram and punch press
- Punch- and-die press
- Ram extrusion press
- Screw extrusion press
- Roller press
- Double roller press
- Flat die pellet mill with press rollers
- Pellet mill with ring die and press rollers

Pellet mills with flat dies are common for the production of animal feed pellets. The roller arrangement consists of at least two rollers which rotate on a stationary die. The feed enters the press from above, falls down by gravity, and is diverted evenly to the rollers and the track of the die. This creates an even material density between die and rollers, and subsequently a uniform extrusion through the die channels. With each rolling sequence, the pellet grows by a new layer while the appearance of the pellets remains homogeneous. The length of the pellets is adjusted by cutting devices located underneath the die. If cylindrical rollers move over a circular track, a continuous travel is only given at one point of the roller surface. The inside edge moves faster and the outside edge slower, causing additional shear force in the material to be pelletized. As a result, additional grinding and heating of the material occurs that might cause uneven material properties and problems for some types of pelletized materials, such as pharmaceuticals or natural products. Conical press rollers with sloping axes can be used to overcome this effect.

For the industrial production of wood pellets, pellet mills with ring dies are mainly used. Material enters the operational area of a ring die from the open front side of the ring, which may cause problems with uneven material distribution across the entire perforated ring area. Special feeding devices, like paddles or adjustable plows, and three rollers are used to overcome this problem. The internal rollers are mostly moved by the continuous flow of feeding material inside the pellet mill.

Appendix D: Data Inputs for Air Quality Analysis

This appendix provides a summary of the relevant input data for each unit modeled in the air quality analysis.

Emission rates are rounded to the nearest 0.0001 lb/h. Emission factors are reported to the nearest 0.00001 lb/MMBtu for pollutants if they were used to calculate the emission rate.

Source(s): EPA 2010; NYSDEC 2013 ($PM_{2.5}$ factor only); NESCAUM 2010 (CO factor only)

Oil Boiler Using Ultra Low Sulfur Heating Oil

Business as Usual Technology — Large School

Installation Characteristics

Maximum Rating	4,042,049	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	86.0	%	86.0	%
Stack Gas Temperature	369	°F	369	°F
Stack Gas Velocity	4.3	ft/s	4.3	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0002	lb/h	0.0002	lb/h
CO	0.0047	lb/h	0.0047	lb/h
NO_x	0.5083	lb/h	0.5083	lb/h
SO_2	0.0072	lb/h	0.0072	lb/h
VOC	-		0.0242	lb/h

Emission Factor		
$PM_{2.5}$	0.00005	lb/MMBtu
CO	0.00100	lb/MMBtu
NO_x	0.10815	lb/MMBtu
SO_2	0.00154	lb/MMBtu
VOC	0.00514	lb/MMBtu

Notes: maximum and typical operating scenarios are identical for oil boilers; chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted; ultra low sulfur heating oil contains 15 ppm sulfur.

Source(s): NESCAUM 2010

Stoker Chip Boiler

Business as Usual Technology — Large School

Installation Characteristics

Maximum Rating	7,133,028	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.60		0.41	
Efficiency	70.0	%	65.0	%
Stack Gas Temperature	416	°F	341	°F
Stack Gas Velocity	17.7	ft/s	13.5	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	2.2760	lb/h	1.0800	lb/h
CO	1.3130	lb/h	5.7300	lb/h
NO_x	1.7651	lb/h	1.2993	lb/h
SO_2	0.2128	lb/h	0.1566	lb/h
VOC	-		0.2192	lb/h

Emission Factor		
$PM_{2.5}$		
CO		
NO_x	0.28870	lb/MMBtu
SO_2	0.03480	lb/MMBtu
VOC	0.04870	lb/MMBtu

Notes: chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted; emissions of CO are higher at partial load due to reduced unit efficiency at lower load.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

2-Stage Gasification Pellet Boiler

Best Available Technology — Large School

Installation Characteristics

Maximum Rating	5,118,213	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	84.7	%	81.3	%
Stack Gas Temperature	356	°F	176	°F
Stack Gas Velocity	11.1	ft/s	5.1	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.2432	lb/h	0.1425	lb/h
CO	1.2165	lb/h	0.7129	lb/h
NO_x	1.4598	lb/h	0.8555	lb/h
SO_2	0.1209	lb/h	0.0708	lb/h
VOC	-		0.0482	lb/h

Emission Factor		
$PM_{2.5}$	0.05030	lb/MMBtu
CO	0.25159	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): Musil-Schlaeffer 2010; Hopke 2010; NYSERDA 2014 (RHNY program)

RHNY-Qualified 2-Stage Gasification Pellet Boiler

Best Available Technology — Large School

<u>Installation Characteristics</u>

Maximum Rating	1,426,606	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	18	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	85.6	%	85.6	%
Stack Gas Temperature	192	°F	192	°F
Stack Gas Velocity	1.03	ft/s	1.03	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$ (institutional 24h)	0.03333	lb/h	0.02292	lb/h
$PM_{2.5}$ (commercial 24h)	0.08889	lb/h	0.06111	lb/h
$PM_{2.5}$ (institutional ann.)	-	lb/h	0.02292	lb/h
$PM_{2.5}$ (commercial ann.)	-	lb/h	0.06111	lb/h
NO_x (Musil-Schlaffer)	0.50316	lb/h	0.50316	lb/h
NO_x (Hopke)	0.13927	lb/h	0.13927	lb/h

Emission Factor		
$PM_{2.5}$ (institutional)	0.03000	lb/MMBtu
$PM_{2.5}$ (commercial)	0.08000	lb/MMBtu
NO_x (Musil-Schlaffer)	0.30191	lb/MMBtu
NO_x (Hopke)	0.08351	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; assumes 3000 gal storage tank; only assessed for annual $PM_{2.5}$, daily $PM_{2.5}$ and daily NO_x; includes two alternate $PM_{2.5}$ emission factors—one for commercial and one for institutional installations (for sensitive populations)—based on requirements of Renewable Heat New York (RHNY); includes two alternate NO_x emission factors—one based on European data (Musil-Schlaffer) and one on the Wild Center (Hopke); assumes 12% NO_x to NO_2 conversion based on stack test data for Hopke test; maximum and typical daily operation are 16 and 11 hours per day, respectively.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Advanced Chip Boiler w/AEC

Best Available Technology — Large School

Installation Characteristics

Maximum Rating	5,118,213	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	74.8	%	70.0	%
Stack Gas Temperature	356	°F	176	°F
Stack Gas Velocity	15.2	ft/s	7.1	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.3671	lb/h	0.2209	lb/h
CO	1.8355	lb/h	1.1045	lb/h
NO_x	2.2026	lb/h	1.3254	lb/h
SO_2	0.1368	lb/h	0.0823	lb/h
VOC	-		0.0560	lb/h

Emission Factor		
$PM_{2.5}$	0.06709	lb/MMBtu
CO	0.33545	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Advanced Chip Boiler w/AEC Using 30% Moisture Chips

Best Available Technology — Large School

<u>Installation Characteristics</u>

Maximum Rating	5,118,213	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	78.2	%	73.4	%
Stack Gas Temperature	356	°F	176	°F
Stack Gas Velocity	12.3	ft/s	5.7	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.3511	lb/h	0.2106	lb/h
CO	1.7555	lb/h	1.0529	lb/h
NO_x	2.1066	lb/h	1.2635	lb/h
SO_2	0.1308	lb/h	0.0785	lb/h
VOC	-		0.0534	lb/h

Emission Factor		
$PM_{2.5}$	0.06709	lb/MMBtu
CO	0.33545	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Condensing Pellet Boiler w/AEC

Next Best Technology — Large School

Installation Characteristics

Maximum Rating	1,706,071	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	94.0	%	90.4	%
Stack Gas Temperature	140	°F	104	°F
Stack Gas Velocity	3.1	ft/s	1.5	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0089	lb/h	0.0046	lb/h
CO	0.2854	lb/h	0.1484	lb/h
NO_x	0.5480	lb/h	0.2849	lb/h
SO_2	0.0454	lb/h	0.0236	lb/h
VOC	-		0.0160	lb/h

Emission Factor		
$PM_{2.5}$	0.00490	lb/MMBtu
CO	0.15724	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Condensing Chip Boiler w/AEC

Next Best Technology — Large School

Installation Characteristics

Maximum Rating	1,706,071	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	88.0	%	82.9	%
Stack Gas Temperature	140	°F	104	°F
Stack Gas Velocity	4.0	ft/s	2.0	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0126	lb/h	0.0067	lb/h
CO	0.4065	lb/h	0.2157	lb/h
NO_x	0.7804	lb/h	0.4141	lb/h
SO_2	0.0485	lb/h	0.0257	lb/h
VOC	-		0.0175	lb/h

Emission Factor		
$PM_{2.5}$	0.00651	lb/MMBtu
CO	0.20966	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Condensing Chip Boiler w/AEC Using 30% Moisture Chips

Next Best Technology — Large School

Installation Characteristics

Maximum Rating	1,706,071	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	91.4	%	85.2	%
Stack Gas Temperature	140	°F	104	°F
Stack Gas Velocity	3.2	ft/s	1.6	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0122	lb/h	0.0065	lb/h
CO	0.3913	lb/h	0.2099	lb/h
NO_x	0.7514	lb/h	0.4031	lb/h
SO_2	0.0467	lb/h	0.0250	lb/h
VOC	-		0.0170	lb/h

Emission Factor		
$PM_{2.5}$	0.00651	lb/MMBtu
CO	0.20966	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2010; NYSDEC 2013 (PM2.5 factor only); NESCAUM 2010 (CO factor only)

Oil Boiler Using Ultra Low Sulfur Heating Oil

Business as Usual Technology — Small School

Installation Characteristics

Maximum Rating	1,920,062	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	18.6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	86.0	%	86.0	%
Stack Gas Temperature	369	°F	369	°F
Stack Gas Velocity	7.2	ft/s	7.2	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0001	lb/h	0.0001	lb/h
CO	0.0022	lb/h	0.0022	lb/h
NO_x	0.2415	lb/h	0.2415	lb/h
SO_2	0.0034	lb/h	0.0034	lb/h
VOC	-		0.0115	lb/h

Emission Factor		
$PM_{2.5}$	0.00005	lb/MMBtu
CO	0.00100	lb/MMBtu
NO_x	0.10815	lb/MMBtu
SO_2	0.00154	lb/MMBtu
VOC	0.00514	lb/MMBtu

Notes: maximum and typical operating scenarios are identical for oil boilers; emission rates were estimated using emission factors unless otherwise noted; ultra low sulfur heating oil contains 15 ppm sulfur.

Source(s): NESCAUM 2010

Stoker Chip Boiler

Business as Usual Technology — Small School

Installation Characteristics

Maximum Rating	3,388,344	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	18.6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.60		0.41	
Efficiency	70.0	%	65.0	%
Stack Gas Temperature	416	°F	341	°F
Stack Gas Velocity	14.4	ft/s	9.7	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	1.0811	lb/h	0.5130	lb/h
CO	0.6237	lb/h	2.7219	lb/h
NO_x	0.8385	lb/h	0.6172	lb/h
SO_2	0.1011	lb/h	0.0744	lb/h
VOC	-		0.1041	lb/h

Emission Factor		
$PM_{2.5}$		
CO		
NO_x	0.28870	lb/MMBtu
SO_2	0.03480	lb/MMBtu
VOC	0.04870	lb/MMBtu

Notes: chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted; emissions of CO are higher at partial load due to reduced unit efficiency at lower load.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

2-Stage Gasification Pellet Boiler

Best Available Technology — Small School

Installation Characteristics

Maximum Rating	3,412,142	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	18.6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	84.7	%	81.3	%
Stack Gas Temperature	356	°F	176	°F
Stack Gas Velocity	12.3	ft/s	7.2	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.1621	lb/h	0.0950	lb/h
CO	0.8110	lb/h	0.4753	lb/h
NO_x	0.9732	lb/h	0.5703	lb/h
SO_2	0.0806	lb/h	0.0472	lb/h
VOC	-		0.0321	lb/h

Emission Factor		
$PM_{2.5}$	0.05030	lb/MMBtu
CO	0.25159	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Containerized 2-Stage Gasification Pellet Boiler w/14-ft Stack

Best Available Technology — Small School

Installation Characteristics

Maximum Rating	1,706,071	Btu/h
Stack Height	14.0	ft
Stack Exit Diameter	18	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.90	
Efficiency	85.0	%	85.0	%
Stack Gas Temperature	192	°F	192	°F
Stack Gas Velocity	10.9	ft/s	6.2	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.1615	lb/h	0.0909	lb/h
CO	0.8080	lb/h	0.4545	lb/h
NO_x	0.9696	lb/h	0.5454	lb/h
SO_2	0.0803	lb/h	0.0452	lb/h
VOC	-		0.0307	lb/h

Emission Factor		
$PM_{2.5}$	0.05030	lb/MMBtu
CO	0.25159	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Containerized 2-Stage Gasification Pellet Boiler w/25' Stack

Best Available Technology — Small School

Installation Characteristics

Maximum Rating	1,706,071	Btu/h
Stack Height	25.0	ft
Stack Exit Diameter	18	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.90	
Efficiency	85.0	%	85.0	%
Stack Gas Temperature	192	°F	192	°F
Stack Gas Velocity	10.9	ft/s	6.2	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.1615	lb/h	0.0909	lb/h
CO	0.8080	lb/h	0.4545	lb/h
NO_x	0.9696	lb/h	0.5454	lb/h
SO_2	0.0803	lb/h	0.0452	lb/h
VOC	-		0.0307	lb/h

Emission Factor		
$PM_{2.5}$	0.05030	lb/MMBtu
CO	0.25159	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Condensing Pellet Boiler w/AEC

Next Best Technology — Small School

Installation Characteristics

Maximum Rating	1,023,643	Btu/h
Stack Height	40.0	ft
Stack Exit Diameter	18.6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	94.0	%	90.4	%
Stack Gas Temperature	140	°F	104	°F
Stack Gas Velocity	3.1	ft/s	1.6	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0053	lb/h	0.0028	lb/h
CO	0.1712	lb/h	0.0890	lb/h
NO_x	0.3288	lb/h	0.1709	lb/h
SO_2	0.0272	lb/h	0.0142	lb/h
VOC	-		0.0096	lb/h

Emission Factor		
$PM_{2.5}$	0.00490	lb/MMBtu
CO	0.15724	lb/MMBtu
NO_x	0.30191	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2010; NYSDEC 2013 (PM2.5 factor only); NESCAUM 2010 (CO factor only)

Oil Boiler Using Ultra Low Sulfur Heating Oil

Business as Usual Technology — Hospital

Installation Characteristics

Maximum Rating	3,368,871	Btu/h
Stack Height	50.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	86.0	%	86.0	%
Stack Gas Temperature	369	°F	369	°F
Stack Gas Velocity	7.6	ft/s	7.6	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0002	lb/h	0.0002	lb/h
CO	0.0047	lb/h	0.0047	lb/h
NO_x	0.4237	lb/h	0.4237	lb/h
SO_2	0.0060	lb/h	0.0060	lb/h
VOC	-		0.0201	lb/h

Emission Factor		
$PM_{2.5}$	0.00005	lb/MMBtu
CO	0.00100	lb/MMBtu
NO_x	0.10815	lb/MMBtu
SO_2	0.00154	lb/MMBtu
VOC	0.00514	lb/MMBtu

Notes: maximum and typical operating scenarios are identical for oil boilers; emission rates were estimated using emission factors unless otherwise noted; ultra low sulfur heating oil contains 15 ppm sulfur.

Source(s): NESCAUM 2010

Stoker Chip Boiler

Business as Usual Technology — Hospital

Installation Characteristics

Maximum Rating	7,133,028	Btu/h
Stack Height	50.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.60		0.41	
Efficiency	70.0	%	65.0	%
Stack Gas Temperature	416	°F	341	°F
Stack Gas Velocity	18.3	ft/s	12.3	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	2.2760	lb/h	1.0800	lb/h
CO	1.3130	lb/h	5.7300	lb/h
NO_x	1.7651	lb/h	1.2993	lb/h
SO_2	0.2128	lb/h	0.1566	lb/h
VOC	-		0.2192	lb/h

Emission Factor		
$PM_{2.5}$		
CO		
NO_x	0.28870	lb/MMBtu
SO_2	0.03480	lb/MMBtu
VOC	0.04870	lb/MMBtu

Notes: chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted; emissions of CO are higher at partial load due to reduced unit efficiency at lower load.

Source(s): EPA 2003 (SO_2 VOC only); Musil-Schlaeffer 2010

Advanced Chip Boiler w/AEC

Best Available Technology — Hospital

Installation Characteristics

Maximum Rating	5,118,213	Btu/h
Stack Height	50.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	74.8	%	70.0	%
Stack Gas Temperature	356	°F	176	°F
Stack Gas Velocity	15.2	ft/s	7.1	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.3670	lb/h	0.2207	lb/h
CO	1.8352	lb/h	1.1037	lb/h
NO_x	2.2022	lb/h	1.3245	lb/h
SO_2	0.1368	lb/h	0.0823	lb/h
VOC	-		0.0559	lb/h

Emission Factor		
$PM_{2.5}$	0.06709	lb/MMBtu
CO	0.33545	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2003 (SO_2, VOC only); Musil-Schlaeffer 2010

Condensing Chip Boiler w/AEC

Next Best Technology — Hospital

<u>Installation Characteristics</u>

Maximum Rating	1,706,071	Btu/h
Stack Height	50.0	ft
Stack Exit Diameter	24	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	87.0	%	82.2	%
Stack Gas Temperature	140	°F	104	°F
Stack Gas Velocity	4.0	ft/s	2.0	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0128	lb/h	0.0068	lb/h
CO	0.4112	lb/h	0.2175	lb/h
NO_x	0.7895	lb/h	0.4176	lb/h
SO_2	0.0490	lb/h	0.0259	lb/h
VOC	-		0.0176	lb/h

Emission Factor		
$PM_{2.5}$	0.00651	lb/MMBtu
CO	0.20966	lb/MMBtu
NO_x	0.40255	lb/MMBtu
SO_2	0.02500	lb/MMBtu
VOC	0.01700	lb/MMBtu

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 2010; NYSDEC 2013 (PM2.5 factor only)

Oil Boiler Using Ultra Low Sulfur Heating Oil

Business as Usual Technology — Home

Installation Characteristics

Maximum Rating	117,682	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	83.0	%	83.0	%
Stack Gas Temperature	420	°F	420	°F
Stack Gas Velocity	4.7	ft/s	4.7	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	<0.0001	lb/h	<0.0001	lb/h
CO	0.0051	lb/h	0.0051	lb/h
NO_x	0.0153	lb/h	0.0153	lb/h
SO_2	0.0002	lb/h	0.0002	lb/h
VOC	-		0.0007	lb/h

Emission Factor		
$PM_{2.5}$	0.00005	lb/MMBtu
CO	0.03600	lb/MMBtu
NO_x	0.10815	lb/MMBtu
SO_2	0.00154	lb/MMBtu
VOC	0.00514	lb/MMBtu

Notes: maximum and typical operating scenarios are identical for oil boilers; emission rates were estimated using emission factors unless otherwise noted; ultra low sulfur heating oil contains 15 ppm sulfur.

Source(s): Gullett et al. 2012 (PM2.5, CO, VOC); EPA 2013

Phase II Outdoor Cordwood Boiler

Business as Usual Technology — Home

<u>Installation Characteristics</u>

Maximum Rating	207,673	Btu/h
Stack Height	9.8	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.70		0.40	
Efficiency	77.6	%	67.7	%
Stack Gas Temperature	311	°F	248	°F
Stack Gas Velocity	7.4	ft/s	4.3	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.2468	lb/h	0.0823	lb/h
CO	0.3016	lb/h	0.1457	lb/h
NO_x	0.0246	lb/h	0.0161	lb/h
SO_2	0.0272	lb/h	0.0178	lb/h
VOC	-		0.2198	lb/h

Emission Factor		
$PM_{2.5}$		
CO		
NO_x	0.13152	lb/MMBtu
SO_2	0.14500	lb/MMBtu
VOC	1.79100	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): Gullett et al. 2012 (PM2.5, CO, VOC); Musil-Schlaeffer 2010 (NO_2); EPA 1996 (SO_2)

Pellet Boiler, No Storage

Business as Usual Technology

Home

Installation Characteristics

Maximum Rating	109,189	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.80		0.45	
Efficiency	85.0	%	81.5	%
Stack Gas Temperature	248	°F	159.8	°F
Stack Gas Velocity	3.3	ft/s	1.7	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0038	lb/h	0.0022	lb/h
CO	0.1428	lb/h	0.0838	lb/h
NO_x	0.0175	lb/h	0.0102	lb/h
SO_2	0.0027	lb/h	0.0016	lb/h
VOC	-		0.0039	lb/h

Emission Factor		
$PM_{2.5}$	0.03700	lb/MMBtu
CO	1.39000	lb/MMBtu
NO_x	0.17000	lb/MMBtu
SO_2	0.02581	lb/MMBtu
VOC	0.06500	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): Musil-Schlaeffer 2010; EPA 1996 (SO_2)

Pellet Boiler, With Storage

Best Available Technology — Home

<u>Installation Characteristics</u>

Maximum Rating	109,189	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	86.0	%	86.0	%
Stack Gas Temperature	248	°F	248	°F
Stack Gas Velocity	4.0	ft/s	4.0	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$ (1h)	0.0025	lb/h	0.0025	lb/h
$PM_{2.5}$ (24h)	0.0010	lb/h	0.0003	lb/h
$PM_{2.5}$ (annual)	-		0.0003	lb/h
CO (1h)	0.0063	lb/h	0.0063	lb/h
CO (8h)	0.0024	lb/h	0.0024	lb/h
NO_x	0.0216	lb/h	0.0216	lb/h
SO_2	0.0033	lb/h	0.0033	lb/h
VOC	-		0.0007	lb/h

Emission Factor		
$PM_{2.5}$	0.02000	lb/MMBtu
CO	0.05000	lb/MMBtu
NO_x	0.17000	lb/MMBtu
SO_2	0.02581	lb/MMBtu
VOC	0.00554	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; thermal storage ensures that the unit operates at highest efficiency (full load) whenever it operates.

Source(s): Butcher et al. 2013 (PM2.5, CO); Musil-Schlaeffer 2010 (NO_2, VOC); EPA 1996 (SO_2)

Advanced Cordwood Boiler, With Storage

Best Available Technology — Home

Installation Characteristics

Maximum Rating	109,189	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	86.0	%	86.0	%
Stack Gas Temperature	320	°F	320	°F
Stack Gas Velocity	4.0	ft/s	4.0	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$ (1h)	0.0523	lb/h	0.0523	lb/h
$PM_{2.5}$ (24h)	0.0098	lb/h	0.0033	lb/h
$PM_{2.5}$ (annual)	-		0.0069	lb/h
CO (1h)	2.3498	lb/h	2.3498	lb/h
CO (8h)	0.3391	lb/h	0.3391	lb/h
NO_x	0.0216	lb/h	0.0216	lb/h
SO_2	0.0036	lb/h	0.0036	lb/h
VOC	-		0.0015	lb/h

Emission Factor		
$PM_{2.5}$		
CO		
NO_x	0.17010	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	0.01215	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; thermal storage ensures that the unit operates at highest efficiency (full load) whenever it operates.

Source(s): Musil-Schlaeffer 2010 (PM2.5, CO, NO_2); EPA 1996 (SO_2)

Condensing Pellet Boiler, No Storage

Next Best Technology — Home

Installation Characteristics

Maximum Rating	85,304	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.90		0.50	
Efficiency	93.6	%	90.4	%
Stack Gas Temperature	126	°F	86	°F
Stack Gas Velocity	2.2	ft/s	1.1	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0002	lb/h	0.0001	lb/h
CO	0.0025	lb/h	0.0014	lb/h
NO_x	0.0139	lb/h	0.0080	lb/h
SO_2	0.0021	lb/h	0.0012	lb/h
VOC	-		0.0003	lb/h

Emission Factor		
$PM_{2.5}$	0.00233	lb/MMBtu
CO	0.03000	lb/MMBtu
NO_x	0.17000	lb/MMBtu
SO_2	0.02581	lb/MMBtu
VOC	0.00554	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): Musil-Schlaeffer 2010 (PM2.5, CO, NO_2); EPA 1996 (SO_2)

Condensing Pellet Boiler, With Storage

Next Best Technology — Home

Installation Characteristics

Maximum Rating	85,304	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		1.00	
Efficiency	94.0	%	94.0	%
Stack Gas Temperature	126	°F	126	°F
Stack Gas Velocity	2.4	ft/s	2.4	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$ (1h)	0.0002	lb/h	0.0002	lb/h
$PM_{2.5}$ (24h)	0.0001	lb/h	<0.0001	lb/h
$PM_{2.5}$ (annual)	-		<0.0001	lb/h
CO (1h)	0.0027	lb/h	0.0027	lb/h
CO (8h)	0.0010	lb/h	0.0010	lb/h
NO_x	0.0154	lb/h	0.0154	lb/h
SO_2	0.0023	lb/h	0.0023	lb/h
VOC	-		0.0005	lb/h

Emission Factor		
$PM_{2.5}$	0.00233	lb/MMBtu
CO	0.03000	lb/MMBtu
NO_x	0.17000	lb/MMBtu
SO_2	0.02581	lb/MMBtu
VOC	0.00554	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; thermal storage ensures that the unit operates at highest efficiency (full load) whenever it operates.

Source(s): Musil-Schlaeffer 2010 (PM2.5, CO, NO_2); EPA 1996 (SO_2)

Condensing Cordwood Boiler, No Storage

Next Best Technology | Home

Installation Characteristics

Maximum Rating	85,304	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.90		0.50	
Efficiency	83.3	%	74.0	%
Stack Gas Temperature	266	°F	195.8	°F
Stack Gas Velocity	2.8	ft/s	1.6	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0017	lb/h	0.0009	lb/h
CO	0.0210	lb/h	0.0115	lb/h
NO_x	0.0180	lb/h	0.0099	lb/h
SO_2	0.0030	lb/h	0.0016	lb/h
VOC	-		0.0007	lb/h

Emission Factor		
$PM_{2.5}$	0.01628	lb/MMBtu
CO	0.19970	lb/MMBtu
NO_x	0.17100	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	0.01215	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): EPA 1996

Non-EPA Certified Cordwood Stove

Business as Usual Technology — Home

Installation Characteristics

Maximum Rating	51,182	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.30	
Efficiency	-	%	-	%
Stack Gas Temperature	592	°F	548.3	°F
Stack Gas Velocity	15.0	ft/s	13.5	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0956	lb/h	0.0478	lb/h
CO	0.7213	lb/h	0.3606	lb/h
NO_x	0.0088	lb/h	0.0044	lb/h
SO_2	0.0013	lb/h	0.0006	lb/h
VOC	-		0.0828	lb/h

Emission Factor		
$PM_{2.5}$	2.18571	lb/MMBtu
CO	16.48571	lb/MMBtu
NO_x	0.20000	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	3.78571	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; emission rates assume six (maximum) or three (typical) 25 lb charges of wood per day; efficiency was not explicitly considered.

Source(s): EPA 1996

EPA-Certified, Non-Catalytic Cordwood Stove

Business as Usual Technology — Home

Installation Characteristics

Maximum Rating	51,182	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	0.55		0.48	
Efficiency	-	%	-	%
Stack Gas Temperature	555	°F	555	°F
Stack Gas Velocity	12.9	ft/s	12.9	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0613	lb/h	0.0306	lb/h
CO	0.4400	lb/h	0.2200	lb/h
NO_x	0.0063	lb/h	0.0031	lb/h
SO_2	0.0013	lb/h	0.0006	lb/h
VOC	-		0.0188	lb/h

Emission Factor		
$PM_{2.5}$	1.40000	lb/MMBtu
CO	10.05714	lb/MMBtu
NO_x	0.14286	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	0.85714	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; emission rates assume six (maximum) or three (typical) 25 lb charges of wood per day; efficiency was not explicitly considered.

Source(s): EPA 1996

EPA-Certified, Catalytic Cordwood Stove

Business as Usual Technology — Home

Installation Characteristics

Maximum Rating	51,182	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.30	
Efficiency	-	%	-	%
Stack Gas Temperature	592	°F	548.3	°F
Stack Gas Velocity	15.0	ft/s	13.5	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0638	lb/h	0.0319	lb/h
CO	0.3263	lb/h	0.1631	lb/h
NO_x	0.0063	lb/h	0.0031	lb/h
SO_2	0.0013	lb/h	0.0006	lb/h
VOC	-		0.0234	lb/h

Emission Factor		
$PM_{2.5}$	1.45714	lb/MMBtu
CO	7.45714	lb/MMBtu
NO_x	0.14286	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	1.07143	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; emission rates assume six (maximum) or three (typical) 25 lb charges of wood per day; efficiency was not explicitly considered.

Source(s): EPA 1996; EPA 2013 (VOC only)

Pellet Stove

Business as Usual Technology — Home

Installation Characteristics

Maximum Rating	60,000	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	77.8	%	65.9	%
Stack Gas Temperature	554	°F	541.85	°F
Stack Gas Velocity	12.9	ft/s	11.8	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0209	lb/h	0.0123	lb/h
CO	0.1960	lb/h	0.1157	lb/h
NO_x	0.0687	lb/h	0.0405	lb/h
SO_2	0.0020	lb/h	0.0012	lb/h
VOC	-		0.0001	lb/h

Emission Factor		
$PM_{2.5}$	0.27097	lb/MMBtu
CO	2.54194	lb/MMBtu
NO_x	0.89032	lb/MMBtu
SO_2	0.02581	lb/MMBtu
VOC	0.00265	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted.

Source(s): Musil-Schlaeffer 2010 (PM2.5, CO, NO_2); EPA 1996 (SO_2)

EPA-Certified, Catalytic Cordwood Stove

Best Available Technology — Home

Installation Characteristics

Maximum Rating	51,182	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.94	
Efficiency	-	%	-	%
Stack Gas Temperature	500	°F	392	°F
Stack Gas Velocity	3.1	ft/s	1.2	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0022	lb/h	0.0011	lb/h
CO	0.0631	lb/h	0.0316	lb/h
NO_x	0.0074	lb/h	0.0037	lb/h
SO_2	0.0013	lb/h	0.0006	lb/h
VOC	-		0.0013	lb/h

Emission Factor		
$PM_{2.5}$	0.05000	lb/MMBtu
CO	1.44300	lb/MMBtu
NO_x	0.17010	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	0.06075	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; emission rates assume six (maximum) or three (typical) 25 lb charges of wood per day; efficiency was not explicitly considered.

Source(s): Musil-Schlaeffer 2010 (PM2.5, CO, NO_2); EPA 1996 (SO_2)

Advanced Cordwood Stove w/AEC

Next Best Technology — Home

<u>Installation Characteristics</u>

Maximum Rating	51,182	Btu/h
Stack Height	19.7	ft
Stack Exit Diameter	6	in

Emission Characteristic	Maximum Expected Operating Scenario		Typical Operating Scenario	
Load Fraction	1.00		0.50	
Efficiency	-	%	-	%
Stack Gas Temperature	500	°F	392	°F
Stack Gas Velocity	2.8	ft/s	1.3	ft/s

Emission Rate	Maximum Expected Operating Scenario		Typical Operating Scenario	
$PM_{2.5}$	0.0005	lb/h	0.0003	lb/h
CO	0.0481	lb/h	0.0241	lb/h
NO_x	0.0075	lb/h	0.0037	lb/h
SO_2	0.0013	lb/h	0.0006	lb/h
VOC	-		0.0013	lb/h

Emission Factor		
$PM_{2.5}$	0.01200	lb/MMBtu
CO	1.10000	lb/MMBtu
NO_x	0.17100	lb/MMBtu
SO_2	0.02857	lb/MMBtu
VOC	0.06075	lb/MMBtu

Notes: emission rates were estimated using emission factors unless otherwise noted; emission rates assume six (maximum) or three (typical) 25 lb charges of wood per day; efficiency was not explicitly considered; emissions controls are electrostatic precipitator and automatic air damper.

D.1 References

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Appendix E: Air Quality Impacts Tables

E.1 Large School – Small Town in Upper New York

Table E-1. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	93.1*	164.3*	28.3*	50.9*	5.9*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	27.9	29.5	8.1	9.1	1.9
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	26.7	31.0	7.8	9.4	2.0
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	20.2	22.6	6.2	6.8	1.4
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	3.0	4.4	0.3
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	1.1	1.6	0.1
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.4	2.0	0.4	0.6	0.1
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.4	2.0	0.4	0.6	0.1
Condensing Pellet Boiler w/AEC	1,710,000	1.2	1.5	0.3	0.5	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$.

Table E-2. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*22.0*	*22.0*	*15.0*	*15.0*	*4.3*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	22.0	22.0	15.0	15.0	4.3
Stoker Chip Boiler	7,130,000	115.1*	186.3*	43.3*	65.9*	10.2*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	49.9	51.5	23.1	24.1	6.2
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	48.7	53.0	22.8	24.4	6.3
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	42.2	44.6	21.2	21.8	5.7
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	18.0	19.4	4.6
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	16.1	16.6	4.4
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	23.4	24.0	15.4	15.6	4.4
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	23.4	24.0	15.4	15.6	4.4
Condensing Pellet Boiler w/AEC	1,710,000	23.2	23.5	15.3	15.5	4.4

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight, unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$; 1-hour average existing conditions are biased low (Felton 2009).

Table E-3. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Large School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150	50	50	50
Stoker Chip Boiler	7,130,000	150	150	50	50	50
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	150	150	50	50	50
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150	50	50	50
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150	50	50	50
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	40	40	80
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	40	40	80
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	40	150	40	40	50
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150	40	40	50
Condensing Pellet Boiler w/AEC	1,710,000	40	150	40	40	50

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight, unless otherwise noted; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$.

Table E-4. Predicted CO Concentrations for Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	0.4*	0.1*	0.2*	0.0*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	0.1	0.1	0.1	0.1
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	0.1	0.1	0.1	0.1
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	0.1	0.1	0.1	0.1
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	0.0	0.1	0.0	0.0
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	0.0	0.1	0.0	0.0
Condensing Pellet Boiler w/AEC	1,710,000	0.0	0.0	0.0	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the large school analysis for CO incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-5. Predicted CO Concentrations for Large School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
Existing Conditions		*1.1*	*1.1*	*0.7*	*0.7*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	7,130,000	1.5*	1.2*	0.9*	0.7*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	1.2	1.2	0.8	0.8
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	1.2	1.2	0.8	0.8
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	1.2	1.2	0.8	0.8
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	1.1	1.2	0.7	0.7
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.1	1.2	0.7	0.7
Condensing Pellet Boiler w/AEC	1,710,000	1.1	1.1	0.7	0.7

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the large school analysis for CO incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-6. Distance from Source for Maximum CO Concentrations for Large School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)			
		1-hour		8-hour	
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150	150	150
Stoker Chip Boiler	7,130,000	150	150	150	150
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	150	150	150	150
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150	150	150
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150	150	150
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	40	150	40	150
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150	40	150
Condensing Pellet Boiler w/AEC	1,710,000	40	150	40	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis for CO incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-7. Predicted NO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	59	59	47	47
Stoker Chip Boiler	7,130,000	101	114	81	91
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	162	160	130	128
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	160	169	128	135
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	111	122	88	98
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	105	105	84	84
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	29	29	4	4
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	79	111	63	89
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	84	112	68	89
Condensing Pellet Boiler w/AEC	1,710,000	61	82	49	66

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; applied emission factors based on both European testing data (Musil-Schlaffer 2010) and the Wild Center (Hopke 2010) for the RHNY-qualified 2-stage gasification pellet boiler; Tier 2 analysis assumes 80 percent of NO_x is NO_2, except for the RHNY-qualified 2-stage gasification pellet boiler using the emission factor from Hopke (2010), which assumes 12 percent conversion based on the testing data; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-8. Predicted NO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (μg/m³)**			
		Tier 1 (100% of NOx is NO_2)		Tier 2	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*33*	*33*	*33*	*33*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	92	92	80	80
Stoker Chip Boiler	7,130,000	134	147	114	124
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	195	193	163	161
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	193	202	161	168
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	144	155	121	131
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	138	138	117	117
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	62	62	37	37
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	112	144	96	122
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	117	145	101	122
Condensing Pellet Boiler w/AEC	1,710,000	94	115	82	99

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; applied emission factors based on both European testing data (Musil-Schlaffer 2010) and the Wild Center (Hopke 2010) for the RHNY-qualified 2-stage gasification pellet boiler; Tier 2 analysis assumes 80 percent of NO_x is NO_2, except for the RHNY-qualified 2-stage gasification pellet boiler using the emission factor from Hopke (2010), which assumes 12 percent conversion based on the testing data; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-9. Distance from Source for Maximum NO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	200	200
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	200	200
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	40	150
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150
Condensing Pellet Boiler w/AEC	1,710,000	40	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures.

Table E-10. Predicted SO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration (μg/m^3)** 1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	1	1
Stoker Chip Boiler	7,130,000	13	14
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	10	10
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	10	11
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	9	10
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	5	7
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	6	7
Condensing Pellet Boiler w/AEC	1,710,000	5	7

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; no technologies modeled for the large school analysis for SO_2 incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-11. Predicted SO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** 1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
Existing Conditions		*10*	*10*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	11	11
Stoker Chip Boiler	7,130,000	23	24
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	20	20
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	20	21
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	19	20
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	15	17
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	16	17
Condensing Pellet Boiler w/AEC	1,710,000	15	17

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; no technologies modeled for the large school analysis for SO_2 incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-12. Distance from Source for Maximum SO_2 Concentrations for Large School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150
2-Stage Gasification Pellet Boiler	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	40	150
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150
Condensing Pellet Boiler w/AEC	1,710,000	40	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis for SO_2 incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-13. Predicted VOC Concentrations for Large School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration ($\mu g/m^3$) Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.21
Stoker Chip Boiler	7,130,000	1.20
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.49
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	0.50
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	0.46
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.24
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	0.24
Condensing Pellet Boiler w/AEC	1,710,000	0.23

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the large school analysis for VOC incorporated thermal storage; unit sizes are reported to three significant figures.

TableE-14. Distance from Source for Maximum VOC Concentrations for Large School Setting – Mountainous Terrain, Low Density

"Business as usual" technologies	Unit Size (Btu)	Distance (m) Annual: Typical
]]Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	50
Stoker Chip Boiler	7,130,000	50
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	50
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	50
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	50
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	50
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	50
Condensing Pellet Boiler w/AEC	1,710,000	50

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis for VOC incorporated thermal storage; unit sizes are reported to three significant figures.

E.2 Large School – Small Town in Mid-New York

Table E-15. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	99.4*	170.5*	22.1*	37.9*	3.9*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	29.4	31.2	6.9	7.0	1.2
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	28.3	33.2	6.7	7.4	1.2
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	21.2	24.0	5.8	5.3	1.1
	1,430,000					
"Next best" technologies	1,430,000					
Condensing Chip Boiler w/AEC	1,710,000	1.3	2.0	0.4	0.6	0.1
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.3	2.0	0.4	0.6	0.1
Condensing Pellet Boiler w/AEC	1,710,000	1.2	1.5	0.3	0.4	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-16. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m^3)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*21.2*	*21.2*	*20.0*	*20.0*	*7.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.0	0.0	20.0	20.0	7.0
Stoker Chip Boiler	7,130,000	99.4*	170.5*	42.1*	57.9*	10.9*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	29.4	31.2	26.9	27.0	8.2
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	28.3	33.2	26.7	27.4	8.2
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	21.2	24.0	25.8	25.3	8.1
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.3	2.0	20.4	20.6	7.1
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.3	2.0	20.4	20.6	7.1
Condensing Pellet Boiler w/AEC	1,710,000	1.2	1.5	20.3	20.4	7.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-17. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Large School Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150	40	40	10
Stoker Chip Boiler	7,130,000	150	150	40	150	10
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	150	150	40	40	10
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150	40	40	10
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150	40	40	10
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	40	150	10	40	10
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150	10	40	10
Condensing Pellet Boiler w/AEC	1,710,000	40	150	10	40	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-18. Predicted NO_2 Concentrations for Large School Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m³)**			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	56	56	45	45
Stoker Chip Boiler	7,130,000	98	110	78	88
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	141	155	113	124
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	136	163	108	130
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	102	118	82	95
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	69	99	55	80
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	68	99	55	79
Condensing Pellet Boiler w/AEC	1,710,000	57	73	46	58

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-19. Predicted NO_2 Concentrations for Large School Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (μg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*33*	*33*	*33*	*33*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	89	89	78	78
Stoker Chip Boiler	7,130,000	131	143	111	121
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	174	188	146	157
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	169	196	142	163
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	135	151	115	128
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	102	132	88	113
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	101	132	88	112
Condensing Pellet Boiler w/AEC	1,710,000	90	106	79	91

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-20. Distance from Source for Maximum NO_2 Concentrations for Large School Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	40	150
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150
Condensing Pellet Boiler w/AEC	1,710,000	40	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-21. Predicted VOC Concentrations for Large School Setting – Valley Terrain, Low Density (No Existing Conditions)

		Concentration ($\mu g/m^3$)
	Unit Size (Btu)	Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.15
Stoker Chip Boiler	7,130,000	0.80
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.31
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	0.30
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	0.35
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.20
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	0.20
Condensing Pellet Boiler w/AEC	1,710,000	0.22

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-22. Distance from Source for Maximum VOC Concentrations for Large School Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m) Annual: Typical
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	10
Stoker Chip Boiler	7,130,000	10
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	10
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	10
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	10
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	10
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	10
Condensing Pellet Boiler w/AEC	1,710,000	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.3 Large School – Populated Area in Mid-New York

Table E-23. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	96.3*	174.0*	23.9*	39.9*	4.1*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	27.8	30.5	7.8	7.5	1.3
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	27.0	32.1	7.6	8.0	1.3
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	20.3	23.1	6.3	5.8	1.1
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	3.0	4.3	0.4
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	1.1	1.6	0.2
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.4	2.0	0.5	0.7	0.1
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	1.4	2.0	0.4	0.7	0.1
Condensing Pellet Boiler w/AEC	1,710,000	1.2	1.5	0.4	0.5	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$.

Table E-24. Predicted $PM_{2.5}$ Concentrations for Large School Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*18.2*	*18.2*	*23.0*	*23.0*	*8.7*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	18.2	18.2	23.0	23.0	8.7
Stoker Chip Boiler	7,130,000	114.5*	192.2*	46.9*	62.9*	12.8*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	46.0	48.7	30.8	30.5	10.0
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	45.2	50.3	30.6	31.0	10.0
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	38.5	41.3	29.3	28.8	9.8
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	26.0	27.3	9.1
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	24.1	24.6	8.9
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	19.6	20.2	23.5	23.7	8.8
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	19.6	20.2	23.4	23.7	8.8
Condensing Pellet Boiler w/AEC	1,710,000	19.4	19.7	23.4	23.5	8.8

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$; 1-hour average existing conditions are biased low (Felton 2009).

Table E-25. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Large School Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150	40	40	10
Stoker Chip Boiler	7,130,000	150	150	40	40	10
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	150	150	40	40	10
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150	40	40	10
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150	40	40	10
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	See notes	See notes	40	40	40
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	See notes	See notes	40	40	40
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	40	150	40	40	10
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150	40	40	10
Condensing Pellet Boiler w/AEC	1,710,000	40	150	40	40	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures; RHNY-qualified pellet boilers were not assessed for 1-hr $PM_{2.5}$.

Table E-26. Predicted NO_2 Concentrations for Large School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m^3)			
		Tier 1 (100% of NOx is NO_2)		Tier 2	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	53	53	42	42
Stoker Chip Boiler	7,130,000	96	111	77	88
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	132	153	106	123
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	128	160	103	128
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	97	116	77	93
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	66	66	53	53
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	18	18	2	2
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	69	95	56	76
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	69	93	55	75
Condensing Pellet Boiler w/AEC	1,710,000	60	69	48	55

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter.

Table E-27. Predicted NO_2 Concentrations for Large School Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*110*	*110*	*110*	*110*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	163	163	152	152
Stoker Chip Boiler	7,130,000	206	221	187	198
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	243	263	216	233
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	238	270	213	238
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	207	226	188	203
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	176	176	163	163
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	128	128	112	112
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	180	205	166	186
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	179	203	165	185
Condensing Pellet Boiler w/AEC	1,710,000	170	179	158	165

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest microgram per cubic meter; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; applied emission factors based on both European testing data (Musil-Schlaffer 2010) and the Wild Center (Hopke 2010) for the RHNY-qualified 2-stage gasification pellet boiler; Tier 2 analysis assumes 80 percent of NO_x is NO_2, except for the RHNY-qualified 2-stage gasification pellet boiler using the emission factor from Hopke (2010), which assumes 12 percent conversion based on the testing data; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-28. Distance from Source for Maximum NO_2 Concentrations for Large School Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	150	150
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	150	150
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Commercial Installation	1,430,000	50	50
RHNY-Qualified 2-Stage Gasification Pellet Boiler, Institutional Installation	1,430,000	50	50
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	40	150
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	40	150
Condensing Pellet Boiler w/AEC	1,710,000	40	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; for technologies modeled at the large school, only the RHNY-qualified 2-stage gasification pellet boiler includes thermal storage; unit sizes are reported to three significant figures.

Table E-29. Predicted VOC Concentrations for Large School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	0.15
Stoker Chip Boiler	7,130,000	0.84
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.33
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	0.32
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	0.37
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.20
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	0.20
Condensing Pellet Boiler w/AEC	1,710,000	0.22

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the large school analysis for VOC incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-30. Distance from Source for Maximum VOC Concentrations for Large School Setting – Flat Terrain, High Density

"Business as usual" technologies	Unit Size (Btu)	Distance (m) Annual: Typical
Oil Boiler Using Ultra-Low Sulfur Heating Oil	4,040,000	10
Stoker Chip Boiler	7,130,000	10
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	10
Advanced Chip Boiler w/AEC Using 30% Moisture Chips	5,120,000	10
2-Stage Gasification Pellet Boiler, No Storage	5,120,000	10
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	10
Condensing Chip Boiler w/AEC Using 30% Moisture Chips	1,710,000	10
Condensing Pellet Boiler w/AEC	1,710,000	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight unless otherwise noted; no technologies modeled for the large school analysis for VOC incorporated thermal storage; unit sizes are reported to three significant figures.

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Table E-31. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	3,390,000	75.6*	136.0*	9.7*	14.8*	0.9*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	44.8	59.3	13.7	16.3	2.4
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	26.7	27.7	4.3	5.6	1.0
2-Stage Gasification Pellet Boiler	3,410,000	12.3	23.1	2.8	2.6	0.3
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	0.5	0.9	0.1	0.2	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-32. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m^3)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*22.0*	*22.0*	*15.0*	*15.0*	*4.3*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	22.0	22.0	15.0	15.0	4.3
Stoker Chip Boiler	3,390,000	97.6*	158*	24.7*	29.8*	5.2*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	66.8	81.3	28.7	31.3	6.7
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	48.7	49.7	19.3	20.6	5.3
2-Stage Gasification Pellet Boiler	3,410,000	34.3	45.1	17.8	17.6	4.6
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	22.5	22.9	15.1	15.2	4.3

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-33. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Small School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	200	200	100	100	80
Stoker Chip Boiler	3,390,000	200	200	80	80	80
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10	10	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	150	200	100	100	100
2-Stage Gasification Pellet Boiler	3,410,000	100	200	100	80	100
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	100	100	100	100	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-34. Predicted CO Concentrations for Small School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.0	0.0	0.0	0.0
Stoker Chip Boiler	3,390,000	0.4*	0.1*	0.1*	0.0*
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	0.2	0.3	0.1	0.2
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	0.1	0.1	0.0	0.1
2-Stage Gasification Pellet Boiler	3,410,000	0.1	0.1	0.0	0.0
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	0.0	0.0	0.0	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-35. Predicted CO Concentrations for Small School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**Concentration (µg/m³)**			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
Existing Conditions		*1.1*	*1.1*	*0.7*	*0.7*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	3,390,000	1.5*	1.2*	0.8*	0.7*
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	1.3	1.4	0.8	0.9
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	1.2	1.2	0.7	0.8
2-Stage Gasification Pellet Boiler	3,410,000	1.2	1.2	0.7	0.7
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	1.1	1.1	0.7	0.7

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-36. Distance from Source for Maximum CO Concentrations for Small School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)			
		1-hour		8-hour	
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	200	200	100	100
Stoker Chip Boiler	3,390,000	200	200	100	100
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	150	200	100	90
2-Stage Gasification Pellet Boiler	3,410,000	100	200	100	100
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	100	100	100	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the large school analysis for CO incorporated thermal storage; unit sizes are reported to three significant figures; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-37. Predicted NO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	25	25	20	20
Stoker Chip Boiler	3,390,000	55	45	44	36
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	256	343	205	275
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	95	136	76	109
2-Stage Gasification Pellet Boiler	3,410,000	70	71	56	57
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	32	49	25	39

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-38. Predicted NO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m^3) Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*33*	*33*	*33*	*33*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	58	58	53	53
Stoker Chip Boiler	3,390,000	88	78	77	69
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	289	376	238	308
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	129	169	109	142
2-Stage Gasification Pellet Boiler	3,410,000	103	104	89	90
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	65	82	58	72

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-39. Distance from Source for Maximum NO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	100	100
Stoker Chip Boiler	3,390,000	100	100
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	90	90
2-Stage Gasification Pellet Boiler	3,410,000	100	100
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	100	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-40. Predicted SO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** 1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0	0
Stoker Chip Boiler	3,390,000	7	7
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	21	29
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	8	12
2-Stage Gasification Pellet Boiler	3,410,000	6	6
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	3	4

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-41. Predicted SO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** 1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
Existing Conditions		*10*	*10*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	10	10
Stoker Chip Boiler	3,390,000	17	17
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	32	39
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	18	22
2-Stage Gasification Pellet Boiler	3,410,000	16	16
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	13	14

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-42. Distance from Source for Maximum SO_2 Concentrations for Small School Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	200	200
Stoker Chip Boiler	3,390,000	200	200
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	150	200
2-Stage Gasification Pellet Boiler	3,410,000	100	200
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	100	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-43. Predicted VOC Concentrations for Small School Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³) Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.02
Stoker Chip Boiler	3,390,000	0.19
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	0.80
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	0.33
2-Stage Gasification Pellet Boiler	3,410,000	0.09
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	0.05

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-44. Distance from Source for Maximum VOC Concentrations for Small School Setting – Mountainous Terrain, Low Density

"Business as usual" technologies	Unit Size (Btu)	Distance (m) Annual: Typical
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	80
Stoker Chip Boiler	3,390,000	80
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	100
2-Stage Gasification Pellet Boiler	3,410,000	100
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.5 Small School – Small Town in Mid-New York

Table E-45. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	3,390,000	55.2*	73.1*	11.1*	20.1*	1.5*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	45.2	58.7	14.2	18.4	2.6
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	17.7	26.3	3.0	5.0	0.7
2-Stage Gasification Pellet Boiler	3,410,000	13.8	14.5	2.3	3.3	0.3
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	0.6	0.9	0.1	0.1	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-46. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*21.2*	*21.2*	*20.0*	*20.0*	*7.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	21.2	21.2	20.0	20.0	7.0
Stoker Chip Boiler	3,390,000	76.4*	94.3*	31.1*	40.1*	8.5*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	66.4	79.9	34.2	38.4	9.6
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	38.9	47.5	23.0	25.0	7.7
2-Stage Gasification Pellet Boiler	3,410,000	35.0	35.7	22.3	23.3	7.3
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	21.8	22.1	20.1	20.1	7.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-47. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Small School Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	100	100	70	70	70
Stoker Chip Boiler	3,390,000	100	100	70	70	70
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10	10	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	90	90	30	90	90
2-Stage Gasification Pellet Boiler	3,410,000	100	100	70	70	70
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	100	100	70	70	70

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-48. Predicted NO_2 Concentrations for Small School Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	24	24	19	19
Stoker Chip Boiler	3,390,000	53	45	42	36
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	256	337	204	270
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	92	142	73	113
2-Stage Gasification Pellet Boiler	3,410,000	67	67	54	54
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	30	48	24	38

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-49. Predicted NO_2 Concentrations for Small School Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m^3)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*79*	*79*	*79*	*79*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	103	103	98	98
Stoker Chip Boiler	3,390,000	132	124	121	115
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	335	416	283	349
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	171	221	152	192
2-Stage Gasification Pellet Boiler	3,410,000	146	146	133	133
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	109	127	103	117

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-50. Distance from Source for Maximum NO_2 Concentrations for Small School Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	100	100
Stoker Chip Boiler	3,390,000	100	100
"Best available" technologies			
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	90	90
2-Stage Gasification Pellet Boiler	3,410,000	100	100
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	100	100

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-51. Predicted VOC Concentrations for Small School Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.04
Stoker Chip Boiler	3,390,000	0.30
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	0.89
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	0.24
2-Stage Gasification Pellet Boiler	3,410,000	0.11
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	0.04

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-52. Distance from Source for Maximum VOC Concentrations for Small School Setting – Valley Terrain, Low Density

		Distance (m)
		Annual: Typical
"Business as usual" technologies	Unit Size (Btu)	
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	70
Stoker Chip Boiler	3,390,000	70
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	90
2-Stage Gasification Pellet Boiler	3,410,000	70
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	70

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.6 Small School – Populated Area in Mid-New York

Table E-53. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	3,390,000	42.7*	64.9*	7.1*	13.4*	0.9*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	46.8	62.0	18.5	25.2	2.6
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	20.4	31.0	2.3	3.8	0.3
2-Stage Gasification Pellet Boiler	3,410,000	10.4	11.5	1.6	2.1	0.2
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	0.5	0.7	0.1	0.1	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-54. Predicted $PM_{2.5}$ Concentrations for Small School Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*18.2*	*18.2*	*23.0*	*23.0*	*8.7*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	18.2	18.2	23.0	23.0	8.7
Stoker Chip Boiler	3,390,000	60.9*	83.1*	30.1*	36.4*	9.6*
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	65.0	80.2	41.5	48.2	11.3
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	38.6	49.2	25.3	26.8	9.0
2-Stage Gasification Pellet Boiler	3,410,000	28.6	29.7	24.6	25.1	8.9
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	18.7	18.9	23.1	23.1	8.7

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-55. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Small School Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	100	100	70	70	40
Stoker Chip Boiler	3,390,000	100	100	70	40	40
"Best available" technologies						
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10	10	10	10	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	90	90	90	90	70
2-Stage Gasification Pellet Boiler	3,410,000	100	100	70	40	40
"Next best" technologies						
Condensing Pellet Boiler w/AEC	1,020,000	70	100	70	70	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-56. Predicted NO_2 Concentrations for Small School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m^3)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	17	17	13	13
Stoker Chip Boiler	3,390,000	38	37	30	29
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	266	352	213	282
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	98	147	78	117
2-Stage Gasification Pellet Boiler	3,410,000	46	49	37	40
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	22	34	18	27

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-57. Predicted NO_2 Concentrations for Small School Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (μg/m³)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*110*	*110*	*110*	*110*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	127	127	123	123
Stoker Chip Boiler	3,390,000	148	147	140	139
"Best available" technologies					
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	376	462	323	392
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	208	257	188	228
2-Stage Gasification Pellet Boiler	3,410,000	156	160	147	150
"Next best" technologies					
Condensing Pellet Boiler w/AEC	1,020,000	133	144	128	137

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-58. Distance from Source for Maximum NO_2 Concentrations for Small School Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	100	100
Stoker Chip Boiler	3,390,000	100	70
"Best available" technologies			
Containerized Pellet Boiler w/14' Stack	1,710,000	10	10
Containerized Pellet Boiler w/25' Stack	1,710,000	90	90
Pellet Boiler	3,410,000	100	100
"Next best" technologies			
Condensing Pellet Boiler w/AEC	1,020,000	70	70

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-59. Predicted VOC Concentrations for Small School Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Concentration ($\mu g/m^3$) Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	0.02
Stoker Chip Boiler	3,390,000	0.18
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	0.89
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	0.09
2-Stage Gasification Pellet Boiler	3,410,000	0.07
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	0.03

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-60. Distance from Source for Maximum VOC Concentrations for Small School Setting – Flat Terrain, High Density

"Business as usual" technologies	Unit Size (Btu)	Distance (m) Annual: Typical
Oil Boiler Using Ultra-Low Sulfur Heating Oil	1,920,000	40
Stoker Chip Boiler	3,390,000	40
"Best available" technologies		
Containerized 2-Stage Gasification Pellet Boiler w/14' Stack	1,710,000	10
Containerized 2-Stage Gasification Pellet Boiler w/25' Stack	1,710,000	70
2-Stage Gasification Pellet Boiler	3,410,000	40
"Next best" technologies		
Condensing Pellet Boiler w/AEC	1,020,000	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the small school analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.7 Hospital – Small Town in Upper New York

Table E-61. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m^3)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	84.6*	144.9*	19.6*	33.6*	7.0*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	24.8	26.3	5.8	6.0	2.2
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.3	1.7	0.3	0.4	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-62. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*22.0*	*22.0*	*15.0*	*15.0*	*4.3*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	22.0	22.0	15.0	15.0	4.3
Stoker Chip Boiler	7,130,000	106.6*	166.9*	34.6*	48.6*	11.3*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	46.8	48.3	20.8	21.0	6.5
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	23.3	23.7	15.3	15.4	4.4

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-63. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Hospital Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150	50	50	50
Stoker Chip Boiler	7,130,000	150	150	50	50	50
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	150	150	50	50	50
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	30	150	40	50	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-64. Predicted CO Concentrations for Hospital Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	0.4*	0.1*	0.2*	0.0*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	0.1	0.1	0.1	0.1
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	0.0	0.0	0.0	0.0

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-65. Predicted CO Concentrations for Hospital Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (ppm)			
		1-hour		8-hour	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*35*	*35*	*9*	*9*
Existing Conditions		*1.1*	*1.1*	*0.7*	*0.7*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	1.1	1.1	0.7	0.7
Stoker Chip Boiler	7,130,000	1.5*	1.2*	0.9*	0.7*
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	1.2	1.2	0.8	0.8
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	1.1	1.1	0.7	0.7

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-66. Distance from Source for Maximum CO Concentrations for Hospital Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)			
		1-hour		8-hour	
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150	150	150
Stoker Chip Boiler	7,130,000	150	150	150	150
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	150	150	150	150
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	30	150	150	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-67. Predicted NO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m³)**			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	33	33	26	26
Stoker Chip Boiler	7,130,000	83	83	66	66
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	125	123	100	98
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	59	90	47	72

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-68. Predicted NO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	1-Hour Concentration (µg/m^3)			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*33*	*33*	*33*	*33*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	66	66	59	59
Stoker Chip Boiler	7,130,000	116	116	99	99
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	159	156	133	131
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	92	123	80	105

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-69. Distance from Source for Maximum NO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	150	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-70. Predicted SO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** 1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0	0
Stoker Chip Boiler	7,130,000	11	11
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	8	8
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	4	6

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-71. Predicted SO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**Concentration (µg/m^3)**	
		1-hour	
T=Typical, M=Maximum		T	M
Applicable Air Quality Standard		*196*	*196*
Existing Conditions		*10*	*10*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	11	11
Stoker Chip Boiler	7,130,000	21	21
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	18	18
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	14	16

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-72. Distance from Source for Maximum SO_2 Concentrations for Hospital Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Distance (m) 1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	30	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-73. Predicted VOC Concentrations for Hospital Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.16
Stoker Chip Boiler	7,130,000	1.43
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.56
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.28

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-74. Distance from Source for Maximum VOC Concentrations for Hospital Setting – Mountainous Terrain, Low Density

		Distance (m)
		Annual: Typical
"Business as usual" technologies	**Unit Size (Btu)**	
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	50
Stoker Chip Boiler	7,130,000	50
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	50
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.8 Hospital – Small Town in Mid-New York

Table E-75. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	81.3*	135.9*	16.3*	32.1*	4.3*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	23.8	24.9	4.8	5.4	1.4
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.1	1.6	0.2	0.4	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-76. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m^3)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*21.2*	*21.2*	*20.0*	*20.0*	*7.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	21.2	21.2	20.0	20.0	7.0
Stoker Chip Boiler	7,130,000	102.5*	157.1*	36.3*	52.1*	11.3*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	45.0	46.1	24.8	25.4	8.4
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	22.3	22.8	20.2	20.4	7.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-77. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Hospital Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150	40	40	10
Stoker Chip Boiler	7,130,000	150	150	150	150	10
"Best available" technologies						
Advanced Chip Stoker Boiler w/AEC	5,120,000	150	150	40	150	10
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	30	150	40	40	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-78. Predicted NO_2 Concentrations for Hospital Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m³)** Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	31	31	25	25
Stoker Chip Boiler	7,130,000	82	88	65	70
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	112	126	90	100
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	44	75	36	60

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-79. Predicted NO_2 Concentrations for Hospital Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m³)** Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*33*	*33*	*33*	*33*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	64	64	58	58
Stoker Chip Boiler	7,130,000	115	121	98	103
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	145	159	123	133
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	77	108	69	93

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-80. Distance from Source for Maximum NO_2 Concentrations for Hospital Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	150	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-81. Predicted VOC Concentrations for Hospital Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.10
Stoker Chip Boiler	7,130,000	0.88
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.35
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.20

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-82. Distance from Source for Maximum VOC Concentrations for Hospital Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Distance (m)
		Annual: Typical
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	10
Stoker Chip Boiler	7,130,000	10
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	10
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	10

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.9 Hospital – Populated Area in Mid-New York

Table E-83. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (μg/m³)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.0	0.0	0.0	0.0	0.0
Stoker Chip Boiler	7,130,000	80.6*	136.6*	15.1*	26.7*	4.8*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	24.2	25.1	5.2	4.6	1.6
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	1.0	1.6	0.3	0.4	0.1

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-84. Predicted $PM_{2.5}$ Concentrations for Hospital Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	Concentration (µg/m^3)				
		1-hour		24-hour		Annual
T=Typical, M=Maximum		T	M	T	M	
Applicable Air Quality Standard		*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions		*18.2*	*18.2*	*23.0*	*23.0*	*8.7*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	18.2	18.2	23.0	23.0	8.7
Stoker Chip Boiler	7,130,000	98.8*	154.8*	38.1*	49.7*	13.5*
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	42.4	43.3	28.2	27.6	10.3
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	19.2	19.8	23.3	23.4	8.8

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-85. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Hospital Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)				
		1-hour		24-hour		Annual
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150	40	40	40
Stoker Chip Boiler	7,130,000	150	150	40	50	50
"Best available" technologies						
Advanced Chip Boiler w/AEC	5,120,000	150	150	40	50	40
"Next best" technologies						
Condensing Chip Boiler w/AEC	1,710,000	150	150	40	40	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-86. Predicted NO_2 Concentrations for Hospital Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m³)**			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	31	31	25	25
Stoker Chip Boiler	7,130,000	81	88	65	70
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	113	124	90	100
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	48	77	39	61

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-87. Predicted NO_2 Concentrations for Hospital Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	**1-Hour Concentration (µg/m^3)**			
		Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum		T	M	T	M
Applicable Air Quality Standard		*188*	*188*	*188*	*188*
Existing Conditions		*110*	*110*	*110*	*110*
"Business as usual" technologies					
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	141	141	135	135
Stoker Chip Boiler	7,130,000	191	198	175	180
"Best available" technologies					
Advanced Chip Boiler w/AEC	5,120,000	223	234	200	210
"Next best" technologies					
Condensing Chip Boiler w/AEC	1,710,000	158	187	149	171

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-88. Distance from Source for Maximum NO_2 Concentrations for Hospital Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)	
		1-hour	
T=Typical, M=Maximum		T	M
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	150	150
Stoker Chip Boiler	7,130,000	150	150
"Best available" technologies			
Advanced Chip Boiler w/AEC	5,120,000	150	150
"Next best" technologies			
Condensing Chip Boiler w/AEC	1,710,000	150	150

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-89. Predicted VOC Concentrations for Hospital Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Concentration (μg/m³) Annual: Typical
Applicable Air Quality Standard		*None*
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	0.11
Stoker Chip Boiler	7,130,000	0.98
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	0.42
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	0.24

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; values rounded to the nearest 0.01 microgram per cubic meter; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

Table E-90. Distance from Source for Maximum VOC Concentrations for Hospital Setting – Flat Terrain, High Density

	Unit Size (Btu)	Distance (m)
		Annual: Typical
"Business as usual" technologies		
Oil Boiler Using Ultra-Low Sulfur Heating Oil	3,370,000	40
Stoker Chip Boiler	7,130,000	50
"Best available" technologies		
Advanced Chip Boiler w/AEC	5,120,000	40
"Next best" technologies		
Condensing Chip Boiler w/AEC	1,710,000	40

Notes: AEC=advanced emission controls (baghouse, electrostatic precipitator); chips are 45% moisture by weight; no technologies modeled for the hospital analysis incorporated thermal storage; unit sizes are reported to three significant figures.

E.10 Residential – Small Town in Upper New York

Table E-91. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (µg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.0	0.0	0.0	0.0	0.0
Phase II Outdoor Cordwood Boiler	208,000	No	89.3*	239.1*	32.9*	91.7*	1.7*
Pellet Boiler, No Storage	109,000	No	5.4	6.4	2.0	2.9	0.8
Non-USEPA Certified Cordwood Stove	51,200	No	33.4	61.7	20.3	37.8	6.2
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	22.1	44.3	13.3	26.5	4.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	22.2	41.2	13.5	25.2	4.1
Pellet Stove	60,000	No	9.5	15.3	5.5	9.1	1.7
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	79.1*	79.1*	2.3*	6.8*	2.1*
Pellet Boiler, With Storage	109,000	Yes	3.8	3.8	0.2	0.7	0.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2.1	3.0	0.9	1.5	0.3
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	3.7	3.6	1.0	1.3	0.4
Condensing Pellet Boiler, No Storage	85,300	No	0.4	0.5	0.1	0.2	0.0
Condensing Pellet Boiler, With Storage	85,300	Yes	0.5	0.5	0.0	0.1	0.0
Advanced Cordwood Stove w/AEC	51,200	No	0.5	0.7	0.2	0.4	0.1

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; “uncertified cordwood stoves” include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-92. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (μg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions			*22.0*	*22.0*	*15.0*	*15.0*	*4.3*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	22.0	22.0	15.0	15.0	4.3
Phase II Outdoor Cordwood Boiler	208,000	No	111.3*	261.1*	47.9*	106.7*	6*
Pellet Boiler, No Storage	109,000	No	27.4	28.4	17.0	17.9	5.1
Non-USEPA Certified Cordwood Stove	51,200	No	55.4	83.7	35.3	52.8	10.5
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	44.1	66.3	28.3	41.5	8.4
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	44.2	63.2	28.5	40.2	8.4
Pellet Stove	60,000	No	31.5	37.3	20.5	24.1	6.0
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	101.1*	101.1*	17.3*	21.8*	6.4*
Pellet Boiler, With Storage	109,000	Yes	25.8	25.8	15.2	15.7	4.4
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	24.1	25.0	15.9	16.5	4.6
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	25.7	25.6	16.0	16.3	4.7
Condensing Pellet Boiler, No Storage	85,300	No	22.4	22.5	15.1	15.2	4.3
Condensing Pellet Boiler, With Storage	85,300	Yes	22.5	22.5	15.0	15.1	4.3
Advanced Cordwood Stove w/AEC	51,200	No	22.5	22.7	15.2	15.4	4.4

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-93. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Residential Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m)				
			1-hour		24-hour		Annual
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20	10	10	10
Phase II Outdoor Cordwood Boiler	208,000	No	30	30	30	30	40
Pellet Boiler, No Storage	109,000	No	20	20	10	10	10
Non-USEPA Certified Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
Pellet Stove	60,000	No	20	20	10	10	10
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20	10	10	10
Pellet Boiler, With Storage	109,000	Yes	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	20	20	10	10	10
Condensing Pellet Boiler, No Storage	85,300	No	20	20	10	10	10
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20	10	10	10
Advanced Cordwood Stove w/AEC	51,200	No	20	20	10	10	10

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-94. Predicted CO Concentrations for Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (ppm)			
			1-hour		8-hour	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*35*	*35*	*9*	*9*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.0	0.0	0.0	0.0
Phase II Outdoor Cordwood Boiler	208,000	No	0.1*	0.3*	0.1*	0.2*
Pellet Boiler, No Storage	109,000	No	0.2	0.2	0.1	0.1
Non-USEPA Certified Cordwood Stove	51,200	No	0.2	0.4	0.2	0.3
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	0.1	0.3	0.1	0.2
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.1	0.2	0.1	0.1
Pellet Stove	60,000	No	0.1	0.1	0.1	0.1
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	3.1*	3.1*	0.3*	0.3*
Pellet Boiler, With Storage	109,000	Yes	0.0	0.0	0.0	0.0
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.1	0.1	0.0	0.1
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	0.0	0.0	0.0	0.0
Condensing Pellet Boiler, No Storage	85,300	No	0.0	0.0	0.0	0.0
Condensing Pellet Boiler, With Storage	85,300	Yes	0.0	0.0	0.0	0.0
Advanced Cordwood Stove w/AEC	51,200	No	0.0	0.1	0.0	0.0

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-95. Predicted CO Concentrations for Residential Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (ppm)			
			1-hour		8-hour	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*35*	*35*	*9*	*9*
Existing Conditions			*1.1*	*1.1*	*0.7*	*0.7*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	1.1	1.1	0.7	0.7
Phase II Outdoor Cordwood Boiler	208,000	No	1.2*	1.4*	0.8*	0.9*
Pellet Boiler, No Storage	109,000	No	1.3	1.3	0.8	0.8
Non-USEPA Certified Cordwood Stove	51,200	No	1.3	1.5	0.9	1
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	1.2	1.4	0.8	0.9
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	1.2	1.3	0.8	0.8
Pellet Stove	60,000	No	1.2	1.2	0.8	0.8
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	4.2*	4.2*	1*	1*
Pellet Boiler, With Storage	109,000	Yes	1.1	1.1	0.7	0.7
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	1.2	1.2	0.7	0.8
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	1.1	1.1	0.7	0.7
Condensing Pellet Boiler, No Storage	85,300	No	1.1	1.1	0.7	0.7
Condensing Pellet Boiler, With Storage	85,300	Yes	1.1	1.1	0.7	0.7
Advanced Cordwood Stove w/AEC	51,200	No	1.1	1.2	0.7	0.7

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.1 ppm; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; “uncertified cordwood stoves” include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-96. Distance from Source for Maximum CO Concentrations for Residential Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m)			
			1-hour		8-hour	
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20	20	20
Phase II Outdoor Cordwood Boiler	208,000	No	30	30	30	30
Pellet Boiler, No Storage	109,000	No	20	20	20	20
Non-USEPA Certified Cordwood Stove	51,200	No	20	20	20	20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	20	20
Pellet Stove	60,000	No	20	20	20	20
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20	20	20
Pellet Boiler, With Storage	109,000	Yes	20	20	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	20
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	20	20	20	20
Condensing Pellet Boiler, No Storage	85,300	No	20	20	20	20
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20	20	20
Advanced Cordwood Stove w/AEC	51,200	No	20	20	10	20

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-97. Predicted NO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**1-Hour Concentration (µg/m³)**			
			Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	18	18	14	14
Phase II Outdoor Cordwood Boiler	208,000	No	16	22	13	18
Pellet Boiler, No Storage	109,000	No	22	27	18	21
Non-USEPA Certified Cordwood Stove	51,200	No	3	5	2	4
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2	4	2	3
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2	4	2	3
Pellet Stove	60,000	No	28	45	23	36
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	29	29	23	23
Pellet Boiler, With Storage	109,000	Yes	30	30	24	24
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	7	9	5	7
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	32	33	25	27
Condensing Pellet Boiler, No Storage	85,300	No	26	30	21	24
Condensing Pellet Boiler, With Storage	85,300	Yes	32	32	26	26
Advanced Cordwood Stove w/AEC	51,200	No	7	10	5	8

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-98. Predicted NO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**1-Hour Concentration (μg/m^3)** Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
Existing Conditions			*33*	*33*	*33*	*33*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	51	51	47	47
Phase II Outdoor Cordwood Boiler	208,000	No	49	55	46	51
Pellet Boiler, No Storage	109,000	No	55	60	51	54
Non-USEPA Certified Cordwood Stove	51,200	No	36	38	35	37
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	35	37	35	36
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	35	37	35	36
Pellet Stove	60,000	No	62	79	56	69
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	62	62	56	56
Pellet Boiler, With Storage	109,000	Yes	63	63	57	57
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	40	42	38	41
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	65	66	58	60
Condensing Pellet Boiler, No Storage	85,300	No	59	63	54	57
Condensing Pellet Boiler, With Storage	85,300	Yes	65	65	59	59
Advanced Cordwood Stove w/AEC	51,200	No	40	43	38	41

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; “uncertified cordwood stoves” include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-99. Distance from Source for Maximum NO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m) 1-hour	
T=Typical, M=Maximum			T	M
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20
Phase II Outdoor Cordwood Boiler	208,000	No	30	30
Pellet Boiler, No Storage	109,000	No	20	20
Non-USEPA Certified Cordwood Stove	51,200	No	20	20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
Pellet Stove	60,000	No	20	20
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20
Pellet Boiler, With Storage	109,000	Yes	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20
Advanced Cordwood Stove w/AEC	51,200	No	20	20

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-100. Predicted SO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration (µg/m³)** 1-hour	
T=Typical, M=Maximum			T	M
Applicable Air Quality Standard			*196*	*196*
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0	0
Phase II Outdoor Cordwood Boiler	208,000	No	18	25
Pellet Boiler, No Storage	109,000	No	3	4
Non-USEPA Certified Cordwood Stove	51,200	No	0	1
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	0	1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0	1
Pellet Stove	60,000	No	1	1
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	5	5
Pellet Boiler, With Storage	109,000	Yes	5	5
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	1	2
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	6	6
Condensing Pellet Boiler, No Storage	85,300	No	4	5
Condensing Pellet Boiler, With Storage	85,300	Yes	5	5
Advanced Cordwood Stove w/AEC	51,200	No	1	2

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-101. Predicted SO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration (µg/m³)** 1-hour	
T=Typical, M=Maximum			T	M
Applicable Air Quality Standard			*196*	*196*
Existing Conditions			*10*	*10*
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10	10
Phase II Outdoor Cordwood Boiler	208,000	No	29	35
Pellet Boiler, No Storage	109,000	No	13	14
Non-USEPA Certified Cordwood Stove	51,200	No	10	11
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	10	11
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10	11
Pellet Stove	60,000	No	11	11
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	15	15
Pellet Boiler, With Storage	109,000	Yes	15	15
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	11	12
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	16	16
Condensing Pellet Boiler, No Storage	85,300	No	14	15
Condensing Pellet Boiler, With Storage	85,300	Yes	15	15
Advanced Cordwood Stove w/AEC	51,200	No	11	12

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-102. Distance from Source for Maximum SO_2 Concentrations for Residential Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m) 1-hour	
T=Typical, M=Maximum			T	M
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20
Phase II Outdoor Cordwood Boiler	208,000	No	30	30
Pellet Boiler, No Storage	109,000	No	20	20
Non-USEPA Certified Cordwood Stove	51,200	No	20	20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
Pellet Stove	60,000	No	20	20
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20
Pellet Boiler, With Storage	109,000	Yes	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20
Advanced Cordwood Stove w/AEC	51,200	No	20	20

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-103. Predicted VOC Concentrations for Residential Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard			*None*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.20
Phase II Outdoor Cordwood Boiler	208,000	No	4.64
Pellet Boiler, No Storage	109,000	No	1.47
Non-USEPA Certified Cordwood Stove	51,200	No	10.76
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2.48
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	3.05
Pellet Stove	60,000	No	0.02
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	0.46
Pellet Boiler, With Storage	109,000	Yes	0.22
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.34
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	0.30
Condensing Pellet Boiler, No Storage	85,300	No	0.11
Condensing Pellet Boiler, With Storage	85,300	Yes	0.18
Advanced Cordwood Stove w/AEC	51,200	No	0.34

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.01 microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-104. Distance from Source for Maximum VOC Concentrations for Residential Setting – Mountainous Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	**Distance (m)** Annual: Typical
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10
Phase II Outdoor Cordwood Boiler	208,000	No	40
Pellet Boiler, No Storage	109,000	No	10
Non-USEPA Certified Cordwood Stove	51,200	No	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
Pellet Stove	60,000	No	10
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	10
Pellet Boiler, With Storage	109,000	Yes	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, With Storage	85,300	Yes	10
Advanced Cordwood Stove w/AEC	51,200	No	10

Notes: AEC=advanced emission controls (electrostatic precipitator); “uncertified cordwood stoves” include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

E.11 Residential – Small Town in Mid-New York

Table E-105. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration (µg/m³)**				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.0	0.0	0.0	0.0	0.0
Phase II Outdoor Cordwood Boiler	208,000	No	89.9*	238.5*	23.6*	67.3*	5.3*
Pellet Boiler, No Storage	109,000	No	5.0	6.2	1.6	2.4	0.5
Non-USEPA Certified Cordwood Stove	51,200	No	31.7	58.2	18.7	35.2	4.7
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20.8	41.6	12.2	24.4	3.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	21.2	38.8	12.5	23.4	3.2
Pellet Stove	60,000	No	8.9	14.3	5.1	8.4	1.7
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	72.7*	72.7*	1.9*	5.8*	1.3*
Pellet Boiler, With Storage	109,000	Yes	3.7	3.7	0.2	0.6	0.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2.0	2.9	0.7	1.3	0.2
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	3.7	3.4	0.7	1.1	0.0
Condensing Pellet Boiler, No Storage	85,300	No	0.4	0.4	0.1	0.1	0.0
Condensing Pellet Boiler, With Storage	85,300	Yes	0.5	0.5	0.0	0.1	0.0
Advanced Cordwood Stove w/AEC	51,200	No	0.5	0.7	0.2	0.3	0.0

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-106. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (µg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions			*21.2*	*21.2*	*20.0*	*20.0*	*7.0*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	21.2	21.2	20.0	20.0	7.0
Phase II Outdoor Cordwood Boiler	208,000	No	111.1*	259.7*	43.6*	87.3*	12.3*
Pellet Boiler, No Storage	109,000	No	26.2	27.4	21.6	22.4	7.5
Non-USEPA Certified Cordwood Stove	51,200	No	52.9	79.4	38.7	55.2	11.7
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	42.0	62.8	32.2	44.4	10.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	42.4	60.0	32.5	43.4	10.2
Pellet Stove	60,000	No	30.1	35.5	25.1	28.4	8.7
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	93.9*	93.9*	21.9*	25.8*	8.3*
Pellet Boiler, With Storage	109,000	Yes	24.9	24.9	20.2	20.6	7.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	23.2	24.1	20.7	21.3	7.2
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	24.9	24.6	20.7	21.1	7.0
Condensing Pellet Boiler, No Storage	85,300	No	21.6	21.6	20.1	20.1	7.0
Condensing Pellet Boiler, With Storage	85,300	Yes	21.7	21.7	20.0	20.1	7.0
Advanced Cordwood Stove w/AEC	51,200	No	21.7	21.9	20.2	20.3	7.0

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-107. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Residential Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m)				
			1-hour		24-hour		Annual
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20	10	10	10
Phase II Outdoor Cordwood Boiler	208,000	No	30	30	30	30	30
Pellet Boiler, No Storage	109,000	No	20	20	10	10	10
Non-USEPA Certified Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
Pellet Stove	60,000	No	20	20	10	10	10
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20	10	10	10
Pellet Boiler, With Storage	109,000	Yes	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	20	20	10	10	10
Condensing Pellet Boiler, No Storage	85,300	No	10	20	10	10	10
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20	10	10	10
Advanced Cordwood Stove w/AEC	51,200	No	20	20	10	10	10

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-108. Predicted NO_2 Concentrations for Residential Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	1-Hour Concentration (μg/m³)			
			Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	17	17	14	14
Phase II Outdoor Cordwood Boiler	208,000	No	16	21	12	17
Pellet Boiler, No Storage	109,000	No	19	25	15	20
Non-USEPA Certified Cordwood Stove	51,200	No	3	5	2	4
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2	4	2	3
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2	4	2	3
Pellet Stove	60,000	No	28	44	22	35
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	27	27	22	22
Pellet Boiler, With Storage	109,000	Yes	28	28	23	23
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	6	9	5	7
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	17	21	14	17
Condensing Pellet Boiler, No Storage	85,300	No	19	25	15	20
Condensing Pellet Boiler, With Storage	85,300	Yes	27	27	22	22
Advanced Cordwood Stove w/AEC	51,200	No	6	9	5	8

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-109. Predicted NO_2 Concentrations for Residential Setting – Valley Terrain, Low Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	1-Hour Concentration (µg/m³)			
			Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
Existing Conditions			*33*	*33*	*33*	*33*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	50	50	47	47
Phase II Outdoor Cordwood Boiler	208,000	No	49	54	46	50
Pellet Boiler, No Storage	109,000	No	52	58	48	53
Non-USEPA Certified Cordwood Stove	51,200	No	36	38	35	37
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	35	37	35	36
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	35	37	35	36
Pellet Stove	60,000	No	61	77	55	68
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	60	60	55	55
Pellet Boiler, With Storage	109,000	Yes	62	62	56	56
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	39	42	38	40
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	50	54	47	50
Condensing Pellet Boiler, No Storage	85,300	No	52	58	49	53
Condensing Pellet Boiler, With Storage	85,300	Yes	60	60	55	55
Advanced Cordwood Stove w/AEC	51,200	No	39	42	38	41

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-110. Distance from Source for Maximum NO_2 Concentrations for Residential Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	Distance (m) 1-hour	
T=Typical, M=Maximum			T	M
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20
Phase II Outdoor Cordwood Boiler	208,000	No	30	30
Pellet Boiler, No Storage	109,000	No	20	20
Non-USEPA Certified Cordwood Stove	51,200	No	20	20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
Pellet Stove	60,000	No	20	20
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20
Pellet Boiler, With Storage	109,000	Yes	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, No Storage	85,300	No	10	20
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20
Advanced Cordwood Stove w/AEC	51,200	No	20	20

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-111. Predicted VOC Concentrations for Residential Setting – Valley Terrain, Low Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard			*None*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.13
Phase II Outdoor Cordwood Boiler	208,000	No	14.27
Pellet Boiler, No Storage	109,000	No	0.88
Non-USEPA Certified Cordwood Stove	51,200	No	8.20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	1.88
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2.32
Pellet Stove	60,000	No	0.02
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	0.30
Pellet Boiler, With Storage	109,000	Yes	0.14
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.21
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	0.00
Condensing Pellet Boiler, No Storage	85,300	No	0.06
Condensing Pellet Boiler, With Storage	85,300	Yes	0.11
Advanced Cordwood Stove w/AEC	51,200	No	0.21

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.01 microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-112. Distance from Source for Maximum VOC Concentrations for Residential Setting – Valley Terrain, Low Density

	Unit Size (Btu)	Thermal Storage	**Distance (m)** Annual: Typical
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10
Phase II Outdoor Cordwood Boiler	208,000	No	30
Pellet Boiler, No Storage	109,000	No	10
Non-USEPA Certified Cordwood Stove	51,200	No	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
Pellet Stove	60,000	No	10
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	10
Pellet Boiler, With Storage	109,000	Yes	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, With Storage	85,300	Yes	10
Advanced Cordwood Stove w/AEC	51,200	No	10

Notes: AEC=advanced emission controls (electrostatic precipitator); “uncertified cordwood stoves” include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

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Table E-113. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (µg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.0	0.0	0.0	0.0	0.0
Phase II Outdoor Cordwood Boiler	208,000	No	93.3*	251.4*	29.7*	82.3*	7.9*
Pellet Boiler, No Storage	109,000	No	5.1	6.0	1.7	2.6	0.6
Non-USEPA Certified Cordwood Stove	51,200	No	31.4	57.6	18.6	34.7	5.2
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	21.5	43.1	12.1	24.2	3.4
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20.9	38.4	12.4	23.2	3.4
Pellet Stove	60,000	No	9.3	14.7	5.1	8.3	1.4
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	70.3*	70.3*	2.1*	6.2*	1.6*
Pellet Boiler, With Storage	109,000	Yes	3.5	3.5	0.2	0.6	0.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2.0	2.7	0.8	1.3	0.2
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	3.4	3.4	0.8	1.2	0.3
Condensing Pellet Boiler, No Storage	85,300	No	0.4	0.4	0.1	0.1	0.0
Condensing Pellet Boiler, With Storage	85,300	Yes	0.5	0.5	0.0	0.1	0.0
Advanced Cordwood Stove w/AEC	51,200	No	0.5	0.7	0.2	0.3	0.0

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-114. Predicted $PM_{2.5}$ Concentrations for Residential Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	Concentration (µg/m³)				
			1-hour		24-hour		Annual
T=Typical, M=Maximum			T	M	T	M	
Applicable Air Quality Standard			*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions			*18.2*	*18.2*	*23.0*	*23.0*	*8.7*
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	18.2	18.2	23.0	23.0	8.7
Phase II Outdoor Cordwood Boiler	208,000	No	111.5*	269.6*	52.7*	105.3*	16.6*
Pellet Boiler, No Storage	109,000	No	23.3	24.2	24.7	25.6	9.3
Non-USEPA Certified Cordwood Stove	51,200	No	49.6	75.8	41.6	57.7	13.9
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	39.7	61.3	35.1	47.2	12.1
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	39.1	56.6	35.4	46.2	12.1
Pellet Stove	60,000	No	27.5	32.9	28.1	31.3	10.1
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	88.5*	88.5*	25.1*	29.2*	10.3*
Pellet Boiler, With Storage	109,000	Yes	21.7	21.7	23.2	23.6	8.8
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20.2	20.9	23.8	24.3	8.9
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	21.6	21.6	23.8	24.2	9.0
Condensing Pellet Boiler, No Storage	85,300	No	18.6	18.6	23.1	23.1	8.7
Condensing Pellet Boiler, With Storage	85,300	Yes	18.7	18.7	23.0	23.1	8.7
Advanced Cordwood Stove w/AEC	51,200	No	18.7	18.9	23.2	23.3	8.7

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest tenth of a microgram per cubic meter; items marked with * are based on modeling using measured emission rates, and all other values are based on modeling using emission factors; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; 1-hour average existing conditions are biased low (Felton 2009).

Table E-115. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Residential Setting – Flat Terrain, High Density

	Unit Size (Btu)	Thermal Storage	Distance (m)				
			1-hour		24-hour		Annual
"Business as usual" technologies							
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10	10	10	10	10
Phase II Outdoor Cordwood Boiler	208,000	No	30	30	30	30	30
Pellet Boiler, No Storage	109,000	No	20	20	10	10	10
Non-USEPA Certified Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
Pellet Stove	60,000	No	20	20	10	10	10
"Best available" technologies							
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20	10	10	10
Pellet Boiler, With Storage	109,000	Yes	20	20	10	10	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20	10	10	10
"Next best" technologies							
Condensing Cordwood Boiler, No Storage	85,300	No	20	20	10	10	10
Condensing Pellet Boiler, No Storage	85,300	No	20	20	10	10	10
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20	10	10	10
Advanced Cordwood Stove w/AEC	51,200	No	20	20	10	10	10

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-116. Predicted NO_2 Concentrations for Residential Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	1-Hour Concentration (μg/m^3)			
			Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	17	17	13	13
Phase II Outdoor Cordwood Boiler	208,000	No	16	21	13	17
Pellet Boiler, No Storage	109,000	No	20	25	16	20
Non-USEPA Certified Cordwood Stove	51,200	No	3	5	2	4
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2	4	2	3
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2	4	2	3
Pellet Stove	60,000	No	27	43	21	34
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	27	27	22	22
Pellet Boiler, With Storage	109,000	Yes	29	29	23	23
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	6	9	5	7
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	27	30	21	24
Condensing Pellet Boiler, No Storage	85,300	No	22	27	17	22
Condensing Pellet Boiler, With Storage	85,300	Yes	29	29	23	23
Advanced Cordwood Stove w/AEC	51,200	No	6	9	5	7

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-117. Predicted NO_2 Concentrations for Residential Setting – Flat Terrain, High Density (with Existing Conditions)

	Unit Size (Btu)	Thermal Storage	1-Hour Concentration (μg/m^3) Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum			T	M	T	M
Applicable Air Quality Standard			*188*	*188*	*188*	*188*
Existing Conditions			*110*	*110*	*110*	*110*
"Business as usual" technologies						
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	127	127	123	123
Phase II Outdoor Cordwood Boiler	208,000	No	126	131	123	127
Pellet Boiler, No Storage	109,000	No	130	135	126	130
Non-USEPA Certified Cordwood Stove	51,200	No	113	115	112	114
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	112	114	112	113
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	112	114	112	113
Pellet Stove	60,000	No	137	153	131	144
"Best available" technologies						
Advanced Cordwood Boiler, With Storage	109,000	Yes	137	137	132	132
Pellet Boiler, With Storage	109,000	Yes	139	139	133	133
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	116	119	115	117
"Next best" technologies						
Condensing Cordwood Boiler, No Storage	85,300	No	137	140	131	134
Condensing Pellet Boiler, No Storage	85,300	No	132	137	127	132
Condensing Pellet Boiler, With Storage	85,300	Yes	139	139	133	133
Advanced Cordwood Stove w/AEC	51,200	No	116	119	115	117

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures; the suggested interpretation of NO_2 results is on a contextual and comparative basis, as the values presented here likely represent an upper bound for near-source impacts.

Table E-118. Distance from Source for Maximum NO_2 Concentrations for Residential Setting – Flat Terrain, High Density

	Unit Size (Btu)	Thermal Storage	Distance (m) 1-hour	
T=Typical, M=Maximum			T	M
"Business as usual" technologies				
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	20	20
Phase II Outdoor Cordwood Boiler	208,000	No	30	30
Pellet Boiler, No Storage	109,000	No	20	20
Non-USEPA Certified Cordwood Stove	51,200	No	20	20
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
Pellet Stove	60,000	No	20	20
"Best available" technologies				
Advanced Cordwood Boiler, With Storage	109,000	Yes	20	20
Pellet Boiler, With Storage	109,000	Yes	20	20
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	20	20
"Next best" technologies				
Condensing Cordwood Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, No Storage	85,300	No	20	20
Condensing Pellet Boiler, With Storage	85,300	Yes	20	20
Advanced Cordwood Stove w/AEC	51,200	No	20	20

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-119. Predicted VOC Concentrations for Residential Setting – Flat Terrain, High Density (No Existing Conditions)

	Unit Size (Btu)	Thermal Storage	**Concentration ($\mu g/m^3$)** Annual: Typical
Applicable Air Quality Standard			*None*
"Business as usual" technologies			
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	0.16
Phase II Outdoor Cordwood Boiler	208,000	No	20.99
Pellet Boiler, No Storage	109,000	No	1.11
Non-USEPA Certified Cordwood Stove	51,200	No	8.93
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	2.05
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	2.53
Pellet Stove	60,000	No	0.01
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	0.37
Pellet Boiler, With Storage	109,000	Yes	0.17
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	0.24
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	0.22
Condensing Pellet Boiler, No Storage	85,300	No	0.08
Condensing Pellet Boiler, With Storage	85,300	Yes	0.14
Advanced Cordwood Stove w/AEC	51,200	No	0.24

Notes: AEC=advanced emission controls (electrostatic precipitator); values rounded to the nearest 0.01 microgram per cubic meter; "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

Table E-120. Distance from Source for Maximum VOC Concentrations for Residential Setting – Flat Terrain, High Density

"Business as usual" technologies	Unit Size (Btu)	Thermal Storage	Distance (m) Annual: Typical
Oil Boiler Using Ultra-Low Sulfur Heating Oil	118,000	No	10
Phase II Outdoor Cordwood Boiler	208,000	No	30
Pellet Boiler, No Storage	109,000	No	10
Non-USEPA Certified Cordwood Stove	51,200	No	10
USEPA-Certified, Non-Catalytic Cordwood Stove	51,200	No	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
Pellet Stove	60,000	No	10
"Best available" technologies			
Advanced Cordwood Boiler, With Storage	109,000	Yes	10
Pellet Boiler, With Storage	109,000	Yes	10
USEPA-Certified, Catalytic Cordwood Stove	51,200	No	10
"Next best" technologies			
Condensing Cordwood Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, No Storage	85,300	No	10
Condensing Pellet Boiler, With Storage	85,300	Yes	10
Advanced Cordwood Stove w/AEC	51,200	No	10

Notes: AEC=advanced emission controls (electrostatic precipitator); "uncertified cordwood stoves" include pre-new source performance standard (NSPS) stoves and units currently sold that are exempt from the NSPS, such as single burn rate stoves and stoves with air to fuel ratios greater than 35:1; unit sizes are reported to three significant figures.

E.13 Neighborhood – Small Town in Upper New York

Table E-121. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Concentration (µg/m³)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	94.3	165.7	29.0	51.4	6.4
Scenario 2: Best Available Technology Growth	47.8	47.8	9.1	9.6	2.8
Scenario 3: Best Available Technology Growth, with Change-outs	39.5	39.5	8.5	9.5	2.3
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	39.5	39.5	7.4	7.4	2.2

Notes: values rounded to the nearest tenth of a microgram per cubic meter.

Table E-122. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Concentration (µg/m^3)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions	*22.0*	*22.0*	*15.0*	*15.0*	*4.3*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	116.3	187.7	44.0	66.4	10.7
Scenario 2: Best Available Technology Growth	69.8	69.8	24.1	24.6	7.1
Scenario 3: Best Available Technology Growth, with Change-outs	61.5	61.5	23.5	24.5	6.6
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	61.5	61.5	22.4	22.4	6.5

Notes: values rounded to the nearest tenth of a microgram per cubic meter; 1-hour average existing conditions are biased low (Felton 2009).

Table E-123. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density

	Distance (m)				
	1-hour		24-hour		Annual
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	150	150	50	50	50
Scenario 2: Best Available Technology Growth	450	450	450	50	450
Scenario 3: Best Available Technology Growth, with Change-outs	450	450	50	50	450
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	450	450	450	450	450

Table E-124. Predicted CO Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Concentration (ppm)			
	1-hour		8-hour	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*35*	*35*	*9*	*9*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	0.5	0.5	0.3	0.2
Scenario 2: Best Available Technology Growth	0.3	0.3	0.2	0.2
Scenario 3: Best Available Technology Growth, with Change-outs	0.3	0.3	0.1	0.1
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	0.3	0.3	0.1	0.1

Notes: values rounded to the nearest 0.1 ppm.

Table E-125. Predicted CO Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Concentration (µg/m^3)			
	1-hour		8-hour	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*35*	*35*	*9*	*9*
Existing Conditions	*1.1*	*1.1*	*0.7*	*0.7*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	1.6	1.6	1.0	0.9
Scenario 2: Best Available Technology Growth	1.4	1.4	0.9	0.9
Scenario 3: Best Available Technology Growth, with Change-outs	1.4	1.4	0.8	0.8
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	1.4	1.4	0.8	0.8

Notes: values rounded to the nearest 0.1 ppm.

Table E-126. Distance from Source for Maximum CO Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density

	Distance (m)			
	1-hour		8-hour	
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	900	900	300	900
Scenario 2: Best Available Technology Growth	900	900	900	900
Scenario 3: Best Available Technology Growth, with Change-outs	900	900	900	900
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	900	900	900	900

Table E-127. Predicted NO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	1-Hour Concentration (µg/m³)			
	Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*188*	*188*	*188*	*188*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	102	114	81	91
Scenario 2: Best Available Technology Growth	151	160	121	128
Scenario 3: Best Available Technology Growth, with Change-outs	151	160	121	128
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	71	112	57	90

Notes: values rounded to the nearest microgram per cubic meter.

Table E-128. Predicted NO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	1-Hour Concentration (µg/m^3)			
	Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*188*	*188*	*188*	*188*
Existing Conditions	*33*	*33*	*33*	*33*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	135	147	114	124
Scenario 2: Best Available Technology Growth	184	193	154	161
Scenario 3: Best Available Technology Growth, with Change-outs	184	193	154	161
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	104	145	90	123

Notes: values rounded to the nearest microgram per cubic meter.

Table E-129. Distance from Source for Maximum NO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density

	Distance (m)	
	1-hour	
T=Typical, M=Maximum	T	M
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	150	150
Scenario 2: Best Available Technology Growth	150	150
Scenario 3: Best Available Technology Growth, with Change-outs	150	150
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	40	150

Table E-130. Predicted SO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Concentration ($\mu g/m^3$)	
	1-hour	
T=Typical, M=Maximum	T	M
Applicable Air Quality Standard	*196*	*196*
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	13	14
Scenario 2: Best Available Technology Growth	10	10
Scenario 3: Best Available Technology Growth, with Change-outs	10	10
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	5	7

Notes: values rounded to the nearest microgram per cubic meter.

Table E-131. Predicted SO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (with Existing Conditions)

	Concentration ($\mu g/m^3$)	
	1-hour	
T=Typical, M=Maximum	T	M
Applicable Air Quality Standard	*196*	*196*
Existing Conditions	*10*	*10*
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	23	24
Scenario 2: Best Available Technology Growth	20	20
Scenario 3: Best Available Technology Growth, with Change-outs	20	20
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	15	17

Notes: values rounded to the nearest microgram per cubic meter.

Table E-132. Distance from Source for Maximum SO_2 Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density

	Distance (m)	
	1-hour	
T=Typical, M=Maximum	T	M
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	300	300
Scenario 2: Best Available Technology Growth	300	300
Scenario 3: Best Available Technology Growth, with Change-outs	300	300
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	80	300

Table E-133. Predicted VOC Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density (No Existing Conditions)

	Concentration ($\mu g/m^3$)
	Annual: Typical
Applicable Air Quality Standard	*None*
Neighborhood Scenario	
Scenario 1: Business as Usual Growth	6.52
Scenario 2: Best Available Technology Growth	4.80
Scenario 3: Best Available Technology Growth, with Change-outs	3.90
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	3.89

Notes: values rounded to the nearest 0.01 microgram per cubic meter.

Table E-134. Distance from Source for Maximum VOC Concentrations for Neighborhood Setting – Mountainous Terrain, Low Density

Neighborhood Scenario	Distance (m) Annual: Typical
Scenario 1: Business as Usual Growth	450
Scenario 2: Best Available Technology Growth	450
Scenario 3: Best Available Technology Growth, with Change-outs	450
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	450

E.14 Neighborhood – Small Town in Mid-New York

Table E-135. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Valley Terrain, Low Density (No Existing Conditions)

	Concentration (µg/m³)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	102.4	172.9	22.6	38.8	4.6
Scenario 2: Best Available Technology Growth	33.0	33.3	7.3	7.4	1.7
Scenario 3: Best Available Technology Growth, with Change-outs	31.7	32.9	7.2	7.3	1.6
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	15.7	15.7	1.7	1.8	0.5

Notes: values rounded to the nearest tenth of a microgram per cubic meter.

Table E-136. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Valley Terrain, Low Density (with Existing Conditions)

	Concentration (μg/m^3)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions	*21.2*	*21.2*	*20.0*	*20.0*	*7.0*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	123.6	194.1	42.6	58.8	11.6
Scenario 2: Best Available Technology Growth	54.2	54.5	27.3	27.4	8.7
Scenario 3: Best Available Technology Growth, with Change-outs	52.9	54.1	27.2	27.3	8.6
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	36.9	36.9	21.7	21.8	7.5

Notes: values rounded to the nearest tenth of a microgram per cubic meter; 1-hour average existing conditions are biased low (Felton 2009).

Table E-137. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Neighborhood Setting – Valley Terrain, Low Density

	Distance (m)				
	1-hour		24-hour		Annual
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	150	150	40	150	10
Scenario 2: Best Available Technology Growth	100	150	40	40	10
Scenario 3: Best Available Technology Growth, with Change-outs	150	150	40	40	10
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	500	500	10	10	10

Table E-138. Predicted NO_2 Concentrations for Neighborhood Setting – Valley Terrain, Low Density (No Existing Conditions)

	1-Hour Concentration (μg/m^3)			
	Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*188*	*188*	*188*	*188*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	99	110	79	88
Scenario 2: Best Available Technology Growth	142	155	113	124
Scenario 3: Best Available Technology Growth, with Change-outs	142	155	113	124
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	71	101	56	81

Notes: values rounded to the nearest microgram per cubic meter.

Table E-139. Predicted NO_2 Concentrations for Neighborhood Setting – Valley Terrain, Low Density (with Existing Conditions)

	1-Hour Concentration (µg/m^3)			
	Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*188*	*188*	*188*	*188*
Existing Conditions	*33*	*33*	*33*	*33*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	132	143	112	121
Scenario 2: Best Available Technology Growth	175	189	146	157
Scenario 3: Best Available Technology Growth, with Change-outs	175	188	146	157
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	104	134	89	114

Notes: values rounded to the nearest microgram per cubic meter.

Table E-140. Distance from Source for Maximum NO_2 Concentrations for Neighborhood Setting – Valley Terrain, Low Density

	Distance (m)	
	1-hour	
T=Typical, M=Maximum	T	M
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	150	150
Scenario 2: Best Available Technology Growth	150	150
Scenario 3: Best Available Technology Growth, with Change-outs	150	150
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	40	150

Table E-141. Predicted VOC Concentrations for Neighborhood Setting – Valley Terrain, Low Density (No Existing Conditions)

	Concentration ($\mu g/m^3$) Annual: Typical
Applicable Air Quality Standard	*None*
Neighborhood Scenario	
Scenario 1: Business as Usual Growth	1.90
Scenario 2: Best Available Technology Growth	1.18
Scenario 3: Best Available Technology Growth, with Change-outs	1.02
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	0.91

Notes: values rounded to the nearest 0.01 microgram per cubic meter.

Table E-142. Distance from Source for Maximum VOC Concentrations for Neighborhood Setting – Valley Terrain, Low Density

Neighborhood Scenario	Distance (m) Annual: Typical
Scenario 1: Business as Usual Growth	10
Scenario 2: Best Available Technology Growth	10
Scenario 3: Best Available Technology Growth, with Change-outs	10
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	10

E.15 Neighborhood – Populated Area in Mid-New York

Table E-143. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Flat Terrain, High Density (No Existing Conditions)

	Concentration (μg/m³)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	96.6	174.1	24.0	39.9	4.2
Scenario 2: Best Available Technology Growth	28.1	30.7	7.8	7.5	1.4
Scenario 3: Best Available Technology Growth, with Change-outs	28.0	30.7	7.8	7.5	1.4
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	2.6	2.6	0.5	0.7	0.2

Notes: values rounded to the nearest tenth of a microgram per cubic meter.

Table E-144. Predicted $PM_{2.5}$ Concentrations for Neighborhood Setting – Flat Terrain, High Density (with Existing Conditions)

	Concentration (µg/m³)				
	1-hour		24-hour		Annual
T=Typical, M=Maximum	T	M	T	M	
Applicable Air Quality Standard	*None*	*None*	*35.0*	*35.0*	*12.0*
Existing Conditions	*18.2*	*18.2*	*23.0*	*23.0*	*8.7*
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	114.8	192.3	47.0	62.9	12.9
Scenario 2: Best Available Technology Growth	46.3	48.9	30.8	30.5	10.1
Scenario 3: Best Available Technology Growth, with Change-outs	46.2	48.9	30.8	30.5	10.1
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	20.8	20.8	23.5	23.7	8.9

Notes: values rounded to the nearest tenth of a microgram per cubic meter; 1-hour average existing conditions are biased low (Felton 2009).

Table E-145. Distance from Source for Maximum $PM_{2.5}$ Concentrations for Neighborhood Setting – Flat Terrain, High Density

	Distance (m)				
	1-hour		24-hour		Annual
Neighborhood Scenario					
Scenario 1: Business as Usual Growth	150	150	40	40	10
Scenario 2: Best Available Technology Growth	150	150	40	40	10
Scenario 3: Best Available Technology Growth, with Change-outs	150	150	40	40	10
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	500	500	40	40	10

Table E-146. Predicted NO_2 Concentrations for Neighborhood Setting – Flat Terrain, High Density (No Existing Conditions)

	1-Hour Concentration (μg/m³)			
	Tier 1 (100% of NOx is NO_2)		**Tier 2 (80% of NOx is NO_2)**	
T=Typical, M=Maximum	**T**	**M**	**T**	**M**
Applicable Air Quality Standard **Neighborhood Scenario**	***188***	***188***	***188***	***188***
Scenario 1: Business as Usual Growth	**97**	**111**	**77**	**89**
Scenario 2: Best Available Technology Growth	**133**	**154**	**106**	**123**
Scenario 3: Best Available Technology Growth, with Change-outs	**133**	**154**	**106**	**123**
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	**69**	**95**	**56**	**76**

Notes: values rounded to the nearest microgram per cubic meter.

Table E-147. Predicted NO_2 Concentrations for Neighborhood Setting – Flat Terrain, High Density (with Existing Conditions)

	1-Hour Concentration (µg/m^3)			
	Tier 1 (100% of NOx is NO_2)		Tier 2 (80% of NOx is NO_2)	
T=Typical, M=Maximum	T	M	T	M
Applicable Air Quality Standard	*188*	*188*	*188*	*188*
Existing Conditions	*110*	*110*	*110*	*110*
Neighborhood Scenario				
Scenario 1: Business as Usual Growth	207	221	187	199
Scenario 2: Best Available Technology Growth	243	264	216	233
Scenario 3: Best Available Technology Growth, with Change-outs	243	264	216	233
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	180	205	166	186

Notes: values rounded to the nearest microgram per cubic meter.

Table E-148. Distance from Source for Maximum NO_2 Concentrations for Neighborhood Setting – Flat Terrain, High Density

	Distance (m)	
	1-hour	
T=Typical, M=Maximum	T	M
Neighborhood Scenario		
Scenario 1: Business as Usual Growth	150	150
Scenario 2: Best Available Technology Growth	150	150
Scenario 3: Best Available Technology Growth, with Change-outs	150	150
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	40	150

Table E-149. Predicted VOC Concentrations for Neighborhood Setting – Flat Terrain, High Density (No Existing Conditions)

	Concentration ($\mu g/m^3$)
	Annual: Typical
Applicable Air Quality Standard	*None*
Neighborhood Scenario	
Scenario 1: Business as Usual Growth	1.00
Scenario 2: Best Available Technology Growth	0.48
Scenario 3: Best Available Technology Growth, with Change-outs	0.45
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	0.33

Notes: values rounded to the nearest 0.01 microgram per cubic meter.

Table E-150. Distance from Source for Maximum VOC Concentrations for Neighborhood Setting – Flat Terrain, High Density

Neighborhood Scenario	Distance (m) Annual: Typical
Scenario 1: Business as Usual Growth	10
Scenario 2: Best Available Technology Growth	10
Scenario 3: Best Available Technology Growth, with Change-outs	10
Scenario 4: Best Available Technology Growth, with Change-outs and Next best Technology Deployment at the School	10

Appendix F: Building and Technology Assumptions in Spreadsheet Analysis

Scenario #1, Residential Sector: Single Family in Upper-NY

Building Characteristics

Scenario number	1
Sector	Residential
Building type	Single Family
Geographic location	Upper-NY
Heated area (sq. ft.)	1,500
Maximum thermal load (MBtu per hour)	64

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	pellet boiler	pellet boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	109	193	109	75
Thermal storage system	no	no	no	no

Costs (2012 Dollars)

		Oil	BAU	BAT	nBAT
Boiler/stove costs					
	Capital costs	$2,544	see total	$19,878	$21,452
	Installation costs	$1,827	see total	$3,500	$18,878
Thermal storage system costs					
	Capital costs	NA	NA	NA	NA
	Incremental installation costs	NA	NA	NA	NA
Total Project Costs		$4,371	$17,900	$23,378	$40,330
Annual O&M, for all except thermal storage		$131	$500	$315	$362
Incremental annual O&M for thermal storage		NA	NA	NA	NA

Efficiency

	Oil	BAU	BAT	nBAT
Full-load efficiency	83%	78%	86%	94%
Percent load for partial-load efficiency value	25%	25%	30%	30%
Partial-load efficiency	75%	60%	78%	86%
Annual efficiency	66%	41%	66%	80%
Fuel consumption	1260 gallons	13 cords	11 tons	9 tons

Emission factors (lbs./MMBtu)

	Oil	BAU	BAT	nBAT
$PM_{2.5}$	0.00005	0.393	0.02	0.00233
CO	0.036	16.6	0.05	0.03
NOx	0.097	0.1315	0.17	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #2a, Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	2a
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	1,500
Maximum thermal load (MBtu per hour)	54

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	pellet boiler	pellet boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	92	162	85	68
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,475	see total	$19,878	$21,452
Installation costs	$1,827	see total	$3,500	$18,878
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,302	$17,500	$23,378	$40,330
Annual O&M, for all except thermal storage	$131	$500	$315	$362
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	83%	78%	86%	94%
Percent load for partial-load efficiency value	25%	25%	30%	30%
Partial-load efficiency	75%	60%	78%	86%
Annual efficiency	66%	40%	67%	79%
Fuel consumption	1012 gallons	11 cords	9 tons	8 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.02	0.00233
CO	0.036	16.6	0.05	0.03
NOx	0.097	0.1315	0.17	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #2b, Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	2b
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	1,500
Maximum thermal load (MBtu per hour)	54

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	woodstove	woodstove
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	92	162	51	51
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,475	see total	$3,259	$3,618
Installation costs	$1,827	see total	$972	$1,129
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,302	$17,500	$4,231	$4,748
Annual O&M, for all except thermal storage	$131	$500	$47	$79
Incremental annual O&M for thermal storage	NA	NA	NA	NA

Efficiency

	Oil	BAU	BAT	nBAT
Full-load efficiency	83%	78%	73%	73%
Percent load for partial-load efficiency value	25%	25%	50%	50%
Partial-load efficiency	75%	60%	72%	72%
Annual efficiency	66%	19%	73%	73%
Fuel consumption	1012 gallons	12 cords	3 cords	3 cords

Emission factors (lbs./MMBtu)

	Oil	BAU	BAT	nBAT
$PM_{2.5}$	0.00005	0.393	0.05	0.012
CO	0.036	16.6	1.443	1.10
NOx	0.097	0.1315	0.1701	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Notes: BAT and nBAT woodstoves are supplemented by existing oil-fired boilers.

Scenario #3, Residential Sector: Single Family in Upper-NY

Building Characteristics

Scenario number	3
Sector	Residential
Building type	Single Family
Geographic location	Upper-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	83

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	pellet boiler	pellet boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	141	249	136	102
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,656	see total	$19,878	$21,452
Installation costs	$1,827	see total	$3,500	$18,878
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,483	$18,800	$23,378	$40,330
Annual O&M, for all except thermal storage	$131	$500	$315	$362
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	83%	78%	86%	94%
Percent load for partial-load efficiency value	25%	25%	30%	30%
Partial-load efficiency	75%	60%	78%	86%
Annual efficiency	66%	41%	66%	79%
Fuel consumption	1560 gallons	16 cords	14 tons	12 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.02	0.00233
CO	0.036	16.6	0.05	0.03
NOx	0.097	0.1315	0.17	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #4a (no storage), Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	4a (no storage)
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	69

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	pellet boiler	pellet boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	118	208	109	85
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,578	see total	$19,878	$21,452
Installation costs	$1,827	see total	$3,500	$18,878
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,405	$18,200	$23,378	$40,330
Annual O&M, for all except thermal storage	$131	$500	$315	$362
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	83%	78%	86%	94%
Percent load for partial-load efficiency value	25%	25%	30%	30%
Partial-load efficiency	75%	60%	78%	86%
Annual efficiency	65%	39%	66%	78%
Fuel consumption	1241 gallons	13 cords	11 tons	9 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.02	0.00233
CO	0.036	16.6	0.05	0.03
NOx	0.097	0.1315	0.17	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #4b, Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	4b
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	69

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	pellet boiler	pellet boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	118	208	109	85
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,578	see total	$19,878	$21,452
Installation costs	$1,827	see total	$3,500	$18,878
Thermal storage system costs				
Capital costs	NA	NA	$1,573	$1,573
Incremental installation costs	NA	NA	$157	$157
Total Project Costs	$4,405	$18,200	$25,109	$42,061
Annual O&M, for all except thermal storage	$131	$500	$315	$362
Incremental annual O&M for thermal storage	NA	NA	$47	$47
Efficiency				
Full-load efficiency	83%	78%	86%	94%
Percent load for partial-load efficiency value	25%	25%	30%	30%
Partial-load efficiency	75%	60%	85%	93%
Annual efficiency	65%	39%	86%	94%
Fuel consumption	1241 gallons	13 cords	8 tons	8 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.02	0.00233
CO	0.036	16.6	0.05	0.03
NOx	0.097	0.1315	0.17	0.17
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #4c (no storage), Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	4c (no storage)
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	69

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	cordwood boiler	cordwood boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	118	208	102	85
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,578	see total	$12,484	$14,631
Installation costs	$1,827	see total	$3,500	$11,484
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,405	$18,200	$15,984	$26,115
Annual O&M, for all except thermal storage	$131	$500	$299	$315
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	83%	78%	83%	85%
Percent load for partial-load efficiency value	25%	25%	50%	50%
Partial-load efficiency	75%	60%	72%	74%
Annual efficiency	65%	39%	44%	49%
Fuel consumption	1241 gallons	13 cords	13 cords	11 cords
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.05	0.01628
CO	0.036	16.6	1.443	0.1997
NOx	0.097	0.1315	0.1701	0.171
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #4d, Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	4d
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	69

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	cordwood boiler	cordwood boiler
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	118	208	102	85
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,578	see total	$12,484	$14,631
Installation costs	$1,827	see total	$3,500	$11,484
Thermal storage system costs				
Capital costs	NA	NA	$1,573	$1,573
Incremental installation costs	NA	NA	$157	$157
Total Project Costs	$4,405	$18,200	$17,715	$27,846
Annual O&M, for all except thermal storage	$131	$500	$299	$315
Incremental annual O&M for thermal storage	NA	NA	$47	$47
Efficiency				
Full-load efficiency	83%	78%	83%	85%
Percent load for partial-load efficiency value	25%	25%	50%	50%
Partial-load efficiency	75%	60%	82%	84%
Annual efficiency	65%	39%	83%	85%
Fuel consumption	1241 gallons	13 cords	7 cords	7 cords
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.05	0.01628
CO	0.036	16.6	1.443	0.1997
NOx	0.097	0.1315	0.1701	0.171
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #4e, Residential Sector: Single Family in Mid-NY

Building Characteristics

Scenario number	4e
Sector	Residential
Building type	Single Family
Geographic location	Mid-NY
Heated area (sq. ft.)	2,500
Maximum thermal load (MBtu per hour)	69

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	PH2 OWB	woodstove	woodstove
Target oversize factor	1.7	3	1.7	1.2
Unit size (MBtu per hour)	118	208	51	51
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$2,578	see total	$3,259	$3,618
Installation costs	$1,827	see total	$972	$1,129
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$4,405	$18,200	$4,231	$4,748
Annual O&M, for all except thermal storage	$131	$500	$47	$79
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	83%	78%	73%	73%
Percent load for partial-load efficiency value	25%	25%	50%	50%
Partial-load efficiency	75%	60%	72%	72%
Annual efficiency	65%	39%	73%	73%
Fuel consumption	1241 gallons	13 cords	4 cords	4 cords
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.05	0.012
CO	0.036	16.6	1.443	1.10
NOx	0.097	0.1315	0.1701	0.170
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #5, Institutional Sector: Small School in Upper-NY

Building Characteristics

Scenario number	5
Sector	Institutional
Building type	Small School
Geographic location	Upper-NY
Heated area (sq. ft.)	55,000
Maximum thermal load (MBtu per hour)	1,334

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	2,269	4,003	3,412	1,024
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$37,358	see total	$300,980	$300,980
Installation costs	$5,958	see total	$35,397	$35,397
Thermal storage system costs				
Capital costs	NA	NA	$18,878	$5,664
Incremental installation costs	NA	NA	$1,888	$566
Total Project Costs	$43,316	$999,395	$357,143	$342,607
Annual O&M, for all except thermal storage	$2,539	$12,000	$9,439	$9,439
Incremental annual O&M for thermal storage	NA	NA	$566	$157
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	73%	36%	83%	93%
Fuel consumption	15833 gallons	474 tons	125 tons	111 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0503	0.0049
CO	0.036	0.6	0.2516	0.1572
NOx	0.097	0.2200	0.3019	0.3019
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #6, Institutional Sector: Small School in Mid-NY

Building Characteristics

Scenario number	6
Sector	Institutional
Building type	Small School
Geographic location	Mid-NY
Heated area (sq. ft.)	55,000
Maximum thermal load (MBtu per hour)	1,129

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	1,920	3,388	3,412	1,024
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$33,669	see total	$300,980	$300,980
Installation costs	$5,821	see total	$35,397	$35,397
Thermal storage system costs				
Capital costs	NA	NA	$18,878	$5,664
Incremental installation costs	NA	NA	$1,888	$566
Total Project Costs	$39,489	$936,500	$357,143	$342,607
Annual O&M, for all except thermal storage	$2,303	$12,000	$9,439	$9,439
Incremental annual O&M for thermal storage	NA	NA	$566	$157
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	72%	35%	82%	93%
Fuel consumption	11463 gallons	355 tons	90 tons	79 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0503	0.0049
CO	0.036	0.6	0.2516	0.1572
NOx	0.097	0.2200	0.3019	0.3019
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7a, Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7a
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,042	7,133	5,118	1,706
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$340,310	$348,176
Installation costs	$7,179	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$63,314	$1,229,000	$381,607	$390,652
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	78%	86%
Annual efficiency	71%	33%	63%	86%
Fuel consumption	23521 gallons	747 tons	236 tons	162 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0503	0.0049
CO	0.036	0.6	0.2516	0.1572
NOx	0.097	0.2200	0.3019	0.3019
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7b, Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7b
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,042	7,133	5,118	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$340,310	$348,176
Installation costs	$7,179	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$28,318	$9,439
Incremental installation costs	NA	NA	$2,832	$944
Total Project Costs	$63,314	$1,229,000	$412,756	$401,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	$850	$283
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	71%	33%	83%	93%
Fuel consumption	23521 gallons	747 tons	181 tons	160 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0503	0.0049
CO	0.036	0.6	0.2516	0.1572
NOx	0.097	0.2200	0.3019	0.3019
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7c (no storage), Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7c (no storage)
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler	chip boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,042	7,133	5,118	1,706
Thermal storage system	no	no	no	no
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$550,310	$558,176
Installation costs	$7,179	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	NA	NA
Incremental installation costs	NA	NA	NA	NA
Total Project Costs	$63,314	$1,229,000	$591,607	$600,652
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	NA	NA
Efficiency				
Full-load efficiency	86%	75%	76%	88%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	65%	77%
Annual efficiency	71%	33%	48%	77%
Fuel consumption	23521 gallons	747 tons	519 tons	300 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7d, Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7d
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler	chip boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,042	7,133	5,118	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$550,310	$558,176
Installation costs	$7,179	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$28,318	$9,439
Incremental installation costs	NA	NA	$2,832	$944
Total Project Costs	$63,314	$1,229,000	$622,756	$611,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	$850	$283
Efficiency				
Full-load efficiency	86%	75%	76%	88%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	75%	87%
Annual efficiency	71%	33%	73%	87%
Fuel consumption	23521 gallons	747 tons	343 tons	285 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7e, Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7e
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler - 30% moisture content chips	chip boiler - 30% moisture content chips
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,042	7,133	5,118	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$550,310	$558,176
Installation costs	$7,179	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$28,318	$9,439
Incremental installation costs	NA	NA	$2,832	$944
Total Project Costs	$63,314	$1,229,000	$622,756	$611,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	$850	$283
Efficiency				
Full-load efficiency	86%	75%	0%	0%
Percent load for partial-load efficiency value	25%	30%	0%	0%
Partial-load efficiency	78%	60%	0%	0%
Annual efficiency	71%	33%	76%	91%
Fuel consumption	23521 gallons	747 tons	328 tons	275 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #7f, Institutional Sector: Large School in Mid-NY

Building Characteristics

Scenario number	7f
Sector	Institutional
Building type	Large School
Geographic location	Mid-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,378

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler - right size	chip boiler
Target oversize factor	1.7	3	1	0.75
Unit size (MBtu per hour)	4,042	7,133	1,706	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$56,134	see total	$400,856	$558,176
Installation costs	$7,179	see total	$18,878	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$9,439	$9,439
Incremental installation costs	NA	NA	$944	$944
Total Project Costs	$63,314	$1,229,000	$430,118	$611,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$5,034	$11,327
Incremental annual O&M for thermal storage	NA	NA	$283	$283
Efficiency				
Full-load efficiency	86%	75%	76%	88%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	75%	87%
Annual efficiency	71%	33%	75%	87%
Fuel consumption	23521 gallons	747 tons	330 tons	285 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #8, Institutional Sector: Large School in Upper-NY

Building Characteristics

Scenario number	8
Sector	Institutional
Building type	Large School
Geographic location	Upper-NY
Heated area (sq. ft.)	130,000
Maximum thermal load (MBtu per hour)	2,801

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	4,761	8,402	5,118	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$63,748	see total	$550,310	$348,176
Installation costs	$8,457	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$28,318	$9,439
Incremental installation costs	NA	NA	$2,832	$944
Total Project Costs	$72,204	$1,349,203	$622,756	$401,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	$850	$283
Efficiency				
Full-load efficiency	86%	75%	76%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	75%	93%
Annual efficiency	72%	35%	73%	93%
Fuel consumption	32351 gallons	991 tons	474 tons	224 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #9, Commercial Sector: Office in Mid-NY

Building Characteristics

Scenario number	9
Sector	Commercial
Building type	Office
Geographic location	Mid-NY
Heated area (sq. ft.)	20,000
Maximum thermal load (MBtu per hour)	406

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	690	1,218	1,024	341
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$17,731	see total	$127,928	$86,074
Installation costs	$2,991	see total	$18,878	$19,822
Thermal storage system costs				
Capital costs	NA	NA	$3,146	$3,146
Incremental installation costs	NA	NA	$315	$315
Total Project Costs	$20,722	$1,032,000	$150,267	$109,358
Annual O&M, for all except thermal storage	$1,546	$6,000	$3,146	$2,674
Incremental annual O&M for thermal storage	NA	NA	$94	$94
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	75%	40%	83%	93%
Fuel consumption	1819 gallons	51 tons	15 tons	13 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.024	0.00233
CO	0.036	0.6	0.048	0.03
NO_x	0.097	0.2200	0.17	0.17
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #10, Commercial Sector: Office in Upper-NY

Building Characteristics

Scenario number	10
Sector	Commercial
Building type	Office
Geographic location	Upper-NY
Heated area (sq. ft.)	20,000
Maximum thermal load (MBtu per hour)	496

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	843	1,488	1,024	341
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$22,268	see total	$127,928	$86,074
Installation costs	$3,612	see total	$18,878	$19,822
Thermal storage system costs				
Capital costs	NA	NA	$3,146	$3,146
Incremental installation costs	NA	NA	$315	$315
Total Project Costs	$25,879	$1,100,000	$150,267	$109,358
Annual O&M, for all except thermal storage	$1,575	$6,000	$3,146	$2,674
Incremental annual O&M for thermal storage	NA	NA	$94	$94
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	75%	39%	83%	93%
Fuel consumption	3266 gallons	93 tons	26 tons	23 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.024	0.00233
CO	0.036	0.6	0.048	0.03
NOx	0.097	0.2200	0.17	0.17
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #11, Commercial Sector: Retail in Mid-NY

Building Characteristics

Scenario number	11
Sector	Commercial
Building type	Retail
Geographic location	Mid-NY
Heated area (sq. ft.)	10,000
Maximum thermal load (MBtu per hour)	256

Technology characteristics

Technology		**Oil**	**BAU**	**BAT**	**nBAT**
Unit type		oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor		1.7	3	2	0.75
Unit size (MBtu per hour)		435	768	512	188
Thermal storage system		no	no	yes	yes
Costs (2012 Dollars)					
Boiler/stove costs					
	Capital costs	$8,257	see total	$56,184	$74,275
	Installation costs	$1,886	see total	$10,855	$15,732
Thermal storage system costs					
	Capital costs	NA	NA	$3,146	$1,573
	Incremental installation costs	NA	NA	$315	$157
Total Project Costs		$10,143	$919,000	$70,500	$91,738
Annual O&M, for all except thermal storage		$1,546	$6,000	$1,416	$2,202
Incremental annual O&M for thermal storage		NA	NA	$94	$47
Efficiency					
Full-load efficiency		86%	75%	86%	94%
Percent load for partial-load efficiency value		25%	30%	30%	30%
Partial-load efficiency		78%	60%	85%	93%
Annual efficiency		75%	40%	83%	93%
Fuel consumption		1809 gallons	51 tons	15 tons	13 tons
Emission factors (lbs./MMBtu)					
$PM_{2.5}$		0.00005	0.279	0.024	0.00233
CO		0.036	0.6	0.048	0.03
NOx		0.097	0.2200	0.17	0.17
SO_2		0.0015	0.025		
VOCs		0.00514	0.017		

Scenario #12, Commercial Sector: Retail in Upper-NY

Building Characteristics

Scenario number	12
Sector	Commercial
Building type	Retail
Geographic location	Upper-NY
Heated area (sq. ft.)	10,000
Maximum thermal load (MBtu per hour)	308

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	524	924	682	239
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$11,541	see total	$64,050	$86,074
Installation costs	$2,269	see total	$13,215	$19,822
Thermal storage system costs				
Capital costs	NA	NA	$3,776	$1,573
Incremental installation costs	NA	NA	$378	$157
Total Project Costs	$13,810	$958,000	$81,418	$107,627
Annual O&M, for all except thermal storage	$1,546	$6,000	$1,809	$2,674
Incremental annual O&M for thermal storage	NA	NA	$110	$47
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	75%	40%	83%	93%
Fuel consumption	2791 gallons	78 tons	23 tons	20 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.024	0.00233
CO	0.036	0.6	0.048	0.03
NOx	0.097	0.2200	0.17	0.17
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #13, Commercial Sector: Large Dairy in Mid-NY

Building Characteristics

Scenario number	13
Sector	Commercial
Building type	Large Dairy
Geographic location	Mid-NY
Number of cows	711 cows
Maximum thermal load (MBtu per hour)	300

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	cordwood boiler	pellet boiler	pellet boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	510	900	682	239
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$11,036	see total	$64,050	$86,074
Installation costs	$2,210	see total	$13,215	$19,822
Thermal storage system costs				
Capital costs	NA	NA	$3,146	$1,573
Incremental installation costs	NA	NA	$315	$157
Total Project Costs	$13,246	$29,000	$80,726	$107,627
Annual O&M, for all except thermal storage	$1,546	$2,000	$1,809	$2,674
Incremental annual O&M for thermal storage	NA	NA	$94	$47
Efficiency				
Full-load efficiency	86%	0%	0%	0%
Percent load for partial-load efficiency value	25%	0%	0%	0%
Partial-load efficiency	78%	0%	0%	0%
Annual efficiency	62%	13%	77%	82%
Fuel consumption	5354 gallons	179 cords	39 tons	36 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.024	0.00233
CO	0.036	16.6	0.048	0.03
NOx	0.097	0.1315	0.17	0.17
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #14, Commercial Sector: Small Dairy in Mid-NY

Building Characteristics

Scenario number	14
Sector	Commercial
Building type	Small Dairy
Geographic location	Mid-NY
Number of cows	110 cows
Maximum thermal load (MBtu per hour)	174

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	cordwood boiler	cordwood boiler	cordwood boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	296	522	341	136
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$3,073	see total	$27,744	$40,117
Installation costs	$1,281	see total	$8,523	$12,035
Thermal storage system costs				
Capital costs	NA	NA	$1,573	$1,573
Incremental installation costs	NA	NA	$157	$157
Total Project Costs	$4,354	$23,000	$37,998	$53,882
Annual O&M, for all except thermal storage	$1,546	$2,000	$1,070	$1,573
Incremental annual O&M for thermal storage	NA	NA	$47	$47
Efficiency				
Full-load efficiency	86%	78%	83%	85%
Percent load for partial-load efficiency value	25%	25%	50%	50%
Partial-load efficiency	78%	45%	82%	84%
Annual efficiency	62%	13%	77%	82%
Fuel consumption	2229 gallons	75 cords	12 cords	12 cords
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.393	0.05	0.01628
CO	0.036	16.6	0.2457	0.1997
NOx	0.097	0.1315	0.171	0.171
SO_2	0.0015	0.145		
VOCs	0.00514	1.7		

Scenario #15, Commercial Sector: Greenhouse in Mid-NY

Building Characteristics

Scenario number	15
Sector	Commercial
Building type	Greenhouse
Geographic location	Mid-NY
Heated area (sq. ft.)	10,000
Maximum thermal load (MBtu per hour)	852

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	pellet boiler	pellet boiler
Target oversize factor	1.25	1.25	1.25	0.75
Unit size (MBtu per hour)	1,065	1,218	1,024	682
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$24,620	see total	$127,928	$137,990
Installation costs	$4,288	see total	$18,878	$34,610
Thermal storage system costs				
Capital costs	NA	NA	$3,146	$3,776
Incremental installation costs	NA	NA	$315	$378
Total Project Costs	$28,908	$1,032,000	$150,267	$176,754
Annual O&M, for all except thermal storage	$1,726	$6,000	$3,146	$4,720
Incremental annual O&M for thermal storage	NA	NA	$94	$110
Efficiency				
Full-load efficiency	86%	75%	86%	94%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	85%	93%
Annual efficiency	75%	50%	85%	93%
Fuel consumption	2522 gallons	47 tons	20 tons	18 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.024	0.0023
CO	0.036	0.6	0.048	0.03
NOx	0.097	0.2200	0.17	0.17
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

Scenario #17*, Institutional Sector: Hospital in Mid-NY

Building Characteristics

Scenario number	17
Sector	Institutional
Building type	Hospital
Geographic location	Mid-NY
Heated area (sq. ft.)	100,000
Maximum thermal load (MBtu per hour)	1,983

Technology characteristics

Technology	**Oil**	**BAU**	**BAT**	**nBAT**
Unit type	oil boiler	chip boiler	chip boiler	chip boiler
Target oversize factor	1.7	3	2	0.75
Unit size (MBtu per hour)	3,372	7,133	5,118	1,706
Thermal storage system	no	no	yes	yes
Costs (2012 Dollars)				
Boiler/stove costs				
Capital costs	$49,037	see total	$550,310	$558,176
Installation costs	$5,989	see total	$41,297	$42,476
Thermal storage system costs				
Capital costs	NA	NA	$28,318	$9,439
Incremental installation costs	NA	NA	$2,832	$944
Total Project Costs	$55,026	$2,096,000	$622,756	$611,036
Annual O&M, for all except thermal storage	$3,033	$12,000	$11,012	$11,327
Incremental annual O&M for thermal storage	NA	NA	$850	$283
Efficiency				
Full-load efficiency	86%	75%	76%	88%
Percent load for partial-load efficiency value	25%	30%	30%	30%
Partial-load efficiency	78%	60%	75%	87%
Annual efficiency	81%	48%	75%	88%
Fuel consumption	90021 gallons	2247 tons	1449 tons	1227 tons
Emission factors (lbs./MMBtu)				
$PM_{2.5}$	0.00005	0.279	0.0671	0.0065
CO	0.036	0.6	0.3355	0.2097
NOx	0.097	0.2200	0.4025	0.4025
SO_2	0.0015	0.025		
VOCs	0.00514	0.017		

* Technical characterization #16 was developed for Greenhouses but the lack of confidence in the data led us to eliminate that analysis.

Appendix G: Technology Classifications

Appendix G contains information about delineation of technologies into Business As Usual, Best Available Technologies and Next Best Available Technologies. These technology classifications were used in the Air Quality Impact Analysis, Technology Characterizations, State Scale up Analysis, and Macroeconomic Analysis.

G.1 Business as Usual Technologies

The following sections provide information on Business As Usual (BAU) technologies. These technologies are those that are typically installed when there are no incentive programs to promote a technology. BAU was analyzed for wood and oil technologies.

G.1.1 BAU Oil Technologies

Table G-1 reflects the emission factor assumptions for BAU oil boilers in the residential, institutional, and commercial sectors. It is assumed that all oil boilers will burn ultra-low sulfur diesel fuel as New York has required the use of heating oil to have sulfur content less than 15 ppm since 2012.

Table G-1. BAU Oil Boiler Emission Factors

Pollutant	Emission Factor (lb/MMBtu)	Emission Factor Data Source
$PM_{2.5}$	0.00005	BNL[343]
CO	0.036	U.S. EPA AP-42
NOx	0.097	Brookhaven National Laboratory[344]
SO_2	0.0015	U.S. EPA AP-42
VOCs	0.00514	U.S. EPA AP-42

G.1.2 BAU Wood Technologies

This section presents basic descriptions of the equipment types typically installed in the United States.

343 The $PM_{2.5}$ emission factor was provided by Nathan Russell, Heating and Cooling R&D, NYSERDA.

344 Brookhaven National Laboratory, Low Sulfur Home Heating Oil Demonstration Project Summary Report, June 2005. Available: http://www.bnl.gov/isd/documents/30441.pdf.

G.1.2.1 BAU Space Heating

BAU Cordwood Stoves

These are small, cordwood-fired appliances that are not connected to a forced air or hydronic distribution system and are typically intended to heat one surrounding space. These stoves are usually characterized within three broad categories:

- *Uncertified/Exempt Stoves* – These are wood stoves that have not had to meet an emission standard. These units fall into two categories: 1) units that were manufactured before the 1988 EPA New Source Performance Standards (NSPS) became effective, and 2) units that were exempted from NSPS due to their air to fuel ratios or single burn rates. These stoves are characterized by low efficiency and high particulate matter (PM) emission levels (30-66 g/hr). [4]
- *Certified Non-Catalytic Stoves* – These wood stoves use secondary combustion air to reduce emissions and were marketed after the 1988 EPA NSPS became effective. These are estimated to burn one-third less fuel than the uncertified stoves and have PM emissions less than 7.5 g/hr under test lab conditions.
- *Certified Catalytic Stoves* – These stoves are equipped with catalytic devices to reduce emissions, and were marketed after the 1988 EPA NSPS became effective. These have a PM emission limit of 4.1 g/hr under test lab conditions.

Table G-2 and Table G-3 provide an overview of typical operational characteristics of these units.

Table G-2. BAU Exempt/Uncertified Cordwood Stove

1. Fuel used (type of biomass)	Cordwood
2. Nominal load (NL) (MBtu/hr)	38
3. Weight (kg)	700-850
4. Efficiency (%) at full load	40-50%
5.1 PM- emissions (lb/hr) or (lb/MMBtu) both at full load and part load	34.6 lb/per ton of wood
5.2 CO- emissions (g/m³) or (lb/MBtu) both at full load and part load	231 lb/per ton of wood
5.3 OGC- emissions (g/m³) or (lb/MBtu) both at full load and part load	VOC = 53 lb/per ton of wood
5.4 NOx- emissions (g/m³) or (lb/MBtu) both at full load and part load	2.8 lb/per ton of wood
7. Hours of operation at NL (hr/a)	3600
8. Typical lifetime (a)	90 yrs
9. Product price (USD)	$100 -400
10. Installation costs (USD)	$200
11. Fuel consumption (kg/a)	4-7 cords
12. Fuel costs (USD/sales unit)	~$1350
14. Repair and maintenance costs (USD/a)	$150

Table G-3. BAU EPA Certified Cordwood Stove

1. Fuel used (type of biomass)	Cordwood
2. Nominal load (NL) (MBtu/hr)	38
3. Weight (kg)	300-400 lb
4.1 Efficiency (%) at full load	60-67%
5.1 PM- emissions (lb/hr) or (lb/MMBtu) both at full load and part load	19.6 lb/per ton of wood
5.2 CO- emissions (g/m^3) or (lb/MBtu) both at full load and part load	141 lb/per ton of wood
5.3 OGC- emissions (g/m^3) or (lb/MBtu) both at full load and part load	VOC = 15 lb/per ton of wood
5.4 NOx- emissions (g/m^3) or (lb/MBtu) both at full load and part load	Unknown
6. Electrical power consumption (% of NL)	Not applicable
7. Hours of operation at NL (hr/a)	3,600
8. Typical lifetime (a)	25 yrs
9. Product price (USD)	$1,000-4,000
10. Installation costs (USD)	$500 - 3000
11. Fuel consumption (kg/a)	Typically three to five cords of wood annually
12. Fuel costs (USD/sales unit)	900
13. Electricity price (USD/ unit)	Not Applicable
14. Repair and maintenance costs (USD/a)	150 – 500

BAU Pellet Stoves

These are designed to heat smaller spaces in the vicinity of the stove and are not connected to a thermal distribution system. Fuel is fed automatically from a hopper or larger storage system. Like cordwood stoves, these units are tested following EPA Method 28. Table G-4 presents performance data on BAU pellet stoves.

Table G-4. BAU Pellet Stoves

1. Fuel used (type of biomass)	Wood pellets
2. Nominal load (NL) (MBtu/hr)	33 5,000-100,000 btu/hr
3. Weight (kg)	Stove 255-370 lb --- Furnace 450 lb
4.1 Efficiency (%) at full load	70%
5.1 PM- emissions (lb/hr) or (lb/MMBtu) both at full load and part load	3.06 lb/ton
5.2 CO- emissions (g/m³) or (lb/MBtu) both at full load and part load	15.9 lb/ton
5.3 OGC- emissions (g/m³) or (lb/MBtu) both at full load and part load	0.41 lb/ton
5.4 NOx- emissions (g/m³) or (lb/MBtu) both at full load and part load	Not available
6. Electrical power consumption (% of NL)	80-150 watts -- up to 400 watts start up
7. Hours of operation at NL (hr/a)	Varies widely
8. Typical lifetime (a)	Unknown for certain 15-20 yrs
9. Product price (USD)	$1,200 - $4,000
10. Installation costs (USD)	Varies Widely -- $500 - $700
11. Fuel consumption (kg/a)	2 – 8 tons per year
12. Fuel costs (USD/sales unit)	$210 - $300 per ton
14. Repair and maintenance costs (USD/a)	$150 – 200

G.1.2.2 Residential Central Heating Systems

Residential central heating systems are connected to a thermal distribution system. Usually, this is a hydronic system where heat is distributed to an entire building and delivered, for example, with baseboard radiators.

BAU Outdoor Wood Boilers (OWBs)

These units are cordwood-fired hydronic heaters and can be installed both outdoors and indoors. Outdoor wood boilers most important distinguishing technical feature is their large firebox volume and large surrounding water volume. These systems are connected to an indoor hydronic heating system through buried piping. The large firebox volume allows these units to be filled with fuel relatively infrequently but because of this, they cycle between an active burn mode and a slumber mode in which air flow is reduced to reduce heat output. Older OWBs used natural draft with only updraft combustion. To reduce emissions, newer OWBs have forced draft or induced draft fans and a two-stage, downdraft combustion design. Indoor units also operate on cordwood. The units may also be installed in a weather-resistant shed or garage or may have a weatherization kit available for direct outdoor installation. Their most important distinguishing technical feature is a smaller firebox volume and small surrounding water volume. Typical features include two-stage, downdraft combustion and an induced or forced draft fan. Oxygen sensors and variable speed fans may be used with modern systems to improve combustion. These units are most likely installed with external thermal storage to prevent rapid cycling. In 2011, New York required that all outdoor wood boilers meet an emission standard of 0.32 lb/MMBtu by M-28 WHH. NYSDEC has also accepted the Brookhaven National Laboratory (BNL) Partial Thermal Storage test method. In this case, it is a more rigorous test that includes cold start emissions and separate measures of start, high burn, and end phase are reported for both $PM_{2.5}$ and CO. Two boilers have been accepted by NYSDEC by this method and more are anticipated. Table G-5 summarizes the emission factor assumptions for Phase 2 outdoor wood boilers, which are modeled in the residential and commercial sectors.

Table G-5. BAU Wood: Phase 2 Outdoor Wood Boiler Emission Factors

Pollutant	Emission Factor (lb/MMBtu)	Emission Factor Data Source
$PM_{2.5}$	0.393	Gullet, et al.[345]
CO	16.6	Gullet, et al.
NOx	0.1315	EPA Residential Wood Combustion Tool[346]
SO_2	0.145	EPA Residential Wood Combustion Tool
VOCs	1.70	Gullet, et al.

G.1.2.3 BAU Systems for Industrial, Commercial, and Institutional (ICI) Applications

At the larger scale of these applications, manual feeding of cordwood is uncommon and automatic feed of pellets and chips is used. The technologies used in this area are described in Technology section of this report. The most common systems can be classified as underfeed or grate systems, and these are all “stoker” automatic fed systems.

Underfeed

Like some residential pellet systems, the fuel is pushed into the active combustion zone from the bottom. An advantage of this system is that the fuel is heated, dried, and partially volatilized as it approaches the combustion zone.

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345 Gullet, et al. New York State Energy Research and Development Authority. Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater Technologies. Available: http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Wood-Fired-Hydronic-Heater-Tech.pdf.

346 Information on the U.S. Environmental Protection Agency’s Residential Wood Combustion Tool can be found on p. 144 of the 2011 National Emissions Inventory, Version 1, June 2014. Available: http://www.epa.gov/ttn/chief/net/2011nei/2011_nei_tsdv1_draft2_june2014.pdf.

Grate Systems

These systems place the biomass fuel across a grate arrangement with combustion air flowing from underneath. There are several different grate systems that differ on the method used to introduce and spread the chip or pellet fuel on the firing surface. The important grate system classifications are:

- Fixed Grate
- Moving Grate
- Vibrating Grate
- Spreader Stoker

Fluidized Bed

This refers to combustion systems in which a bed of inert material (e.g., sand) is put into a turbulent, suspended state by a flow of air fed underneath. Very strong mixing and turbulence leads to good combustion and heat transfer performance. Systems can be categorized as bubbling beds and circulating beds. These are more commonly used at the large end of ICI applications.

Table G-6. BAU Wood-chip Boiler Emission Factors

Pollutant	Emission Factor (lb/MMBtu)	Emission Factor Data Source
$PM_{2.5}$	0.279	NYSERDA boiler emission characterization study
CO	0.6	U.S. EPA AP-42
NOx	0.22	U.S. EPA AP-42
SO_2	0.025	U.S. EPA AP-42
VOCs	0.017	U.S. EPA AP-42

G.2 Best Available Technologies

This section provides an overview of the Best Available Technologies (BATs) in the European and North American biomass combustion markets, with an emphasis on emissions and efficiency performance. The BATs and nBATs are grouped according to the following seven categories:

1. Cordwood stoves
2. Pellet stoves
3. Cordwood boilers
4. Pellet boilers
5. Small-scale commercial/institutional heating systems (<1 MMBtu/hr)
6. Medium-scale commercial/institutional heating systems (1 – 10 MMBtu/hr)
7. Large-scale commercial/institutional heating systems (<10 MMBtu/hr)

G.2.1 Definition of BATs

The Project Team used the results of a market analysis by Musil-Schlaeffer (2010) to obtain data on the top performing units in Europe for cordwood and pellet stoves as well as cordwood and pellet boilers. This data was than analyzed to determine if devices with comparable performance were available in the United States. Units that met these criteria were considered BAT technologies.

G.2.1.1 BAT Cordwood Stoves

Cordwood stoves are typically used for room-size space heating, such as in living rooms and kitchens, and may be used for their aesthetic appeal in addition to their functional use for space heating. The European cordwood stove BAT has the following characteristics:

- Staged combustion air inlet (primary and secondary air inlet).
- Door window for viewing the flame.
- Air inlet above the window to prevent residue build-up on the window.
- Combustion chamber with ceramic lining.
- No electrical power connection (natural draught, no control unit).

Table G-7 represents characteristics of BAT cordwood stoves with a nominal load between 0.02 and 0.13 MMBtu/hr (Musil-Schlaeffer 2010). The project team defined the average nominal load for a cordwood stove as 0.038 MMBtu/hr.

Table G-7. Performance Characteristics of BAT Cordwood Stoves.

Evaluation characteristics	Average values
Efficiency (%) based on gross calorific value [a] (GCV) at full load (FL)	73
Particulate matter (PM) emissions (lb/MMBtu) at FL	0.05
Carbon monoxide (CO) emissions (lb/MMBtu) at FL	1.443
Organic gaseous carbon (OGC) emissions (lb/MMBtu) at FL	0.06075
Nitrogen oxides (NOx) emissions (lb/MMBtu) at FL	0.1701
Electrical power consumption (% of NL)	0

[a] GCV is the same as the higher heating value (HHV) of combustion.

G.2.1.2 BAT Pellet Stoves

Pellet stoves differ from cordwood stoves in the fuel they use and in that they can operate more or less automatically due to automated fuel feeding and pellet storage tanks. The characteristics for BAT pellet stoves include the following characteristics (EC Lot 15, 2009, p. 14):

- Staged combustion air (primary and secondary air inlet) with air inlet above the window.
- Window in the door for viewing the flame.
- Fan-assisted draught.
- Draught and temperature control.
- Automated ignition.
- Automated fuel feeding and a pellet storage tank.
- Combustion chamber with ceramic lining.

Table G-8 represents characteristics of the average of the best 25% pellet stoves with a nominal load between 0.008 and 0.034 MMBtu/hr (Musil-Schlaeffer 2010). The project team defied the average nominal load for a pellet stove as 0.033 MMBtu/hr.

Table G-8. Performance Characteristics of BAT Pellet Stoves

Source: Musil-Schlaeffer, 2010, p. 79.

Evaluation characteristics	Average values
Efficiency (%) GCV-based at FL	82.5
PM emissions (lb/MMBtu) at FL	0.044
CO emissions (lb/MMBtu) at FL	0
OGC emissions (lb/MMBtu) at FL	5.063
NOx emissions (lb/MMBtu) at FL	0.12
Electrical power consumption (% of NL)	0.6[a]

[a] Base Case from Moser et al. 2010, p. 56.

G.2.2 Cordwood Boilers

BAT boilers are gasification units designed on the downdraft combustion principle. The following list summarizes the features of BAT cordwood boilers:

- Staged air inlet (primary and secondary air) and control.
- Combustion chamber with ceramic lining.
- Fan to force draught (necessary in downdraft).
- Load and/or combustion control unit (e.g., oxygen sensor, weather and room temperature control, CO probes).
- Full thermal storage

The typical nominal load of North American cordwood boilers was defined at 0.081 MMBtu/hr. Table G-9 presents performance levels for BAT cordwood boilers with a nominal load between 0.04 and 0.116 MMBtu/hr.

Table G-9. Performance Characteristics of BAT Cordwood Boilers

Evaluation characteristics	Average values
Efficiency (%) GCV-based at FL	0% 80%
PM emissions (lb/MMBtu) at FL	0.050
CO emissions (lb/MMBtu) at FL	0.245
OGC emissions (lb/MMBtu) at FL	0.0122
NOx emissions (lb/MMBtu) at FL	0.171
Electrical power consumption (% of NL)	0.1[a]

[a] Best value from (Moser et al. 2010, p. 56).

G.2.2.1 BAT Pellet Boilers Residential and Small-scale Commercial/Institutional Heating Systems (<1 MMBtu/hr)

BAT pellet boilers are similar to pellet stoves. A screw feeds the fuel automatically into the combustion chamber by top feed, underfeed, or horizontal feeding. Often pellet boilers are connected with water storage tanks, enabling the boiler to run automatically over an entire heating period. BAT pellet boilers have the following characteristics:

- Staged air inlet (primary and secondary air) and control.
- Combustion chamber with ceramic lining.
- Fan-assisted draught.
- Load and/or combustion control unit (e.g., oxygen sensor, temperature control, CO-probes).
- Automatic fuel feeding (power modulating possibility).
- Automatic ash removal.
- Automatic heat exchanger cleaning
- Partial Thermal Storage

In Europe BAT chip boilers are widely available in this size range and when coupled with low moisture content have high efficiency, low emissions performance. In the U.S., the boilers or the fuel were not found to be available for these units, so they were not defined as a BAT technology for New York State. Table G-10 shows the performance characteristics of BAT pellet boilers. The average nominal load for a pellet boiler was defined as 0.081 MMBtu/hr. Units such as these are available in the U.S. today.

Table G-10. Performance Characteristics of BAT Pellet Boilers.

Source: Musil-Schlaeffer, 2010, p. 83.

Evaluation characteristics	Average values
Efficiency (%) GCV-based at FL At PL (30% of NL)	82%
PM emissions (lb/MMBtu) at FL	0.02
CO emissions (lb/MMBtu) at FL	0.05
OGC emissions (lb/MMBtu) at FL	0.0055
NOx emissions (lb/MMBtu) at FL	0.17
Electrical power consumption (% of NL)	0.1[a]

[a] Best value from Moser et al., 2010, p. 57.

G.2.2.2 BAT Medium-scale Commercial/Institutional Heating Systems (1 – 10 MMBtu/hr)

Heating plants with a maximum heat load of 1 to 10 MMBtu/hr are often fueled automatically with pellets or wood chips due to their operational requirements. Units smaller than 4MMBtu/hr tend to be pellet-fired systems, systems sized larger than 4 MMBtu/hr tend to be chip units. Both boilers typically use fixed bed combustion, such as grate furnaces or underfeed stokers, with no additional fuel treatment needed. Typical characteristics for these systems are:

- Staged air inlet (primary and secondary air) and control.
- Combustion chamber with ceramic lining.
- Load and combustion control unit (e.g., oxygen sensor, temperature control, CO probes).
- Fuel storage and drying.
- Automatic fuel feeding (power modulating possibility).
- Automatic ash removing.
- Automatic heat exchanger cleaning facility.
- Flue gas treatment (e.g.: bag filters, electrostatic precipitation, cyclones).
- Secondary measures for efficiency enhancement like flue gas condensation.

Table G-11 highlights performance characteristics for medium-sized BAT boilers.

Table G-11. Performance Characteristics of Medium-Sized BAT Boilers

Pollutant/Performance Value	NL 1-6 MMBtu/hr	NL 6-10 MMBtu/hr
Efficiency (%) GCV-based at FL	81% [a]	81% [a]
PM emissions (lb/MMBtu) at FL	0.07	0.03
CO emissions (lb/MMBtu) at FL	0.34	0.34
OGC emissions (lb/MMBtu) at FL	0.54	0.54
NOx emissions (lb/MMBtu) at FL	0.34	0.34

[a] Value from reference plant (1.32 MMBtu/hr NL) from Kaltschmitt, Streicher, 2009, p. 448.

G.3 Next Best Available Technologies

This section describes efforts to improve the performance of current biomass BATs, which lead to the "next Best Available Technologies" (nBATs). Generally, research is focusing on using renewable energy sources, lowering emissions further, decreasing nominal power needs, reducing costs, increasing efficiency, and enhancing ease of use and reliability. In addition, improving combined heat and power (CHP) production and optimizing control units and application systems (e.g., combining with solar heating.) are active areas of research (Moser et al. 2010). These technologies are beginning to enter the marketplace in Europe but are not yet available in the U.S. market. It is anticipated that nBAT units will be commercially viable within the next ten years.

The following sections describe innovations and areas of possible improvement for biomass combustion systems for each of the BAT groups described previously. This summary is based on the literature from Moser et al. (Moser et al. 2010) and the European Commission (EC Lot 15, 2009) as well as from experts with Bioenergy2020+ GmbH, a consortium specializing in the research, development, and demonstration of biomass-based technologies (http://www.bioenergy2020.eu/).

G.3.1 nBAT Cordwood stoves

For this technology, the current research focus for nBATs is on reducing emissions either by primary or secondary combustion measures. Areas for improvement currently being investigated include:

- Natural draft control.
- Combustion (air) control for more stable combustion conditions (emissions reduction).
- Additional water heat exchanger for hot water production (efficiency enhancement).
- Secondary post-combustion measures for reducing emissions (e.g., catalytic afterburning, electrostatic precipitation)

G.3.2 nBAT Pellet stoves

Pellet stoves are a relatively well-developed technology. Below is a list of areas where nBAT pellet stove characteristics:

- Automatic ash removal (improves ease of use).
- Additional water heat exchanger for hot water production (efficiency enhancement).
- Secondary post-combustion measures for reducing emissions (e.g., catalytic conversion, bag filters, electrostatic precipitation).
- Thermoelectric generators for electricity to eliminate need for electricity for operation.

G.3.3 nBAT Cordwood boilers

The state of the art of cordwood boiler technology has reached a high level as combustion and load control units are now standard equipment. Generally, research on areas of future improvement includes reducing emissions and improving efficiency of whole heating systems using different heat sources (e.g., solar thermal). Other research areas include small-scale combined heat and power production (micro-CHP) and combined heat and cooling (and power) production. These and other possible features of future cordwood boilers are listed below:

- Semi-automatic fuel feeding with cordwood reservoirs to improve ease of use.
- Secondary post-combustion measures for reducing emissions (e.g., catalytic afterburning, bag filters, electrostatic precipitation).
- Secondary heat exchanger for condensing appliance technology (enhances efficiency and reduces PM emissions).
- Hybrid system development to reduce emissions (e.g., combination with solar thermal power).
- Control units for (hybrid) heating systems to improve efficiency (e.g., including weather forecasts).
- Thermal cooling units (ad-/absorption chillers).

G.3.4 nBAT Pellet boilers

Research areas for pellet boilers are similar to those of cordwood boilers. Improving efficiency and adding generation of cooling and/or electricity are two of the main fields of interest, along with optimizing the integration of hybrid systems. These and other areas of possible future improvements are:

- Secondary post-combustion measures for reducing emissions (e.g., catalytic afterburning, bag filters, electrostatic precipitation).
- Secondary heat exchanger for condensing appliance technology to improve efficiency and reduce PM emissions.
- Hybrid system development to reduce emissions (e.g., combining with solar thermal power).
- Control units for (hybrid) heating systems to improve efficiency (e.g., including weather forecasts).

- Micro-power generation units (e.g., Stirling engines, steam engines, Organic Rankine cycle processes).
- Thermal cooling units (ad-/absorption chillers).

G.3.5 nBAT Wood chip boilers (< 1 MMBtu/hr)

Small-scale commercial/institutional heating systems (e.g., wood chip boilers) are undergoing further development to lower emissions and increase efficiency. In the U.S., the availability of a dry wood chip is required to use BAT or nBAT wood chip technologies. Primary areas of improvement for nBAT boilers include:

- Secondary post-combustion measures for reducing emissions (e.g., catalytic afterburning, bag filters, electrostatic precipitation, secondary de-NOx).
- Secondary heat exchanger for condensing appliance technology to improve efficiency.
- Hybrid system development to reduce emissions (e.g., combining with solar thermal power).
- Control units for (hybrid) heating systems to improve efficiency (e.g., including weather forecasts).
- Small power generation units (e.g., Stirling engines, steam engines, Organic Rankine cycle processes).
- Thermal cooling units (ad-/absorption chillers).

G.3.6 nBAT Medium-scale Commercial/Institutional Heating Systems (1 – 10 MMBtu/hr)

For medium-scale heating systems, advanced emission control systems, such as ESPs, are already common in Europe in order to meet national emission limits and are beginning to be used in the United States. Areas of improved performance for medium-sized nBAT boilers include:

- Hybrid system development.
- Integration with other heating options to reduce emissions (e.g., solar thermal power).
- Combining with additional components to improve efficiency (e.g., heat pumps – “active flue gas condensation”).
- Control units for (hybrid) heating systems to improve efficiency.
- Medium-power generation units (e.g., Stirling engines, steam engines, Organic Rankine cycle processes).

  Thermal cooling units (ad-/absorption chillers).

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