


BIOMASS
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Wood-Chip Heating Systems

A Guide For Institutional and Commercial Biomass Installations

By Timothy M. Maker

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How to Use This Book

Different readers will use this guide differently; the types of individuals who will find it useful are outlined in the section "Who Should Read This Guide?" at the beginning of Chapter One. The depth to which readers will study the various chapters will depend on their interest and experience. For example, a school board member whose school is considering a wood-chip heating system may want only a brief overview of automated wood systems and related issues, while a mechanical engineer who has been hired to specify and oversee a system's installation might want to read the guide cover to cover. The following paragraphs give a brief overview and suggest how readers might use the book.

A Chapter-by-Chapter Overview

Chapter One is intended to be useful to anyone interested in wood-chip systems. Its opening sections ("Who Should Read This Guide?" and "What Kinds of Facilities Use Biomass?") describe the kinds of settings for which wood-chip systems are appropriate and the people at those facilities who might benefit from this book. The next section looks at the reasons for considering a wood-chip system. The next section gives an introduction to the sources of biomass fuel. The final section ("What Does a Wood-Chip System Look Like?") briefly describes the appearance and function of a wood-chip heating plant.

Readers who want an overview of wood-chip systems might skim Chapter Two, dealing with wood chips and other biomass fuels, and Chapter Three, which lists in detail the components of a wood-chip system. Decision-makers for facilities might spend more time with Chapters Seven and Nine to learn about analyzing the cost-effectiveness of a wood-chip system and finding capital to finance the installation. Chapter Eight gives useful information on sources for technical and professional assistance.

Chapter Ten covers a variety of topics of interest to both lay decision-makers and technically oriented participants. Decision-makers and owners will find information here on putting together the pieces of a wood-chip system project, including the role of technical and professional resource people. The message on "The Importance of the System Operator" (page 57) is important for all readers.

A section of Chapter Ten, "Public Involvement, Public Education," is meant to assist anyone who will interact with the public in proposing a wood-chip heating system. See in particular "Commonly Asked Questions About Burning Wood Chips" on page 58.

The information in Chapter Eleven, "Operating and Maintaining a Wood-Chip System," will help the owners, managers, or operators of any installation. Along with the installation and first-year operation of a new system, this chapter covers ongoing issues related to maintaining and monitoring a system's performance.

Some chapters are intended in particular for readers who are concerned with the technical details of a wood-chip system. For example, the mechanical engineer hired to oversee the selection and installation of a chip system will benefit from a careful reading of all the technical sections, including Chapter Three on system components, Chapter Four on system efficiency, Chapter Five on emissions, Chapter Six on types of automatic wood combustion systems, and parts of Chapter Ten on implementing a wood-chip system project. The sections of Chapter Ten on performance specifications (page 61) and system sizing (page 62) will be especially useful to those responsible for specifying the wood-chip system during the process of selecting a manufacturer.

Chapter Twelve takes a speculative look at the future of biomass. This concluding chapter is intended to give the reader an idea of the larger world of the biomass resource and its possible future uses.

The appendices may be consulted as guides to further information on a variety of topics.

The Process of Analyzing and Installing a Wood-Chip System

This guide discusses in detail the steps involved in investigating the feasibility of burning wood chips, studying its cost-effectiveness, and installing a biomass system that will meet your facility's needs. Here is a brief summary of that process, with citations of the chapters most relevant to each step:

- **First, discuss the concept of biomass burning for energy.**
  Discuss how your facility could make use of wood chips or biomass energy. What fuel would it displace? How would it integrate with existing systems? Is there a good space for a fuel storage bin and boiler room? Is there any problem with truck access? What is the political climate that might affect decision-making for a biomass system? Who is interested in and supportive of the concept, and who is not? Why? (See Chapters One, Two, and Three.)

- **Review similar installations in your state or region.**
  Talk with your state energy and forestry offices and with others, including system manufacturers, who are knowledgeable about biomass installations in your area. (See Chapter Eight)

- **Research state air quality regulations.**
  Find out what state regulations, if any, apply to wood-fired boilers in the size range that your facility would need. Determine what is needed to meet the state environmental regulations, both for air quality and ash disposal. (See Chapters Three, Five and Ten.)

- **Research the availability of biomass fuel.**
  Find out what forms of biomass are readily available in your area, which suppliers serve institutional and commercial clients, what kind and size of delivery vehicles are in use, and what the prevailing prices are. (See Chapters Two and Three.)

- **Analyze the potential and the cost-effectiveness of burning biomass.**
  Study the economics of using biomass for heat, specific to your facility. (See Chapter Seven.)

- **Decide whether to install a biomass system.**
  Using the results of your analysis, weigh both the economic and other criteria and decide whether installing a biomass system makes sense for you. (See Chapter Ten.)

- **Set up the project structure for installing a wood energy system.**
  Secure financing (Chapter Nine); put together the project team and apply for all permits (Chapter Ten); research options for system design (Chapters Three, Four, Six, and Eight); produce wood-system specifications and solicit bids from system manufacturers and installers (Chapter Ten). Fully involve decision-makers and the general public (Chapter Ten).

- **Select a biomass system.**
  Review the bids, select the system that best suits your requirements and fine-tune the options and system components. (See Chapter Ten.)

- **Install and commission the selected system.**
  Contract with the selected installer, oversee the installation, and make sure that the system operates as it should. (See Chapter Eleven.)

- **Maintain the system for peak performance.**
  Maintain the system on a regular schedule, monitor its performance, and keep good records to document its effectiveness. (See Chapter Eleven.)

Chapter One

First Questions

Wood chips have been burned to make heat for decades, but the past 20 years have witnessed an exciting growth in the numbers of wood-fired heating plants for schools, hospitals, government buildings, and businesses. At the heart of this new application of wood energy is the attraction of using a renewable, locally produced energy source that is generally the least expensive fuel available.

One purpose of this book is to increase the number of people in decision-making positions who are knowledgeable about wood-chip heating, and who can bring an understanding of this technology to the process of making decisions about heating buildings. Wood-chip heating generally comes under consideration only because someone involved in the facility has heard about the technology, or knows of another facility where a wood-fired heating plant is operating successfully. Despite its obvious attractions, burning wood chips does not usually come to mind when new buildings are built or when heating plants are modernized.

This guide aims to give a broad understanding of the components and workings of a wood-chip system. Along with discussing features common to all systems, the guide presents options and alternatives, and their strengths and weaknesses for different settings. The clear intent is to assist readers in selecting the approaches that are best-suited to their particular situations, so the systems installed will be appropriate, will save money, and will be easy to operate and maintain. The guide also offers help with the process of selecting a system so that its features and first costs can be analyzed in relation to long-term operating costs.

This chapter of the guide looks at some initial questions: What individuals are likely to benefit from reading the guide? What kinds of facilities are good candidates for burning wood chips? What are the reasons for burning wood chips or other forms of biomass? Where does biomass come from? What does a wood-chip system look like, and how does it fit in with a building's appearance?

Who Should Read This Guide?

This book is intended for prospective owners of institutional, commercial, and light industrial heating systems fired with wood chips or similar biomass fuels. (Biomass is biological matter that can be burned for energy. In this guide the word is used as shorthand for wood, one of the categories of biomass.) Although the guide was developed for the 11-state Northeastern region of the United States, much of the information here can be applied to facilities in other regions with similar biomass resources.

Among those who may profit from reading this guide are:

- prospective owners of wood-chip systems;
- board members, executives, and decision-makers;
- business and facility managers;
- maintenance directors and heating plant operators.

Although this is not a system design manual, the guide is a technical resource for the professional consultants — mechanical engineers, architects, and project managers — hired by the owners to study and implement biomass energy systems. In addition, laypeople and volunteer members of institutional building committees will find in these pages useful information on wood-chip systems and related issues. People associated with existing biomass energy facilities may use the guide to broaden their understanding of their own systems.

What Kinds of Facilities Use Biomass?

In each of the categories listed below are a number (in some categories a large number) of facilities in the United States that currently have automated biomass energy plants and purchase wood fuel. The facilities listed do not include the hundreds of larger wood burners in the biomass fuel-producing forest products industry.

Facility Types Suitable for Biomass Systems:

- Schools
- Colleges
- Hospitals
- Public buildings
- Hotels and motels
- Commercial buildings
- Greenhouses
- Large-scale agricultural operations
- Manufacturing plants

As part of the development of this guide, a 1993 survey of biomass installations in the Northeast and adjacent regions found 43 schools, 26 hospitals, 17 colleges, 22 greenhouses, six correctional institutions, and 20 commercial or industrial facilities that are using biomass fuel. Another 20 installations are operating in a wide range of settings: an environmental education center, two monastic orders, an urban arts center and library complex, two government forestry education centers, a luxury resort hotel/ski area/industrial plant complex, a low-income housing project, two state building complexes, and two downtown district heating systems. Since 1993, dozens of other wood-burning facilities have been added.

Most biomass energy plants use some form of wood to meet their facilities' needs for space heating or domestic hot water. Industrial plants that use process steam (either low or high pressure) in manufacturing are also good candidates for biomass energy systems, because their energy requirements are high and their demand for energy is steady year-round.

The information in this guide is applicable to both existing and new buildings. Many biomass systems are installed as conversions in existing facilities, but it is even more cost-effective to install them in new construction, usually with an oil-fired or gas-fired backup system. In Vermont, for example, a number of new schools have been built with wood-chip burners as their original primary heating systems.

The size range of the heating plants considered here is from 1 to 10 million Btus per hour output (1-10 MMBH). Above 10 MMBH, biomass systems are typically designed by specialized engineers, who may select various components from different manufacturers and take responsibility for making the package work. However, some manufacturers of large systems do provide complete design and installation services for plants much larger than 10 MMBH. Most of the examples cited on page 6 are smaller than 10 MMBH; some of the hospital, college, and district heating systems cited are larger.

Most systems smaller than 1 MMBH are less automated and take more operator involvement than the fully automated systems that are the focus of this guide. Small systems, in the range of 200,000 Btu/hour to 1 MMBH, are more likely to be found in large residential or agricultural settings, or in small schools. These small systems typically require the use

Shelburne Farms, Shelburne, Vermont
Facility Type: Farm educational center
System Size: 2.1 MMBH
Manufacturer: Chiptec Wood Energy Systems
Right photo shows a two-chamber system with boiler (on right) and combustor, connected by a blast tube.

Beyond Economics:
Other Reasons for Burning Biomass Fuels

- **Biomass fuel comes from a renewable, sustainable resource base.**
  Fossil fuels will eventually run out, but with proper forestry practices, the biomass resource base can be sustained indefinitely.

- **The fuel is available in great quantity in every state of the Northeast and in other regions.**
  There is an excess of existing biomass fuel in the Northeast now, and the forest resource can support a greater utilization of biomass in the future. Huge volumes of low-grade wood in the national forests of the western states pose a fire forest risk to communities; using this wood for energy both protects communities and reduces reliance on costly fossil fuels.

- **Biomass fuel dollars stay in the local and state economy.**
  Biomass comes from in-state businesses that use local labor for cutting, hauling, chipping, and delivering fuel. The raw material - growing trees - is purchased from local landowners. Increasing the use of biomass helps the local tax base and builds tax revenues.

- **Biomass fuel prices have been stable historically and are not directly linked to national or global energy markets. Biomass fuels can be expected to increase in price more slowly than competing fuels.**
  Over the last 15-20 years biomass prices have stayed level or decreased, regardless of the dramatic fluctuations in the prices of oil and gas.

- **Biomass systems are often capable of giving higher levels of comfort at a lower energy cost.**
  Because biomass fuels are very inexpensive, many building owners feel they can now afford comfortable building temperatures in winter weather. With higher-priced conventional fuels, owners often reduce temperatures or reduce ventilation to save money.

- **Biomass pricing is not subject to monopolistic control.**
  Because the fuel comes from scores of independent mills and chippers in every state of the Northeast, it is unlikely that any large fuel supplier could corner the market.

- **Future energy taxes, such as a carbon tax or a Btu tax, are less likely to impact the price of biomass fuels compared to fossil fuels.**
  In national policy discussions, energy taxes generally give preference to renewable, locally supplied fuels that do not lead to global warming.

- **Biomass has a negligible sulfur content, so its combustion does not contribute to the atmospheric buildup of oxides of sulfur (SOx), a cause of acid rain.**

- **When biomass is burned for energy, using wood from sustainable forestry practices, there is no net increase in the greenhouse gases that cause climate change.**
  When biomass replaces fossil fuels, there is a net reduction in greenhouse gas emissions.

- **Using wood wastes from sustainable forestry as fuel increases the health of the forest resource.**
  Forestry officials in the Northeast are looking for new markets for low-grade wood wastes from the forest, as a way to remove cull trees and improve forest health.

- **Biomass systems are relatively easy to convert to other fuels and so offer great flexibility for an uncertain energy future.**
  Solid-fuel systems, particularly those made to burn chunky fuels like wood chips, can readily be converted to burn almost any other fuel.

- **In some regions, certain forms of biomass are considered waste products; burning them for energy can reduce disposal costs and free up landfill space.**

- **As public consciousness and information about environmental and resource issues increases, voters often see wood energy as an attractive choice over fossil fuels.**

Comparative Fuel Prices

Fuel	Fuel unit	Fuel price range per unit	Gross fuel cost per MMBtu	Net fuel cost per MMBtu
Hardwood Chips	ton	$20 – $34.00	$2.00 – $3.45	$3.10 – $5.30
No. 2 Fuel Oil	gal	$.80 – $1.40	$5.90 – $10.30	$7.85 – $13.75
No. 6 Fuel Oil	gal	$.80 – $1.20	$5.70 – $8.55	$7.60 – $11.45
Electricity	kwh	$.06 – $.15	$17.60 – $43.95	$17.60 – $43.95
LP Gas	gal	$.80 – $1.50	$8.70 – $16.30	$10.85 – $20.40
Natural Gas	ccf	$.65 – $1.00	$6.50 – $10.00	$8.15 – $12.50
Coal	ton	$100 – $150	$4.00 – $6.00	$5.70 – $8.55

of a small tractor with a front-end bucket to move chips from an inside storage pile to a day bin that feeds the combustion system. The operator will generally spend less than an hour daily for this task.

Biomass-fired cogeneration systems and electric generating plants are not covered in this guide in much detail. Cogeneration, the simultaneous supply of heat and electricity, is attractive because it provides more energy from the same amount of fuel. Commercially available biomass cogeneration systems are typically of an industrial scale - larger than the systems covered in this guide. These biomass cogeneration systems employ high pressure steam boilers and require a high level of operator skill and attention.

New biomass gasification equipment, which will supply combined heat and power (CHP) from wood wastes, is currently under development. This technology promises higher efficiency, better emissions, and easier operation when compared to cogeneration using steam boilers.

District heating is another good application of biomass energy. District heating is the use of a central heating plant to provide heat to multiple buildings, using buried pipes to distribute the energy. Wood-fired district heating is an appropriate technology for providing heat to small communities, college campuses, and groups of public buildings. In Scandinavia it is common to use biomass cogeneration in the central plants of community district heating systems, providing both heat for the system and power to the community.

Why Use Biomass Fuels?

For most building owners, extremely low fuel cost is the main attraction of burning wood chips, and other biomass fuels such as sawdust and bark. There are other reasons to use biomass for energy as well. Some are statements of good public policy, some are based on user preference for "green" energy, and others are practical.

The Economics of Using Biomass for Energy

The table at left compares the cost of green hardwood chips to the costs of other available fuels. It lists the 2003 price range for each fuel, based on a survey of facilities done for the development of this guide. Note that for each fuel, the high end of the range is the retail price for customers with low consumption, and the low end is the wholesale price for high consumption. The table also lists the fuel cost per million Btus of delivered energy, on both on a gross and a net basis. The gross is the cost of fuel before combustion; the net fuel cost, including the seasonal efficiency of the heating plant, gives the cost per million Btus of usable heat output. The supporting calculations for this table include the Btu content of the fuel, and the appropriate seasonal efficiency for each fuel type.

To make a fair comparison of fuels for low-use situations, look at the high ends of the two fuels' price ranges. For high-use situations where wholesale pricing would be available, compare the low-range figures. Note that no. 6 fuel oil is an industrial and large-commercial fuel that has only wholesale pricing. It would be appropriate to compare it to the low-range price of wood chips.

Keep in mind that the figures in this table are specific to one point in time, and are presented to support the general conclusion that biomass fuel is considerably less expensive than the competing fuels. In making actual comparisons it is important to use current fuel prices from local suppliers.

In contrast to its low fuel cost, the capital cost of a wood-chip system is considerably higher than that of conventional fuel systems. But in many cases, the fuel-cost savings from burning wood chips will be substantial enough to pay for the cost of borrowing capital over a period much shorter than the life of the system.

Generally, wood-chip systems will most likely be cost-effective where conventional fuels are expensive, when installed in larger facilities, when they are financed for periods of 10 years or more, and/or when there are state funds that help the local user by subsidizing the cost. For example, the simple payback for automated systems in schools is about 12 years. If a school finances a system with a 20-year bond, the cash flow may be positive from the early years and throughout the bond period. After the bond is retired, fuel savings of fifty percent compared to fuel oil are normal and can generate significant cash savings.

Other Reasons

Beyond the economics of burning an inexpensive fuel, there are many more reasons why building owners or facility decision-makers in the Northeast might want to burn biomass. Some of those reasons, though hard to quantify, have a positive impact on long-range economics and on the reliability of both the supply and the price of energy.

In recent years, there has been a strong growth of interest in "green" energy (clean, renewable, sustainable energy), and in public programs that target reducing the emissions of climate-change gases into the atmosphere. The primary human-induced cause of climate change is the atmospheric buildup of carbon dioxide from burning fossil fuels. When wood is burned for energy, there is no net addition of carbon dioxide to the atmosphere, making biomass energy a powerful tool for greenhouse gas reduction.

While all the reasons listed here present a strong case for burning biomass, decision-makers should also give serious thought to the problems associated with biomass fuel systems. Some of these are listed in "Concerns Associated with Biomass Fuels."

Concerns Associated with Biomass Fuels

- **Burning biomass usually takes more operator attention then burning conventional fuels.**
  A biomass system can be shut down if an oversized chip jams the fuel handling equipment. Operators need to watch for jamming and shutdowns, which are more frequent than with oil or gas systems. (See "The Importance of the System Operator" on page 57.)

- **In contrast to other fuels, biomass fuel is variable in quality. It may require more vigilance and effort from the owner to ensure the desired fuel quality.**
  Fuel quality can vary with the time of year and the species of wood being chipped. Chip suppliers may become lax about the size characteristics of the fuel they provide and about keeping the fuel from getting wet when it rains or snows.

- **It may require time and effort to set up a stable biomass fuel supply network in a region where one is not in place.**
  Most marketable biomass in the Northeast is sold to paper mills and electric generating plants. It may be difficult to get biomass suppliers to meet the needs of institutions such as schools and hospitals that are used to the level of customer service that oil dealers provide.

- **Biomass does not burn as cleanly as natural gas. The public may be worried about a new biomass installation because of the reputation of wood burning as being "dirty".**

  Public education about modern wood-chip heating is critically important for the success of any project. The public's perception of wood-burning is often based on home wood stove experience, with little or no understanding of the new generation of wood-chip systems.

- **Some biomass systems require more maintenance than systems using conventional fuels.**

  While the best biomass installations have no higher maintenance costs and personnel needs than facilities that burn oil or gas, some biomass system owners have experienced increase maintenance costs for either operator time or parts replacement and repairs.

Randolph Union High School, Randolph, Vermont
System Size: 3.5 MMBH
Manufacturer: Chiptec Wood Energy Systems
The wood heating plant shown heats a large building encompassing a middle school, a high school and a vocational center. The wood system was installed when old heating equipment was modernized.

Public Policy

The economic and other reasons for burning biomass are the basis of state and federal energy policies that encourage the increased use of biomass for energy in the Northeast and elsewhere. States with aggressive and proactive renewable energy policies may also consider the following:

- Offsetting consumption of fossil fuels is a viable policy goal. Success can be measured in barrels of oil (or tons of coal) displaced annually by biomass in the state.
- Success in promoting biomass for energy can be also measured in annual tons of biomass burned in the various sectors of the state's energy economy.
- Another indicator of success is the net reduction in carbon dioxide emissions, and the associated climate change benefit, resulting from displacing fossil fuel with biomass.
- Federal and state forestry agencies strongly support the use of biomass for energy because it creates new markets for low-grade wood wastes, supporting the forest products industry and the health of the forest resource.

Where Does Biomass Come From?

The most common type of biomass used in heating systems is chipped wood, a byproduct that usually comes from sawmills. Mills have stationery chippers that chip up slabs and other green (un-dried) wood that is not suitable for lumber. This material is rarely allowed to build up on site, but is instead loaded into tractor trailer trucks that deliver it, either to pulp and paper mills or to operators of wood energy systems. Heating system operators like mill residue chips because they are quite uniform, with few oversized pieces that might jam machinery.

Some biomass energy facilities use chips that come from harvesting operations in the woods. Mobile chippers are used to turn diseased and other "cull" logs into chips, while most of the tops and branches stay in the forest to return nutrients to the soil. These chips are blown from the chipper into delivery trucks, which deliver them to pulp and paper mills and to biomass energy users. Because chips from the woods are less uniform than mill residue chips, energy users may prefer mill chips, unless there is a significant price difference.

The third common source of biomass comes from the waste stream of forest products industries, such as furniture manufacturers. These wastes are typically dry, so they include more wood and less water per ton of biomass. Manufacturing wood wastes are often used by the plants that produce them, and are less likely to be available for purchase by energy users. Also, institutional users tend to avoid dry wood because it comes with more dust, compared to green wood wastes, and its much higher level of flammability increases fire risk.

Small biomass energy users rarely burn wood from the municipal solid waste stream, such as construction and demolition wood, because it is not likely to be readily available for purchase and may not be acceptable to air quality regulators.

Although a common perception of wood fuel may be that it is dirty and hard work to handle, that view is not accurate for the automated biomass systems considered in this guide. Modern, fully automated biomass energy systems involve no manual fuel handling, and semi-automated systems require minimal operator involvement. The fuel is stored out of sight in enclosed bins, and the combustion process is more efficient and clean-burning than the modern wood stove. (Chapter Ten discusses in detail the issues of public perception and public education in biomass burning.)

What Does a Wood-Chip System Look Like?

Biomass heating plants are similar in their functional parts to heating plants that run on conventional fuels. They include large-volume fuel storage capability, a means of moving the fuel from the storage bin to the burner, a burner and boiler to burn the fuel and extract the useable heat from combustion, and connection to a chimney that disperses the combustion gases. Boiler rooms or boiler houses for biomass systems are usually larger than conventional boiler rooms, because wood boilers are larger and the fuel-handling equipment takes up extra space. The chimney of a biomass system is usually taller than that for an oil or gas system.

From the outside, a biomass system looks much like a conventional boiler facility, except for its fuel storage bin. While oil and liquid propane (LP) gas are typically stored in buried tanks (natural gas requires no on-site storage), wood-chip bins may be above or below ground. If the wood-chip bin is below ground, which is the common case, only its loading doors are visible. Above-ground bins may look just like farm silos: they are round concrete or metal silos of varying heights.

In most cases, to the casual observer, biomass energy systems in the 1-10 MMBtu size range do not alter the outer appearance of the facility. They fit into the look of the existing buildings and the surrounding locale. When operated properly, they do not produce visible smoke. However, because the biomass fuel usually burned is green, or close to one-half water, in cold weather the chimney may show a plume of condensed water vapor. Interviews with dozens of system operators support the conclusion that odor generated by the fuel or the smoke is almost never a problem.

Many of the photographs in this book were selected to show how the biomass heating plant fits into the overall appearance of a facility.

Interviews with system owners indicate that truck traffic for institutional biomass systems is not a significant issue. Just as a large oil-burning facility will receive fuel deliveries from large tanker trucks, chip systems get fuel delivered in tractor trailers. It takes five to six chip deliveries to equal one 7,500-gallon oil tanker load. As an example, most biomass systems in schools average from six to 40 deliveries per year. Truck traffic for wood-chip deliveries is usually less frequent than that for other school supplies delivered by tractor trailer. For other institutional or commercial facilities that burn biomass, the number of deliveries may be comparable to or higher than that of schools, depending on the size of the facility and its heating requirements.

Chapter Two

Wood Chips and Other Types of Biomass Fuels

In this book the terms wood chips and biomass are used interchangeably, because wood chips are the fuel currently burned by almost all the facilities that use biomass energy in the Northeast. Biomass generally means any biological matter that can be burned for energy, including cordwood, wood chips, sawdust, bark, various other forms of chipped sawmill wastes, and wood shavings or other ground-up wood from wood manufacturing operations. Other, less usual forms of burnable biomass include straw, corncobs, nut shells, seed hulls, pine cones, and some food-processing wastes.

Wood pellets are another form of biomass fuel — but for a number of reasons, pellets are not included in this discussion of wood burning. Unlike most other biomass fuels, pellets are a manufactured product. They therefore have a considerably higher price per Btu than other forms of biomass, and so do not carry the price advantage that makes biomass attractive. Pellets are generally better-suited to smaller heating plants than to the systems considered here. Pellets are easier to store and handle automatically, compared to wood chips, and pellet systems are usually simpler and less expensive to install.

Although wood chips are by far the most prevalent form of biomass fuel in the Northeast, potential users should be aware that local markets and changes in markets over time may present attractive opportunities for burning other biomass fuels. For example, sawdust might be available inexpensively from a local source. While there are practically no sawdust burners outside the wood products industry in the Northeast, in eastern Canada it is fairly common to burn sawdust for energy in agricultural and commercial settings.

Mill Residue Chips

For institutional users in the Northeast, sawmills are the main source for wood chips. Mills typically chip their slab wood and other residues that are unsuitable for lumber. Stationary mill chippers usually include some sort of screening and rechipping to make the product more uniform in size and quality. The typical mill chip is about the size of a matchbook. A good-quality mill chip is considered a high-grade product, both for combustion systems and as a feedstock for paper mills. For this reason, the price is likely to be higher than for whole-tree chips, which are described in the next segment.

Most sawmills chip directly into tractor trailer vans for immediate delivery. Some store the chipped product in metal silos, which are excellent for keeping the fuel clean and dry. Other mills may stockpile the fuel in open piles.

Users should be very cautious about burning fuel that has been stored outdoors. Surface moisture from rain and snow may make it harder to burn. Also, gravel and rocks may be picked up when chips are scraped off the ground to load into the delivery truck. Both excess moisture and foreign matter will definitely cause problems with chip handling and combustion equipment.

Whole-Tree Wood Chips

Whole-tree chips come from harvesting operations in the woods. (Chips are typically rectangular, about 1/2-1" x 1-3" x 1/4".) Large portable chippers that can reduce whole trees to chips blow the chips into tractor trailer vans (the term van refers to the trailer). The trucks then go on the road immediately to deliver to customers.

Mountain View School, Kingsley, Pennsylvania
Facility Type: Two schools on adjacent properties
System Size: 9.5 MMBH
Manufacturer: Sylva Energy Systems
Showing chip delivery from self-unloading tractor-trailer van.

These chippers can be used on whole trees, on tops left over from logging or firewood operations, or in forestry-thinning practices. In the more urban parts of the Northeast, land clearing for highways or development can also be a major source of whole-tree chips.

Whole-tree chips can be produced from entire trees, or only from their trunks (stems) and major branches. The latter type of chipping produces bole chips. Bole chips are much more likely to be uniform in size than chips made from entire trees, which include small branches. Screening, to separate out oversized chips, is not common in whole-tree chipping operations.

Whole-tree chips are primarily sold to wood-fired electric generating plants and paper mills. In some areas, however, there may be enough institutional and commercial wood-chip burners to support suppliers who cater specifically to that market.

Fuel quality is extremely important in burning whole-tree chips. Whole-tree bole chips can be produced with the kind of size uniformity that makes them a good fuel for automated burners. However, a supplier who is not careful in routine sharpening of the chipper knives may get a significant number of oversized chips. Chipping small branches can also produce oversized chips. These long, skinny pieces can jam the augers that convey fuel to the wood burner, temporarily shutting it down. Such shutdowns can increase operating costs and be very aggravating for system operators.

The best way to ensure fuel uniformity and quality is to have a good fuel procurement specification. Suppliers can control chip quality by developing good operating and maintenance procedures for chipping, by training the chipping equipment operators, and by enforcing use of the procedures.

Some whole-tree chippers work under contract to supply large mills or power plants that have equipment on site to screen and rechip the fuel. These chippers may not be as careful about chip quality as are those who chip specifically for the institutional and commercial markets. Potential users need to check a supplier's chip quality, since reprocessing machinery is generally too expensive for the types of facilities addressed here.

Sawdust, Bark, and Other Mill Biomass

Green sawdust produced by sawmills is a viable fuel for combustion. (Green sawdust comes from the cutting of undried timber, as opposed to sawdust that comes from the cutting of kiln-dried lumber.) The ability of green softwood sawdust to burn well depends on the species; in general, users should be wary of counting on softwood sawdust as a reliable fuel. Hardwood sawdust is preferable. Burning dry sawdust (from kiln-dried wood or other dry wood sources) is not recommended outside the wood products industry because the sawdust is extremely flammable, making special precautions necessary for safe burning.

The price and availability of sawdust can vary dramatically from region to region. The price for sawdust as fuel also depends on the competing uses for it. In areas with many dairy farms, sawdust has traditionally been in great demand for animal bedding, and so has commanded a high price. In other areas with no ready market, sawdust is seen as a waste product and may cost little more than the expense of trucking it.

Barre Town Elementary School, Barre, Vermont
System Size: 4.5 MMBH
Manufacturer: Messersmith Manufacturing
This large school was converted from electric heat to a hot water system with a new stand-alone wood boiler plant.

Sawdust is very smooth-burning and easy on the fuel handling equipment. However, it is prone to freezing in cold weather. Above-grade bins or silos are not recommended for sawdust systems in cold climates. If a potential biomass user plans to burn sawdust, both the combustion equipment and the fuel storage facility must be designed specifically for it.

Bark is known as a dirty and difficult fuel, even though it has a higher energy content per dry pound than wood. Bark tends to pick up mud and grit during logging, is abrasive to machinery, and creates problems on combustion grates. Ground-up or hogged bark pieces tend to be long and stringy and can jam auger systems.

In some areas where there is little competing demand for it, bark can be purchased very cheaply — and some users are willing to put up with the problems of burning bark if they can get it inexpensively. In most of the Northeast, however, there is a competing demand for bark to be used as mulch for gardening and landscaping. In general, only the most dedicated biomass burners should consider bark for energy.

The term hogged fuel covers a range of mill residues produced by a hog mill, which grinds up scrap wood. Some hogged fuel is a coarse mixture of sawmill wastes (sawdust, bark, and unsalable wood), ground up and mixed together. Like bark, it is considered a difficult fuel, and institutional users generally stay away from it unless there is a ready supply and fuel price is of overriding importance. Hogged fuel can also refer to high-quality wood scrap that has been hogged and screened; this very uniform product makes a good combustion fuel.

Clean Municipal Wood Waste

In most areas, the various forms of biomass are no longer regarded as waste but as resources for energy and other purposes. In keeping with this trend, a new form of biomass is becoming available. Municipal wood waste (MWW) includes wood from sources like urban demolition and construction debris, waste material from some industrial processes, and chipped biomass from urban tree waste and utility right-of-way clearing. Used shipping pallets can also be considered MWW.

MWW differs from other forms of biomass in that it is more likely to contain contaminants that should not become part of the combustion process. For this reason, MWW has to be processed by the supplier, both to reduce it to manageable-sized pieces (similar to wood chips) and to remove nails, tramp metal, and other foreign objects.

While attractive for larger utility-sized boilers, MWW is not commonly used as a fuel source for the types and sizes of institutional and commercial facilities being addressed in this book. Biomass burners should be aware that fuel quality and the possibility of toxic components, such as paint or chemical treatments, are very important factors in considering the use of MWW as a fuel. Air quality regulators are likely to look more critically at MWW than at forest and mill-residue biomass, and the public is more likely to oppose the construction of a plant that uses MWW.

The Role of Fuel Moisture

All biomass fuels are made up partly of water. Fuel moisture is commonly expressed on a wet basis: a fuel that is half water by weight would have a 50% wet basis moisture content. Fuels are also sometimes characterized on a dry basis. In the example just given, the same fuel would have a 100% dry basis moisture content, because the weight of water is equal to the weight of dry wood. Most purchased biomass fuel is green or undried, with 30-55% of the delivered weight being water. All references to fuel moisture in this guide are on a wet basis. See Appendix C for data on fuel moisture and its relationship to available fuel energy.

Mill chips usually average about 40% moisture (wet basis), whereas whole-tree chips are slightly higher. Moisture levels vary up and down, 5-10%, by the season of the year and the species of wood. It is hard for chip purchasers to specify moisture levels closely, because suppliers have little control over moisture content. Some purchasers spot-check fuel moisture to assure that the fuel conforms to their specifications and is not being stored in open piles before delivery.

Fuel should always be protected from precipitation to prevent freezing and clumping, composting, and heat buildup. Biomass fuel that has always been kept under cover will dry out if left over time. In most systems, though, the fuel does not stay in the storage bin long enough to dry significantly, or to begin composting if it has been rained on.

High fuel moisture levels decrease burning efficiency because the significant portion of the fuel that is water is not burnable. Efficiency is also reduced because a large part of the energy available in the wood itself is used to heat up and evaporate this moisture. One way to increase efficiency would be to dry the fuel on site. However, the cost of equipment to do this is very high. For this reason, fuel driers are almost never found in facilities sized below 10 MMBtu.

Another way to boost system efficiency is to purchase and burn dry biomass fuel. Dry biomass fuels, in the form of shavings, sander dust, or hogged dry scrap, may be available from furniture mills and other wood products industries that use kiln-dried wood. The biomass combustion equipment must be specifically designed or tuned for this dry fuel, since its combustion characteristics are different.

For institutional burners, green biomass offers decided advantages in safety and peace of mind. Green chips are almost unburnable outside the controlled conditions of the combustion chamber. Dry fuel, in contrast, combusts readily. Systems that are intended to burn dry fuel must have special burnback and fire-suppression devices, along with more sophisticated alarm signals.

Hardwood, Softwood, and Wood Species

In the Northeast, most institutional and commercial biomass systems burn hardwood rather than softwood, in part because of the characteristics of the fuel available on the market, and also because of hardwood's inherent advantages over softwood. There are important differences between hardwood and softwood. The first is that softwoods are on average about 10% less dense than hardwoods, and some softwood species are much less dense (white pine, for example, is 35% less dense than hardwood)[1]. A tractor trailer van of hardwood chips might hold 25 tons of hardwood chips, but only about 22.5 tons of softwood chips.

The second difference is that softwood's moisture content is higher, by as much as 10%. A ton of hardwood chips at 40% moisture would have 1,200 pounds of dry wood, whereas a ton of softwood chips at 50% moisture would have only 1,000 pounds of dry wood.

Together, these two effects give the same volume of softwood significantly less available energy for combustion. A van load of hardwood might have 260 million Btus of energy, while the same load of softwood chips might have only 190 million Btus. And because a significant portion of the available energy is used to evaporate the moisture in fuel, high-moisture softwood fuels have even less useful heat output.

Neither hardwoods nor softwoods have an inherently higher Btu content per pound of dry wood. The amount of energy in wood, expressed in Btus per pound of dry wood, does vary by species (see Appendix C for a species listing). But with a mix of species, there is little difference between hardwood and softwood in the amount of energyper ton of dry fuel. As explained above, the major differences are in density and moisture content.

There is a common misconception among burners of hardwood that "you just can't get enough heat out of softwood." In fact, facilities in areas where softwood predominates burn it successfully; they simply have to burn a higher volume — and more tons — than if they burned hardwood.

Designers need to know whether the fuel intended for a system is softwood or hardwood. Softwood combustion systems have faster feed rates and may have differently designed combustion chambers and grates. In general, it is easier to burn hardwood in a system designed for softwood than to burn softwood in a system designed to burn hardwood. Some manufacturers' systems can burn either of the two fuels interchangeably.

Sources, Availability, and Price of Biomass Fuel

In most parts of the Northeast, institutional and commercial biomass energy systems represent a small market. These facilities typically buy from sawmills and whole-tree chippers that serve other, much larger markets such as paper mills or wood-fired electric generating plants. Sometimes the small biomass energy user will buy from local truckers who specialize in hauling wood chips or other biomass.

If a region has a large-enough market of institutional or commercial users of fuel biomass, it may also have mills or chippers that cater to this market. These suppliers will have delivery vehicles specifically suited to serving small institutional systems — and they will be more responsive to the special needs of institutional and commercial users that are not part of the forest products industry. Suppliers in a healthy, competitive chip market may be willing to invest in the equipment and time needed to screen their chips to give a more consistent product.

Because the two markets are quite different, small biomass users rarely buy through the brokers who procure biomass fuel for large power-plant and industrial users on a contract basis. Institutional users often have higher standards for fuel quality, and require more load-by-load administrative work, than large users who might need one or more truckloads of fuel each day. Small users are also almost certain to require deliveries from self-unloading trucks, while most large users have truck-unloading equipment on site.

In some cases, an institutional or commercial biomass user may develop a special relationship with a local fuel supplier in the immediate vicinity. This might lead to lower fuel prices or the availability of types of biomass not generally found in the regional market. It can also provide stability of supply and assurance of continuity.

In some areas, biomass users are able to find suppliers within a 30-mile radius, which helps to reduce the transportation component of fuel cost. In other areas, suppliers are already shipping fuel 100 miles or more, and may be very happy to find a local market. (This may be reflected in lower prices to the local user, or inhigher profits for the supplier.)

The 1999 price for premium biomass fuel, high-quality hardwood mill chips, was generally in the range of $25-30 per ton in the Northeast. Whole-tree chip prices are often cheaper than mill chip prices, depending on the competitiveness of the regional market. In some areas it may be possible to get whole-tree chips for $15-20 per ton. Only the largest institutional and commercial users generally purchase enough volume to get prices below $15 per ton. The exception would be the case of a specific local relationship between an individual user and a nearby supplier.

[1] Bruce McCallum, Handbook for Small Commercial Biomass Systems on Prince Edward Island (prepared by Ensight Consulting for Energy, Mines and Resources Canada, Charlottetown, PEI, Canada).

Chapter Three

The Components of a Biomass Energy System

Even more than gas and oil systems, solid fuel systems require a careful integration of components to make sure the whole operation runs smoothly. These components include:

- the fuel storage facility,
- any driveways necessary to provide access for large fuel-delivery trucks,
- a boiler room to house the combustion equipment,
- the boiler or combustion appliance,
- fuel-handling equipment to move the fuel from storage to the boiler,
- a chimney to exhaust the combustion gases,
- any necessary exhaust-gas cleaning devices,
- ash disposal equipment, and
- the controls that keep all the equipment operating optimally.

Also, the person who actually operates the plant is one of the most important components of a successful system. This will be discussed in more detail later.

Types of Fuel Storage Systems

The most common type of biomass fuel storage for automated commercial and institutional facilities is the rectangular, below-ground concrete bin. Compared to above-ground storage, these bins have a number of advantages:

- Because the bottom layers of chips are well below frost level, below-ground bins keep chips from freezing in cold weather.
- Self-unloading delivery trucks can use gravity to discharge quickly into the bin without any other mechanical equipment.
- Below-ground bins may be less visually obtrusive than those built above ground.

Photographs throughout this book illustrate various configurations of loading doors for below-ground bins. Doors can be either horizontal (set into the ground-level roof of the bin), sloped (when the bin is located next to the side of a building), or vertical (when the bin is covered by a roofed building taller than a delivery truck). See photos on pages 46, 49, and 14 for examples of horizontal, sloped, and vertical door systems. Whether they work manually, hydraulically, or on electric winches, these doors must be designed to be easily operable in all weather conditions.

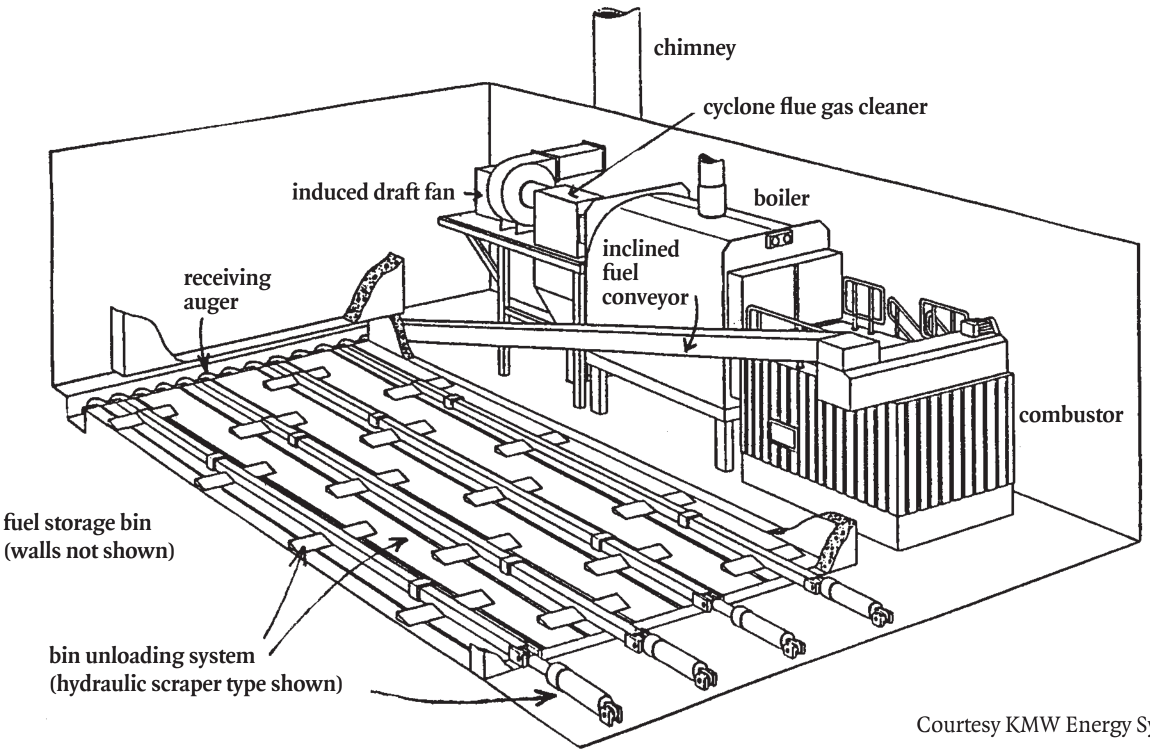
It is best to have loading doors that work for deliveries from self-unloading tractor trailer vans and from dump trucks. With vertical door systems, the door height must be carefully designed to assure that it can accept deliveries from dump trucks.

Above-grade bins or silos are also sometimes used for biomass storage. These are typically circular (similar to concrete or steel agricultural silos), although rectangular bins have also been used. See the photos on page 69 for one example of a metal silo. Above-ground bins can present freezing problems with green fuel in the coldest weather. They also require mechanical loading equipment, usually powered by electric motors, to convey the fuel from ground level (where it is discharged by the delivery truck) to the top of the bin.

Small metal silos (sized to hold considerably less than a tractor-trailer load of chips) can be used to decrease a project's initial cost. The disadvantage is that deliveries will be more frequent, and fuel suppliers may charge more per ton. Although a small metal silo may be less expensive than a full-sized below-grade bin, a metal silo big enough to hold a full 40-foot van load of chips will have probably have little or no cost advantage over a concrete bin.

In the lower-cost agricultural biomass systems that are typically found on farms or in greenhouses, fuel is

Figure 3.1
A Typical Biomass System



Courtesy KMW Energy Systems

sometimes stored in ground-level sheds with concrete floor pads (dirt and asphalt floors should be avoided). These sheds can be very inexpensive to build. On delivery the fuel is dumped onto the pad in or in front of the building, and shoved or scooped in place with a tractor or front-end loader. The tractor is also used to remove the fuel from storage and transport it to an automated receiving bin; see photo on page 50 for an example.

Although construction costs for this type of bin are lower, it involves operator labor on a daily basis and requires a tractor or loader of some kind. These systems are also well-suited for small schools where a fully automated system is prohibitively expensive. Semi-automated systems cost about half as much as fully automated systems.

In some cases, storage system costs can be reduced by using one or more fuel delivery trailers for on-site fuel storage. The simplest approach is to use a conventional delivery van backed up to a loading dock or ramp. A small loader/tractor removes fuel from the trailer and fills an automatic day bin. A more sophisticated approach is to use a self-unloading trailer (see photo on page 52), which is backed up and connected to a day bin in one wall of the boiler room. In this way the unloading and handling of fuel is fully automatic. In either case the day bin must be large enough to feed the system while the trailer is off-site being refilled. Systems using more than one trailer have some advantages, but may cost as much as building a permanent fuel bin.

Sizing the Fuel Storage System

Every biomass system must have sufficient on-site fuel storage. For small systems, such as those in schools, the storage is usually sized according to the volume of the delivery vehicle. Generally, storage bins should hold at least one and one-third to one and one-half times the volume of delivered fuel per truckload. Fuel suppliers usually do not like to deliver partial loads, so sizing at less than a delivery load is not a good idea. Sizing the effective volume of the bin bigger than the truck volume allows the operator to order a delivery before the bin is empty.

When designing a storage bin, it is important to account for the difference between the bin's gross volume and its effective volume. The effective volume depends on the percentage of the bin that can actually

Hydraulic Scraper Bin Un-loading System:
Note shape of scrapers: as they move forward, the leading edge pushes fuel ahead; as they retract, the tapered edge slides back under the chips.

Chip Conveyor System:
In a fully automated system chips are moved from the storage bin to the combustion chamber using fuel handling equipment such as the conveyor system shown here. No manual labor is involved.

be filled.

Schools typically get fuel delivered in 40-foot tractor trailer vans, which carry about 2,400 cubic feet of fuel (for green hardwood chips, a van load of fuel weighs about 25 tons). The number of deliveries per year depends on the school size and heat load and can range anywhere from three to 40. Each delivered load might last from a week to two months.

Large commercial or industrial users may require one or more van loads of fuel per day. In these facilities it is common to size the storage capacity to last from three to five days, so the system can run through weekends without needing a delivery.

It is imperative to know what size and kind of delivery vehicle will be used. It is also useful to consider whether the type and size of delivery vehicle to be used in the first year will continue to be available in the future. For example, a facility might expect to get 10-ton dump truck deliveries from a local mill, and so might size its bin to hold 15 tons. But a problem could develop if that source dries up and the only other sources available deliver in 40-foot vans carrying 25 tons.

Although the capital cost for larger bins is high, it is usually a good investment to have more than minimum storage.

The Fuel Handling System

Automated equipment is used to convey biomass fuel from the storage facility into the boiler room and the combustion chamber. The first step is to remove fuel from the storage bin. This is most commonly done with reciprocating hydraulic scrapers at the base of the bin (see photo above). The scrapers discharge fuel from the bin and drop it onto a horizontal receiving auger that runs along one of the bin's sides. Figure 3.1 (page 19) shows the scraper system and receiving auger, as well as other system components in a typical boiler room.

Another system type that has proven very durable and trouble-free uses a traveling auger at the base of the bin for unloading fuel. It travels from end to end and sweeps the flat bottom of the bin, pulling fuel forward and dropping it into a receiving auger.

Circular, above-ground fuel silos use one of two types of equipment to remove fuel from storage. The first is a "flying Dutchman," or maypole, which uses weighted chains attached at one end to a rotating vertical centerpost. As post and chains rotate, the weights on the ends of the chains knock chips down into an opening at the center of the slope-sided bottom of the silo. The other type of equipment, for unloading a flat-bottomed circular silo, is a center-pivot auger that

An Important Relationship:

Fuel Source, Delivery Vehicle and Storage Bin

One of the most important tasks in putting together a successful biomass system is building a fuel storage facility that will meet both the immediate and long-term needs of the system, its owners, and its operators. The fuel supplier, fuel type, and delivery vehicle used all may change over the life of the installation.

First, the bin must be sized adequately (as discussed on the next page). An undersized bin will constrain the system throughout its life. The bin must also be conveniently located for deliveries from large trucks, with consideration for snow removal and parked vehicles.

Second, the bin should be capable of receiving deliveries from vehicles of different sizes and different types. Any facility may, at various points in the future, want to order fuel from a sawmill, a whole-tree chipper, or a trucker who hauls biomass. These various suppliers might use small or large dump trucks, dump trailers, or self-unloading vans.

In the Northeast, self-unloading tractor trailer vans (also called live-bottom trailers) are the most common type of delivery vehicle. These trailers look just like a conventional tractor trailer except that they have a hydraulically operated floor system that pushes fuel out the back (see photo on page 52).

The fuel bin should be configured to eliminate or minimize any time facility staff must spend to assist the driver during deliveries. The need to have staff involved in unloading may also constrain the supplier's delivery schedule. For a larger system with frequent deliveries, these considerations will be important.

Bins that fill by gravity are best, and the bin doors should enable quick unloading (30 minutes on site for live-bottom vans, 10-15 minutes for dump trucks). Gravity-fill bins are located below grade, or have a ramped-up driveway so that trucks can easily dump fuel down into them (see photo above). Fuel suppliers prefer delivering to facilities where a full truck can be unloaded quickly. Suppliers may charge more for fuel delivered to sites that take two hours per delivery.

Bin door design needs to accommodate the possibility for delivery from dump trucks. While

the door cannot be high enough to accept a fully-extended dump body, it has to be tall enough so that the truck, with its body up, can back part way into the door so that the fuel will slide down into the bin without unnecessary spilling onto the ground. There should be a paved apron in front of the doors, to facilitate scooping up any spilled fuel.

Gravity-fill bins have a strong advantage over bins that require mechanical filling equipment. Bin-loading equipment carries an added capital cost and means another set of mechanical devices that requires maintenance and can fail. The electrical-demand charges of motors for bin-loading or bin-leveling equipment can add significantly to electric bills and can wipe out some of the cost advantage of burning an inexpensive fuel (see the sections of Chapter Ten that deal with bid forms and assessing bid information).

In addition to self-unloading vans and dump trucks, regular tractor trailers may be readily available to deliver chips. These trailers must be unloaded at a loading dock using a small tractor or skid-steer loader. The loader drives right into the trailer, scoops up fuel, backs out, and deposits the fuel into the storage area. Most institutional or commercial biomass burners decide from the start, however, that they do not want to be tied to the labor and equipment associated with unloading fuel from conventional (not self-unloading) tractor trailers.

sweeps the silo base, discharging chips into an opening at the center. These silo unloaders function best when the silo is in a heated space, to avoid problems with chips freezing to the walls of the silo.

Most systems use a series of screw augers in covered steel troughs, either on the level or inclined, to move fuel to the boiler. Belt conveyors and drag chains are much less common means of transporting fuel in institutional and commercial systems. Bucket elevators are sometimes used in large systems for conveying fuel vertically, but they require more maintenance than inclined augers and are avoided in smaller systems.

Most systems have a small metering bin between the fuel storage and the combustion chamber. It separates the rapid flow of fuel being taken out of the bin from the carefully controlled feed rate of fuel into the combustion chamber.

The handling equipment described above requires no intervention by site personnel. The fuel is moved automatically from storage to combustion. Some facilities, however, use small tractors or front-end loaders to convey the fuel from the storage facility to a day bin (see photo on page 31). The day bin typically holds enough fuel so that it needs to be loaded by the tractor operator once or twice a day, in an operation that may take only half an hour. An auger in the base of the day bin conveys fuel automatically to the combustion chamber.

Although tractor-based systems require daily operator involvement, they have been used successfully by a variety of facilities - including small agricultural operations, greenhouses, large industrial plants, and a district heating system for a complex of state office buildings. The system is attractive because it reduces capital costs. Tractor-based systems work best when there is already appropriate staff on site to operate the tractor on a daily basis.

The Combustion System

The furnace is the part of the combustion appliance where burning of the solid fuel actually takes place. (Examples of furnace configurations can be found in Figures 6.1, and 6.2 in Chapter Six.) Fuel is automatically injected into the furnace, combustion air is added, and the fuel burns to produce heat. The hot exhaust gases then flow out of the furnace area and into the heat exchanger. As they pass through the heat exchanger, heat is transferred to the surrounding water (or air). The cooled exhaust gases then pass up the chimney for discharge into the outdoor air. (See Chapter Six for a discussion of the different generic types of combustion systems.)

The proper conditions for complete and efficient combustion are achieved by:

- accurate control of the fuel feed rate;
- accurate control of the combustion air feed to different areas within the furnace;
- the turbulence of hot gases (air, wood gases, and water vapor);
- the ability of the furnace to maintain high temperatures;
- the right furnace geometry, to give wood gases enough time to burn completely, and,
- the means to prevent ash buildup.

The equipment that is used to achieve efficient combustion is described below.

Parts of the Combustion System

Most non-industrial systems use the last auger of the fuel handling system, called the stoker or the injection auger, to feed fuel to the fire. The fuel feed can come in at one end of the furnace, or it can be underfed and forced up through an opening in the middle of the grates. Some systems use a large injector fan to blow fuel into the furnace. This approach is called "suspension burning" because the smaller particles of fuel burn suspended, while the heavier pieces fall to the grates and burn there.

Most wood-chip furnaces have grates — either sloped, stepped, or flat — that support the burning fuel and allow for under-fire air to be blown up through holes in the grate (pile burners get combustion air fed from above). Under-fire air dries the fuel, helps the solid fuel on the grates to "devolatilize" or "gasify" (changing its state from solid to gas), and aids in burning fixed carbon (or charcoal) on the grates. Over-fire air, which is often preheated, is blown in from above the grates to provide oxygen and turbulence, so the wood gases burn completely before passing into the heat exchanger. There are often separate fans for under-fire and over-fire air.

Larger or more sophisticated systems sometimes have moving grates. Grate movement can maintain an even bed of fuel across the grates, giving a more uniform and efficient combustion. Moving grates are also used to convey ash to the bottom of the grate area, so that it does not build up and prevent combustion air from reaching the fuel.

Any moving parts in the furnace area (such as moving grate systems or under-feed augers) are subjected to very high temperatures, and so must be well-designed to keep them functional and prevent

Murray Farms Greenhouse, Penacook, New Hampshire
Size: 2.5 MMBH
Manufacturer: Chiptec Wood Energy System
Greenhouses are a good match with wood-chip heating systems because they have very high heat loads.

them from burning out quickly. Otherwise, they can add to the costs of maintenance and replacement parts. The experience of operators who have run a particular brand or type of system will best predict the lifetime and maintenance requirements of these system components.

Some systems, typically larger ones, use water-cooled grates when very high temperatures in the primary combustion zone could otherwise warp or deteriorate the grates. Some two-chamber systems (see Chapter Six) water-cool the parts of the combustor that are in contact with the grates, rather than cooling the grates themselves. Water cooling is generally considered an expensive feature, and is rarely used in systems of smaller the type considered in this guide.

The furnace is lined with high-temperature "refractory," a material that reflects some heat back to the fuel and keeps the furnace at an even high temperature. The refractory also protects the material of the walls and base of the furnace from the high temperatures of the combustion zone.

Combustion Controls

The conditions for efficient biomass combustion are set by controlling the rates at which fuel and combustion air are fed to the fire. The simplest systems have on/off fuel feed. When the boiler water temperature or steam pressure drops below a set value, this type of system turns on and supplies fuel (and combustion air) to the fire until the water temperature or steam pressure is brought back up to its set value. Then the system shuts off the fuel feed system and combustion air. These simpler systems usually have timed fuel injection cycles during the period when the boiler temperature is being brought back up. The timed "on" and "off" periods can be set manually to adjust for different kinds of fuel or different seasons.

Systems with on/off controls usually have an idle mode so they can hold a fire during periods when there is little or no load. In this mode a small amount of fuel is fed to the fire periodically, and the combustion air fans are turned on to keep the coals from burning out.

The weakness of the simple on/off control strategy is that it does not respond well to varying loads. If the feed cycles are set for efficient combustion during midwinter conditions when there is a heavy heating load, the combustion may be inefficient and smoky at times when there is a much lower load (at certain times of day or in warmer months).

The "turn-down ratio" characterizes a system's ability to burn efficiently over a broad range of loads, such as heating loads from fall to midwinter. This ratio compares the full rated output of the boiler to the lowest boiler output at which efficient combustion is still achieved. For example, a system with a full output rating of 3.0 MMBtu and a 3:1 turn-down ratio would be able to maintain its parameters for efficient combustion at varying loads from 1.0 to 3.0 MMBtu.

More sophisticated systems use a control strategy with multiple, separate firing modes. Controlling how the system switches back and forth between the different firing modes (such as low, medium, and high) can achieve a much greater degree of control and a very good turn-down performance. It also avoids the potential for smoking when an on/off system switches frequently out of its "off" mode.

The most precise combustion control can be achieved when the rates at which fuel and air are fed to the fire can be automatically varied or modulated. When the load is high, the fuel feed rate and combustion air supply increase; at low load, fuel and air are fed to the fire more slowly. Under this control strategy the fire burns efficiently whether the load on the system is high or low. The fire is stable, its strength modulating up and down in response to the load. A modulating fuel feed system can also be made to adjust automatically for variations in fuel moisture or energy content.

Modulating combustion systems have microprocessors to receive inputs from sensors in the system, and use a control logic to convert this information into signals that regulate the fuel stoker rate and the combustion air fans. The types of inputs used vary from system to system. Boiler water temperature, steam pressure, furnace draft, exhaust gas oxygen content, and outdoor temperature are all variables that can be integrated into the control strategy of a system with microprocessor controls.

Heat Exchange

In the combustion zone where burning takes place, heat is primarily transferred from the flame to the heat transfer medium (water, steam, or air) by radiation. (The medium is the vehicle for heat distribution to the building, carrying heat to the point of use.) After combustion is completed, heat continues to be transferred from the flue gases to the medium, primarily by convection.

The heat exchanger is the device which performs the function of heat transfer from the flame and flue gases to the medium. The type of heat exchanger used depends on the heat transfer medium and the boiler or furnace design.

Heat exchangers for biomass combustion systems need to be carefully sized, to be able to extract enough energy out of the hot flue gases. If the heat exchanger is undersized compared to the output of the furnace, the stack temperature will be too high and excessive energy will go up the chimney, reducing the system's efficiency.

For the types of facilities considered in this book, hot water is the most common heat distribution medium, because space heating that uses circulating hot water is the most common institutional and commercial use of biomass energy. Steam distribution is also fairly common, especially in older buildings. The heat exchanger for a hot water (or steam) system is incorporated into a boiler. The boiler heat exchanger consists of a series of flue passages surrounded by water (a fire-tube boiler) or water tubes surrounded by hot exhaust gases (a water-tube boiler). As the hot combustion gases go through the passages, they heat the boiler metal, which in turn heats the surrounding water. The heat exchanger will reduce the flue gas temperature from that of the furnace (typically 1,200°-2,200°F) to that of the chimney (300°-450°F). In so doing it will raise the boiler water temperature to levels between 150°F and 300°F.

Because most biomass systems use water or steam as a medium for heat exchange, the term "boiler" is often used in this book to indicate the most common type of heat exchanger. For a facility with a hot-air distribution system, there would be no boiler; instead, an exhaust-gas-to-air heat exchanger would be used, as explained later in this section.

In some existing facilities, steam may be the medium for a variety of heat-related uses. Heating systems in older buildings may have steam distribution piping and radiators. Hospitals often have steam systems because steam can be used for heating, kitchen equipment, laboratory uses, sterilization, laundry equipment, and absorption chillers for air conditioning. Industrial plants sometimes use process steam as a high-temperature medium for certain manufacturing processes.

A steam boiler is very similar to a water boiler, and their heat exchangers are virtually identical. In a steam boiler, the water heated in the heat exchanger is allowed to boil in a chamber at the top of the boiler. Steam boilers are rated as either low pressure (typically up to 15 psi) or high pressure (over 15 psi), depending on the use to which the steam will be put.

Hot air is much less common than hot water or steam as the heat distribution medium for institutional and commercial biomass systems. In a hot air heat exchanger, the combustion gases transfer their heat to airstreams that are pulled through the heat exchanger with fans. Hot air can be used for space heat in large open areas, but it is more difficult to zone and control with the precision and flexibility that hot water systems offer.

Boiler Room Equipment, Backup Fuel Systems, and Domestic Hot Water

The ancillary equipment in a biomass boiler room is largely the same as that for any large conventional boiler facility. However, the backup fuel system deserves special consideration.

Most commercial and institutional biomass plants have oil or gas backup capability, with one or more separate boilers that burn either oil or gas. In some facilities the backup oil or gas burner is installed to fire into the biomass boiler. In a few cases, usually industrial applications with round-the-clock staffing, there is no backup fuel capability.

Backup systems are useful in a variety of circumstances:

- during periods when the heating load is too small for the biomass boiler to run efficiently without smoking,
- when the wood system is shut down intentionally for servicing,
- when the storage bin is empty,
- when an oversized wood chip unexpectedly jams an auger and stops the fuel supply, and
- when the load on the system exceeds the wood boiler's capacity.

Backup systems can be manually activated or controlled to come on automatically if the wood fire fails or is insufficient to meet the load. Institutional applications that are not staffed at night or on weekends usually have separate backup boilers with automatic firing. In this way the backup system takes over with no operator involvement. Some larger, well-staffed facilities have oil or gas burners on swing-out doors in the wood boiler. These burners can be manually positioned when there is need to use them.

Most facilities that burn biomass use the wood boiler to supply the domestic hot water (DHW) load along with the primary load of the building. A DHW heat exchange water tank (or a stand-alone heat exchanger with storage tank) is used for this purpose, piped as a zone off the distribution system. Facilities that do not use the biomass burner in the summer, but still have a summer DHW load, must have a separate water heater.

Emissions Control Systems

Institutional and commercial biomass burners typically burn with very low levels of undesirable stack emissions (especially compared to older wood stoves and industrial boilers), and easily meet state emissions standards. State air quality regulations are usually activated according to the size of the boiler heat exchanger. The minimum level for review or for permitting varies from state to state. (Chapter Ten discusses the process of checking state air quality regulations.)

The smallest institutional and commercial biomass systems may not be required to meet state emissions standards, and so would need no special equipment to reduce stack emissions. Nonetheless, most system manufacturers routinely install devices to remove particulates from the exhaust gases, regardless of unit size (the exception being small agricultural systems below 1 MMBtu). These devices, called cyclone separators or multi-cyclones, mount between the heat exchanger and the chimney connection. Systems with particulate removal devices always have induced draft fans, which create a negative pressure in the combustion chamber and assure proper movement of flue gases up the stack.

A relatively new technology called a "core separator" has started to be used in some larger institutional wood boiler facilities. The core separator functions much like a multi-cyclone, but it is particularly effective at removing very fine particulate matter that is of increasing concern because of its effect on human respiratory health.

In very large biomass plants, further levels of stack gas cleaning may be required to meet state emissions standards. These devices (for example, char reinjectors, wet scrubbers, and bag houses) are almost never found in plants of the size considered in this book. Small facilities should avoid these devices because they are expensive to install and maintain.

Ash Removal Systems

Ash — unburnable minerals in the fuel, mixed with any unburned carbon — accumulates in certain locations and must be removed regularly. Every ton of green biomass burned produces about 25 pounds of ash. Most of the ash accumulates in the combustion chamber. If there are sloped or moving grates, the ash moves to the bottom of the grates. It is important that this ash be removed on a continuous or daily basis. One method is removal by automatic ashing augers (also called screws), which collect ash at low points and move it outside the combustion chamber. Automatic ashing is sometimes preferred in schools, since it reduces maintenance time for staff. However, it can add capital cost to the system.

Many plants, including some fairly large ones, use manual ashing: the ash is raked and shoveled out of the boiler by hand, a task that typically takes about 10-20 minutes a day. In most systems, manual ashing can be done easily without shutting down the boiler; in others the task is more complex and requires that the boiler first cool down. The time needed for ashing is an important maintenance issue to cover during system selection.

As long as ashing does not require that the boiler be shut down, neither manual nor automatic ash removal is inherently preferable. The decision on this issue is usually based on cost and on the owner's sense of the operator's safety and convenience.

Fine ash that is carried by the movement of the flue gases (called fly ash) also accumulates in the heat exchanger's flue passages and smoke box. While there is less of this ash and it builds up more slowly, it must still be removed regularly. Ash on the heat exchange surfaces slows down the transfer of heat to the boiler water, and sends too much of the system's heat output up the chimney.

The rate at which fly ash builds up varies from system to system. Most systems require manual brushing of ash, anywhere from once a week to once or twice a year. Some systems are equipped with automatic soot blowers or sonic devices to reduce the frequency of manual cleaning.

Ash accumulates under the grates as well. This bottom ash also needs to be removed regularly, although much less often than grate ash. It is usually removed manually, but automatic ashing screws can be installed.

Ash also builds up at the cyclone or dust collector, which removes ash and other particulates from the stack gases before they go up the chimney. The bottom of the cyclone typically discharges ash through a rotary airlock to drop by gravity into a 55-gallon drum or an ashing screw.

Ashing screws (if there are more than one) usually carry ash to a final common screw, which conveys the ash to a steel ash bin or trailer outside the boiler room for cooling and disposal. In smaller systems with manual ash removal, ash is carried out of the boiler room in buckets or metal trash cans. If the boiler room is below grade, an electric hoist may be required.

In most states, ash from institutional and commercial biomass burners is not classed as hazardous waste by solid waste regulators. In fact, it is an excellent soil additive; small facilities often give their ash away to local gardeners and farmers. Larger facilities typically truck their ash to the local landfill or contract with ash removal vendors, who utilize the ash for land spreading, as an additive to sewage sludge, or for other commercial purposes.

Safety Devices

Biomass can be burned safely provided that systems include necessary safety features. Every biomass heating plant must have the code-mandated safety devices and controls associated with any large heating system. In addition, some safety issues and equipment are unique to wood-burning plants.

Every biomass combustion system needs safeguards against burnback, or fire traveling back from the combustion area along the incoming fuel stream. Every biomass-burning system must have an automatic water-quenching system on the incoming fuel feed near the combustion chamber. This includes a temperature sensor — which, when it detects temperatures that indicate burning fuel, opens a valve to douse the fuel stream with water. Boiler rooms must have general sprinkler protection as well.

Many systems also have one or more locations in the fuel stream where there is an open vertical drop from the end of one fuel conveyor to the beginning of the next. These open-air drops serve to prevent fire from moving from one auger to the next; they make it virtually impossible for fire to travel all the way back to the fuel storage bin.

Some systems use rotary air locks, devices that permit the flow of fuel in one direction without allowing air to move through them. They also act as a stop to prevent fire from moving up from below into gravity-discharge fuel hoppers. Air locks are one method used to limit unintentional air supply through the fuel feed system.

Biomass combustion systems require a safety device that cuts off fuel supply to the furnace when the fire has failed. Failure of the fire is sensed by a stack temperature probe connected to a fuel cutoff switch. Different biomass system manufacturers incorporate a variety of other types of safety switches in their control systems.

The boiler room may be equipped with automatic alarm systems or dialers to alert operators to dangerous situations or system malfunctions. For example, a dialer could call the system operator whenever the wood unit loses fire, or if burnback into the incoming fuel stream is detected.

All systems must be designed to function safely in the event of power outages. System manufacturers and suppliers must be able to explain exactly what happens to all aspects of the system operation in a power outage, and what automatic controls are in place to keep the system safe in these situations.

The use of powerful and potentially dangerous fuel handling equipment mandates that all augers in accessible spaces be covered and that public access to all equipment be limited. Warning signs must be posted in dangerous locations. The fuel storage bin must be locked and off-limits to all but facility staff.

The Chimney

The chimney or stack is the final element of the biomass system. Its job is to remove the products of combustion from the combustion system and the building, and to disperse the flue gases to the atmosphere. Natural draft systems rely solely on the chimney to generate the draft needed to evacuate combustion products from the system. Induced draft fans can act to ensure more consistent draft at the boiler and steadier flow through the venting system.

The chimney must be carefully matched to the combustion appliance or appliances that are connected to it. In retrofit situations, existing chimneys can sometimes be used, providing they are adequate to meet the particular needs of the new biomass plant. Chimneys can be made of either masonry or steel.

The important characteristics of a chimney are the cross-sectional area of its flue, its height, its structural strength, the longevity of its construction, and whether it is insulated. An insulated stack keeps the flue gases warmer and more buoyant. Stack height must be integrated with the height of the building and other surrounding buildings, and with local topography and wind conditions. Adequate dispersal of stack gases is extremely important when the biomass plant is located in a heavily populated area. Tall, insulated steel stacks (45-75 feet from the boiler room floor) are becoming popular, since they provide excellent draft and disperse the combustion products into the prevailing wind streams. A tall, "best engineering practice" stack is sized so that there will be virtually no impact from stack gases on either indoor air or outside air in the vicinity of the wood plant.

Chapter Four

Efficiency of Biomass Combustion Systems

The primary goal of most building owners who install a biomass-fired heating system is to save money. These savings must come from reduced operating costs.

It is especially important to minimize fuel costs, because biomass systems typically have significantly higher capital costs than conventional-fuel systems. Operating costs can be kept low by ensuring maximum efficiency, reasonable installation costs, and low maintenance requirements. Increasingly stringent emission regulations and environmental awareness make clean, efficient combustion doubly important.

To achieve both maximum efficiency and minimum emissions, it is helpful to understand the basics of combustion and the factors that go into determining a system's efficiency. This will allow the potential purchaser of a biomass system to know what information to ask for, to understand the information provided by system manufacturers, to make intelligent decisions about components of the system, and to achieve low fuel consumption and fuel costs.

A. The Basics of Biomass Combustion

The principal chemical reactions that produce heat energy are the same for all common fuels. Carbon and/or hydrogen are oxidized rapidly, releasing energy. The chemical equations for these reactions are:

$$C + O_2 = CO_2 + \text{ENERGY}$$

Carbon combines with oxygen to form carbon dioxide and release energy.

$$H + O_2 = H_2O + \text{ENERGY}$$

Hydrogen combines with oxygen to form water and release energy.

Whether the fuel is solid, liquid, or gaseous, the carbon and hydrogen in it provide the energy. To calculate a system's efficiency, you must know three fuel characteristics: the amount of carbon, hydrogen, ash, and other chemical components present in the fuel (called the ultimate analysis of the fuel); how much energy the fuel can release when burned (called the calorific value of the fuel); and the fuel's moisture content.

1. Chemical Constituents of the Fuel

The ultimate analysis of a fuel sample gives the proportion by weight of each elemental constituent of the fuel. Most biomass fuels have very similar ultimate analyses, as shown in the table below, which gives typical data for a hardwood, a softwood, an agricultural grain, and (for comparison) fuel oil and natural gas.

The three biomass fuels analyzed here vary in physical appearance because the complex hydrocarbon molecules of each are quite different, despite the similarity of their constituent elements. The molecular structure of biomass fuels also determines how easily they burn. The complex molecules that make up biomass are comparatively difficult to break down to simple carbon and hydrogen. For this reason, biomass requires high temperatures and a long combustion zone (or flame path) for clean, efficient burning.

2. Moisture Content of the Fuel

Considerable energy is contained in the hot steam that forms part of the flue gases vented from a biomass combustion system. In biomass combustion, steam is produced when the moisture in the fuel is heated and vaporized (and steam is also produced by the burning of any hydrogen in the fuel). The lower the moisture content of the biomass fuel, the less energy will be lost. Thus, fuel moisture content plays a critical role in efficiency: the higher the moisture, the lower the efficiency.

3. ENERGY CONTENT OF THE FUEL

The final piece of information provided by a fuel analysis is the energy content of the fuel — its calorific value. The following table gives typical calorific values of the three representative biomass fuels and of fuel oil and natural gas, on a per-pound-of-dry-fuel basis.

On a dry weight basis, the energy content of most biomass is quite consistent. By comparison, heating oil is a more concentrated form of energy, with more than twice as much energy per pound. Natural gas also has a high energy content by weight, although not by volume.

4. FACTORS THAT DETERMINE STEADY STATE EFFICIENCY

Having looked at the basic components of biomass fuel, now consider the combustion system itself. System efficiency is most often characterized using temperature measurements, along with measurements of the constituent parts of the flue gases. The following factors determine the overall appliance efficiency — also called "steady state efficiency," because it refers to the system when it is running under steady full-load conditions.

5. COMPLETENESS OF COMBUSTION (COMBUSTION EFFICIENCY)

If combustion is incomplete, only a portion of the energy potentially available is released, and undesirable pollutants are produced. For example, carbon monoxide (CO) may be produced instead of carbon dioxide.

Most chip-fired systems lose only a small amount of efficiency from incomplete combustion. When exhaust gases contain 500 parts per million (ppm) of CO, for example, the energy loss is only 0.15%. Even though there may be little decrease in efficiency from high levels of carbon monoxide, high CO levels do indicate poor combustion with the likelihood of high toxic emissions levels.

6. AMOUNT OF EXCESS AIR

The theoretical amount of air needed for complete fuel combustion can be calculated. Any air that exceeds this amount absorbs energy as its temperature is raised to that of the flue while passing through the system; this causes a loss of available energy.

In practice, systems require more than the theoretical amount of air to ensure complete combustion. The closer they can approach the theoretical requirement, the more efficient the system will be.

7. STACK TEMPERATURE

The energy produced from burning fuel is extracted by the system's heat exchanger. Any heat that cannot be extracted in the heat exchanger is lost up the chimney. The lower the exhaust temperature (stack temperature), the lower this loss of energy. Too low a stack temperature, however, leads to condensation of flue gas moisture in the chimney, causing corrosion and/or ice blockage as well as insufficient furnace draft.

Stack temperature can best be controlled by good design of the controls and by appropriate sizing of the combustion grates, the furnace volume, and the heat exchanger surfaces. Stack temperature can also be

Heat Value of Various Fuels[2]

	Maple	Spruce	Corn	Fuel Oil	Natural Gas
Calorific Value (Btu/dry pound)	8,350	8,720	8,120	19,590	22,080

Ultimate Analysis of Various Fuels[1]

(as a percentage of dry fuel weight)

	Maple	Spruce	Corn	No. 2 Oil	Natural Gas
Carbon	48.94	51.97	47.63	86.40	71.60
Hydrogen	5.60	5.59	6.66	12.70	23.20
Nitrogen	.22	.43	1.46	0	4.30
Sulfur	.16	.10	.11	.70	0
Oxygen	43.67	41.24	42.69	.20	.90
Ash	1.41	.67	1.45	trace	0

regulated, to some extent, by scientific tuning of the system to optimize the effectiveness of the controls. Stack temperature is also affected by ash or soot buildup — so ash cleaning is an important way to keep stack temperature down.

8. MOISTURE LOSSES

There are two sources of moisture in the flue gas: moisture contained in the fuel and moisture produced by the burning of the hydrogen in the fuel. In theory, moisture losses can be reduced by pre-drying the fuel or condensing the flue gas vapor in a tertiary heat exchanger, which condenses gases and captures the heat that is released. As a rule, neither of these methods is practical with current biomass system technology, particularly for systems in the size range considered here.

9. TYPICAL PERFORMANCE OF CURRENT SYSTEMS

System manufacturers design their equipment to minimize energy losses from each of the components noted above, while at the same time ensuring safe, reliable operation with minimum maintenance requirements. Recent tests show that typical steady-state efficiencies of current systems are likely to be in the 55-75% range.[3] This means that 25-45% of the energy in the fuel is lost. (A typical oil or gas-fired boiler would be expected to have losses of 10-20% under similar measurement conditions.)

The lower efficiency of wood systems is due in part to the nature of the fuel itself. Biomass fuel can vary dramatically by particle size, species, and moisture content. It is difficult to design a system that can deliver high efficiency across this range of variables. Wood system efficiencies can, however, be expected to rise as manufacturers improve their products and as the market for systems grows. It should be kept in mind that the primary advantage of burning wood fuel lies in its low cost — which offsets the mediocre efficiency — and its status as a locally produced renewable fuel.

In the following paragraphs, recent test results on several Canadian systems[4] illustrate the effect of system improvements on efficiency. These units ranged in size from .3 MMBH to 6.2 MMBH output. Despite the wide range of design outputs, there was no clear link between steady state efficiency and size.

Excess air levels ranged from 185% to 71%, stack temperatures from 579°F to 466°F, fuel moisture contents from 49% to 39% (wet basis), and CO levels from 614 ppm to 29 ppm. The effect on steady state efficiency at the high or low end of each of these parameters is as follows:

South Shore Regional Hospital, Bridgewater, Nova Scotia
System Size: 4.0 MMBH
Manufacturer: KMW Energy Systems
Showing top-hinged hydraulically operated loading doors for below-grade bin adjacent to boiler room.

- Reducing excess air from 185% to 71% will increase efficiency about 7%.
- Reducing stack temperature from 579°F to 466°F will increase efficiency about 5%.
- Reducing fuel moisture content from 49% to 39% will increase efficiency about 5%.
- Reducing carbon monoxide emissions from 614 ppm to 29 ppm will increase efficiency by only about 0.3%.

If the poorest values in each category are used (185% excess air, 579°F stack temperature, and 49% moisture content), the steady state appliance efficiency will be 50%. At the other end of the performance range (71% excess air, a stack temperature of 466°F, and 39% moisture content), the system would have

Power Line Pork, Borden, Prince Edward Island
Facility Type: Pig farrowing farm
System Size: 1 MMBH (two-boiler)
Manufacturer: Grove Wood Heat
Heating plant is housed in shed on left (lower photo). Fuel is delivered to overhead door and pushed onto shed's floor slab for storage, using tractor. Two side-by-side "Bioblast" systems (like the one in photo at left), located in the same shed, are sized at 45% and 55% of peak load. Each Bioblast consists of a tractor-loaded day bin (shown in foreground), a combustor (middle) and a boiler (rear).

an efficiency of 69%. This difference represents a 38% fuel savings. Further improvements in excess air and stack temperature values, and the use of lower moisture fuel, will boost efficiencies even more.

These figures show that substantial increases in efficiency and reductions in fuel consumption — and cost — can be achieved in many systems. If the critical components of fuel moisture, excess air, and stack temperature can be addressed at reasonable cost, the added expense of maximizing system efficiency may be quickly recovered through lower fuel costs. Chapters Ten and Eleven discuss practical ways to optimize system efficiency through the system specification and commissioning procedures.

B. Seasonal Efficiency

The factors noted above determine the steady state efficiency of the wood system — its efficiency when the system is running steadily under ideal conditions. But in actual use over the course of a heating season, there are several other potential areas of heat loss that can reduce a system with excellent steady state efficiency to mediocre performance.

"Seasonal efficiency" is the term used to categorize the performance of a heating system over the duration of an entire heating season. This long-term look at efficiency includes the periods when the system is running optimally (at steady state), and also periods when the system load is low and combustion is idling at low efficiency.

Seasonal efficiency will always be lower than steady state efficiency. Chip-fired systems currently on the market typically are assumed to have seasonal efficiencies in the 55-65% range, although gross oversizing can reduce efficiencies even further.

Five areas of energy loss can reduce seasonal efficiency:

1. Cycling Losses

Seasonal efficiency is reduced when a system runs in an on/off mode, cycling back and forth between full fire and the idle mode, compared to a system that automatically modulates the fire. With modulating fuel feed systems, inefficient combustion takes place only when the load on the boiler is below the minimum turn-down load.

2. JACKET LOSSES

If the system is poorly insulated, and especially if it is located in an area where heat is not needed, the heat lost from the surface of the boiler reduces its seasonal efficiency. (Note that jacket losses are sometimes included in the steady state efficiency calculation.)

3. DISTRIBUTION LOSSES

The heat produced by the system is transported via pipes from the boiler room to the point of use. Any heat lost in this distribution piping process reduces overall efficiency, as it does with all combustion systems regardless of fuel type.

4. STANDBY LOSSES

If the system burns more fuel than is necessary in periods of low demand (such as warm weather), then fuel is wasted. This will be a problem for a system that is significantly oversized, and for any system during periods of very low heat demand.

5. OVERHEATING LOSSES

If a system is poorly controlled, so that it puts out more heat than is required and overheats a space, the excess energy output is wasted.

C. Considerations in System Selection

When the potential owner of a biomass system is selecting equipment, careful attention to efficiency-related factors can result in the installation of a system that achieves optimum fuel efficiency, lower energy bills, and better operation.

Here are six important points to consider:

1. SYSTEM SIZING

Recent testing of wood-chip systems in the Northeast[5] has shown that gross oversizing and inefficient seasonal operation are common. An owner who wishes to optimize efficiency will want the furnace to be very carefully sized. One possibility is to deliberately undersize the furnace, so the system will run efficiently more of the time. The added capacity for periods of greatest demand on the system must then be supplied by the backup fuel system. The heat exchanger, however, must not be undersized compared to the furnace output; if it is, stack temperatures will be too high and energy will be wasted. For a more detailed discussion of sizing, see Chapter Ten (page 62).

2. COMBUSTION CONTROLS

As discussed in the section on combustion controls in Chapter Three, modulating controls that automatically vary the rate of fuel fed to the fire give better efficiency over a wide range of conditions than do simple on/off controls.

3. INSTRUMENTATION

While an automatic modulating control system will necessarily include sensors and the ability to monitor key indicators of performance, simpler systems may not have this level of instrumentation. At a minimum, any system should have gauges showing the operator the stack temperature and an indicator to show what firing mode it is in. Hot water boilers should also have gauges showing supply and return temperatures; steam boilers should have gauges for steam pressure and condensate return temperature. There should also be a convenient location for sampling stack gases.

Measurements of carbon dioxide or oxygen levels in the flue gases, taken with simple hand-held equipment, can easily be translated into excess air readings. An accurate flow meter at the wood boiler, combined with temperature probes on the supply and return pipes, will give useful data to confirm the boiler's heat output.

4. FUEL MOISTURE

If the prospective user has long-term access to dry or low- moisture fuel, the system can be designed specifically to burn dry fuels. The overall efficiency of the system will be significantly higher than a system that burns green fuel. However, a system set up for dry fuel will perform poorly or not at all on green wood, so an adequate dry-fuel supply must be assured. There are other reasons (discussed on page 13) why a prospective institutional or commercial user may prefer green fuel, even though the efficiency will be lower than with dry fuel.

5. BOILER AND PIPE INSULATION

The proposed system should be carefully examined for insulation on high-temperature surfaces of the combustor or boiler, and for good enclosure of the combustion area by the heat exchange medium. Distribution piping, in the boiler room and throughout the facility, should be insulated to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards. While heat loss from the system may provide some benefit in heating the boiler room or adjacent areas, the lack of control makes for a very inefficient way to heat these spaces.

6. MULTIPLE WOOD BOILERS

For applications with a wide range of load over a full year, two or more small units may offer better performance than a single large unit, although usually at a higher capital cost. For example, a facility with a large domestic hot water load in the summer might use a small wood-fired summer boiler, switch to a larger boiler during the heating season, and use both boilers during periods of peak demand. Each unit can be fired in the more efficient upper portion of its operating range over a longer period. In addition, one system can be shut down for maintenance or repairs without losing all heating capability. For an example of a two-boiler wood system, see photo on page 31.

In selecting a system, the contribution of each component must be weighed against its cost. There are no absolute rules on the best approach. Sometimes the fuel or maintenance savings of going with upgraded components will pay fairly quickly for the higher capital cost; in other cases it will not. In some cases, decisions on specific components may be made on factors that are not primarily economic. By determining the costs and impact on performance, potential users of the system can assemble the optimum package for their needs.

D. Combined Heat and Power (CHP)

As seen from the discussion above, some of the factors in system inefficiency are excessive jacket losses, standby losses, overheating losses and losses to the environment from hot exhaust gases. Reducing these losses is an important design goal for heat-only wood boiler systems. If this lost heat can be captured and put to productive use, overall efficiency will be increased.

In electric power producing wood-fired systems, "cogeneration" — also called combined heat and power, or CHP — is an enhancement that captures thermal losses to increase system efficiency. The terms "cogeneration" and "combined heat and power" refer to the production of both electricity and usable heat from a single system using a single fuel. Generally these systems have higher efficiencies than do power-only systems, and so represent a more cost-effective way to produce electricity.

The overall efficiency of CHP systems, however, may be less than that of heat-only systems. Wood-fired industrial CHP systems that utilize high-pressure steam boilers and backpressure steam turbines to serve process heat loads produce only a modest amount of electricity. While the high value of this electricity (compared to the value of thermal energy) may improve system economics, this type of CHP does not increase system efficiency and may actually reduce overall efficiency slightly.

1 Data supplied by the Energy Research Laboratories of the Canada Centre for Mineral and Energy Technology (CANMET), Ottawa, Ontario.

2 Data supplied by CANMET.

3 Commercial Testing and Engineering Company, Small and Medium-Sized Wood Energy Boiler Efficiencies (prepared for the Northeast Regional Biomass Program, CONEG Policy Research Center, Washington, D.C., December 1993); R. W. Braaten and T. G. Sellers, Prince Edward Island Wood Chip-Fired Boiler Performance, Division Report ERL 92-43 (TR) (Ottawa: Energy Research Laboratories, 1993).

4 Ibid.

5 Commercial Testing and Engineering Company, Small and Medium-Sized Wood Energy Boiler Efficiencies. See also comments on oversizing by Branyon Jarrett in "Catch 22 in Wood Fuel Design," Heating, Piping and Air Conditioning, January 1990.

Chapter Five

Air Emissions From Institutional Wood Energy Systems

Anyone interested in wood heating systems in schools or other public buildings invariably wants to know the answer, at some level, to the question, *What comes out the chimney?*

Unfortunately, the answer is not simple. All combustion processes — whether the fuel is oil, gas, wood, or coal — produce dozens of flue gas components, all with different characteristics. The air pollutants of primary interest are discussed below. Also discussed is the impact of wood combustion on the emissions and buildup in the atmosphere of carbon dioxide (CO_2). While carbon dioxide is not a pollutant that is controlled by state air quality regulations, it is the key culprit in global climate change.

The question of stack emissions is further complicated by the incorrect assumption that what we know about residential wood stoves also holds true for the modern wood combustion systems now in use in schools and public buildings. These modern wood systems are significantly cleaner than wood stoves for three reasons.

First, the mess associated with cordwood being stored and used in a home's living space, and with cleaning ashes out of the stove, is absent in schools. The wood chips are confined to the storage bin and the boiler room, with no dirt or dust getting into the school itself. Second, unlike home woodstoves, there are virtually no visible emissions and no odor associated with institutional wood-chip systems. Third, these modern wood systems emit far less particulate matter, the component of wood combustion emissions of greatest concern for human health.

Emission Components

Particulates

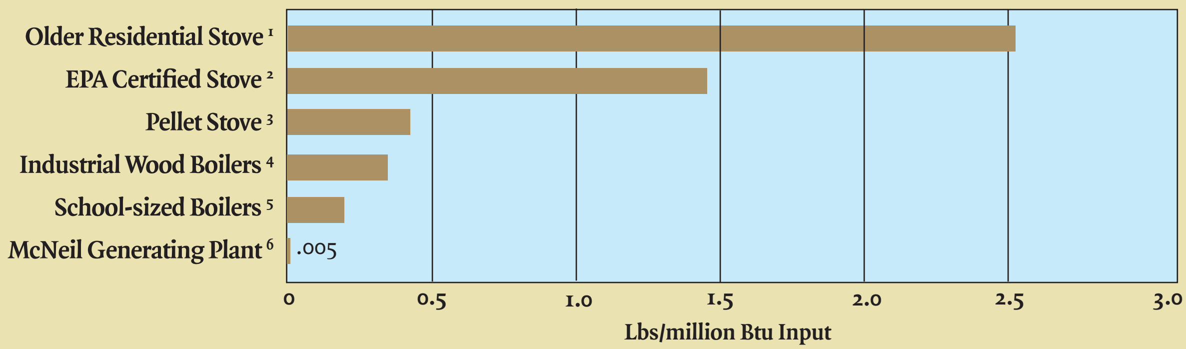
In terms of the health impacts of burning wood, the emission component of greatest concern is particulate matter (PM). Particulates are tiny pieces of solid matter (or very fine droplets) that span a size range from quite large and visible, to extremely fine and invisible. It is the finest PM that is the greatest concern, because these particles remain air-born and can enter and stay deep inside the lungs.

Modern institutional wood system chimneys emit virtually no visible smoke (although they do show a white plume of condensed water vapor on cold days). Finer particulate matter, with particles smaller than 10 micrometers, is called PM_{10}. The following chart shows the PM emission rate for a number of wood energy technologies, from common wood stoves to an extremely clean-burning wood power plant.

In general, a school wood energy system emits only one fifteenth (7%) the PM of the average wood stove in use today, for the same level of fuel energy input. Over the course of a year, a large, wood-heated high school (150-200,000 square feet) may have the same particulate emissions as four or five houses heated with wood stoves.

Even the best wood burning systems, whether in schools or at power plants, have significantly higher PM emissions than do corresponding gas and oil systems. For this reason, it is becoming more common to use a tall chimney to disperse the emissions into the prevailing wind stream and reduce ground-level impacts to almost zero. The respiratory health risk to

Particulate Matter from Various Wood Combustion Systems



[1] Calculations by Biomass Energy Resource Center, based on EPA AP-42 data for a mix of pre-certification and post-certification residential wood stoves and on school wood energy systems characterized in note 2.5 (below).

[2,3] U.S. Environmental Protection Agency. *Compilation of Air Pollutant Emission Factors*, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources: External Combustion Sources, Residential Woods Stoves: Final Section; Table 1-10.1: Pre-Phase I Non-Catalytic (SCC 21-04-008-050), Phase II Non-Catalytic (SCC 21-04-008-050), Pellet Stove Type (Certified) (SCC 21-04-008-053), (PM10) at 5100 BTU/lb (dry wood value) and 40% moisture content.

[4] U.S. Environmental Protection Agency. *Compilation of Air Pollutant Emission Factors*, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources: External Combustion Sources, Wood Residue Combustion Boilers: Final Section; Table 1.6-1: Bark and Wet Wood Mechanical Collector, Filterable PM 10.

[5] Holzman, Michael I. Richard S. Atkins, Leigh A. Gammie. 1996. *Wood-Chip Fired Furnaces Testing Project Air Emissions Testing and Public Health Impacts Analysis.* Coalition of Northeastern Governors, Washington D.C. 13-14 pp. Average of all tests (PM10).

[6] Clean Air Engineering PM Tests (EPA standard) of the Joseph C. McNeil Generating Station, Burlington, Vermont, 1988. (Average of test results)

Note: The values in the graph represent uncontrolled stoves and controlled boilers/power plant. This represents the situations most often found in the field.

a child attending a wood-heated school is negligible compared to the risk of living in a home where a wood stove is in regular use. Children are also at much greater risk from particulate matter in the exhaust of idling school buses than from wood heating plant emissions.

Climate Change

The greatest environmental benefit of burning wood for energy is in its positive impact in moderating climate change. CO_2 buildup in the atmosphere is the primary cause of global climate change. Fossil fuel combustion takes carbon that was locked away underground (as crude oil and gas) and puts it in the atmosphere as CO_2. When wood is burned, however, it recycles carbon that was already in the natural carbon cycle. The net effect of burning wood fuel is that no new CO_2 is added to the atmosphere, as long as the forests from which the wood came are sustainably managed. Therefore, when wood replaces fossil fuel, the net impact is to reduce CO_2 levels in the atmosphere significantly.

For a school district or other public building owner interested in meaningfully addressing climate change and renewable energy through its energy use, heating with wood is a powerful tool. Making the building itself more efficient is always an excellent strategy for addressing fuel consumption and CO_2 emissions. This approach may reduce heating fuel use (oil or gas) and related CO_2 emissions by 10-20 percent. However, if the heating system is converted to wood fuel, CO_2 emissions are reduced by 75-90 percent.

Other Emissions

Oxides of sulfur (SO_x) cause acid rain. Modern wood systems have one sixth the SO_2 emissions of fuel oil. Oxides of nitrogen (NO_x) cause ozone, smog, and respiratory problems. Wood and fuel oil combustion have similar levels of NO_x emissions.

All fuel combustion processes produce carbon monoxide (CO). The level produced by wood combustion depends very much on how well the system is tuned. Nevertheless, wood combustion produces significantly more CO than does oil. CO emissions from wood burning are of relatively minor concern to air quality regulators, except in areas that have high CO levels in the air due to automobile exhaust. Natural gas is the cleanest burning of all fuels, having significantly lower SOx and NOx stack emissions than wood or oil. Natural gas has higher CO emissions than oil, but lower than wood.

Volatile organic compounds (VOCs) are a large family of air pollutants, some of which are produced by fuel combustion. Some are toxic, and VOCs in general contribute to ozone, smog and respiratory problems. Both wood and oil combustion produce VOCs; wood is higher in some and oil is higher in others.

Public Perception

The general public, and particularly people who consider themselves environmentally conscious, may have an initial negative reaction to the idea of burning wood in schools or other public buildings. Part of this may be from an assumption that burning wood chips means cutting down trees. In fact, most wood chips used as fuel for schools come from sawmill wastes – chipped-up slabs and edges that cannot be made into marketable lumber. The other sources for chips are diseased and deformed trees that are thinned from the forest to increase its health and vigor. In neither case does the supply of wood chips as a fuel source create a demand for harvesting additional trees.

In some instances, people have objected to using wood in public schools under the assumption that wood energy is dirty and will create a health hazard for school children, neighbors, and the general public. There is no published data showing any link between the use of wood for school heating and negative human health impacts. As shown above, overall emissions from modern wood burners are no worse than those from conventional fossil fuels. Climate change impacts from fuel combustion are significantly reduced when wood is used instead of fossil fuels.

State air quality regulations that are intended to protect air quality and the general public health apply to some institutional wood heating systems (depending on system size and permit threshold levels). If there are conflicts or concerns over the air impacts of a proposed or existing wood heating system, state air quality regulators should be consulted for professional, unbiased information and guidance.

Chapter Six

Types of Biomass Combustion Systems

All biomass combustion systems share some common operational and design features. All inject fuel into the hot environment of the combustion chamber in the presence of air. First, in a process called pyrolysis, moisture and volatiles in the wood fuel are driven off. (Volatiles are substances that can be vaporized or turned to gas at fairly low temperatures.) Pyrolysis reactions also convert wood solids to carbon-rich char, a solid that either burns directly on the grate or is converted to combustible gases.

As the wood gases mix with over-fire and under-fire air, they burn and give off heat. This heat maintains the temperature of the combustion chamber by reflecting off the refractory, and raises the temperature of the combustion fuel. Passing through the heat exchanger, the hot exhaust gases give up their energy to the boiler water, transforming that energy into useful heat.

To achieve efficient, clean-burning combustion, different manufacturers design and build their systems in different ways. The two principal combustion designs and their variations are discussed below. Certain approaches may be best suited for particular fuels or types of usage — but there is little objective data at this writing to indicate that any one of the generic combustion system designs or variations gives better efficiency, lower emissions, or smoother operation. The most important factors in performance are solid engineering and design, as well as effective controls, regardless of the type of combustion system employed.

Some manufacturers make and install both direct-burn systems and two-chamber systems, with the selection depending on the type of fuel to be burned at a particular facility.

Regardless of the type of combustion system employed, the most important considerations are: that the system achieve high appliance efficiency (through low stack temperature and high excess air); that the system requires little attention by the operator; and that the equipment has a good record of reliable operation and minimal repairs.

Direct-Burn Furnaces

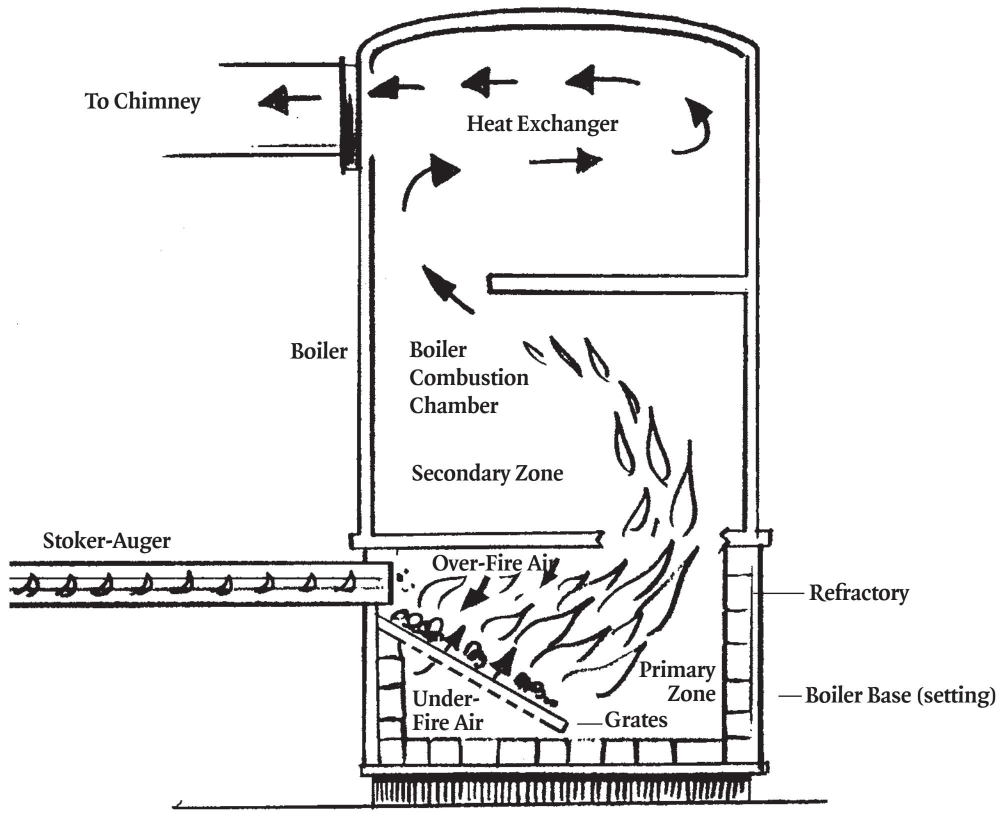
In a direct-burn system, the furnace is a single combustion chamber. It is generally (but not always) located directly under the boiler, in a specially constructed base or setting on which the boiler sits (see Figure 6.1 on the next page). The grates and fuel feed system are located in the refractory-lined setting, and the combustion air is injected into it, both below and above the grates.

In older designs, the furnace volume of the setting (above the grates) is open to the combustion chamber of the boiler, which sits above it. The hot gases rise up from the grate area into the combustion chamber of the boiler, where combustion of the hot gases and solid combustible particles is completed. The hot exhaust gases then pass into the heat exchanger.

In newer designs, there is a refractory baffle separating the primary and secondary combustion zones (see Figure 6.1). The baffle is used to enclose the primary combustion area above the grates, thus increasing primary zone temperature and lengthening the flame path to give more time for the carbon in the hot gases to oxidize completely. This also gives better burning in low-load conditions.

In a mechanical forced-draft direct-burn system, unless the base and access doors of the boiler are effectively sealed, it can be difficult to limit the introduction of unintentional air to the combustion chamber. The result can be high excess air levels and

Figure 6.1
Direct Burn Combustion



decreased efficiency.

Relative simplicity and low cost are features of direct-burn systems. Properly designed, with effective combustion controls, direct-burn systems are capable of highly efficient combustion with low emissions.

Two-Chamber Furnaces

In two-chamber systems, a separate refractory-lined combustion chamber, or combustor, sits next to the boiler, connected by a short horizontal passage that is also refractory-lined (see Figure 6.2 on the next page and the boiler room photograph on page 7). This passage can be a round blast tube, connecting the combustor and boiler, or the rectangular combustor outlet can open directly into the boiler.

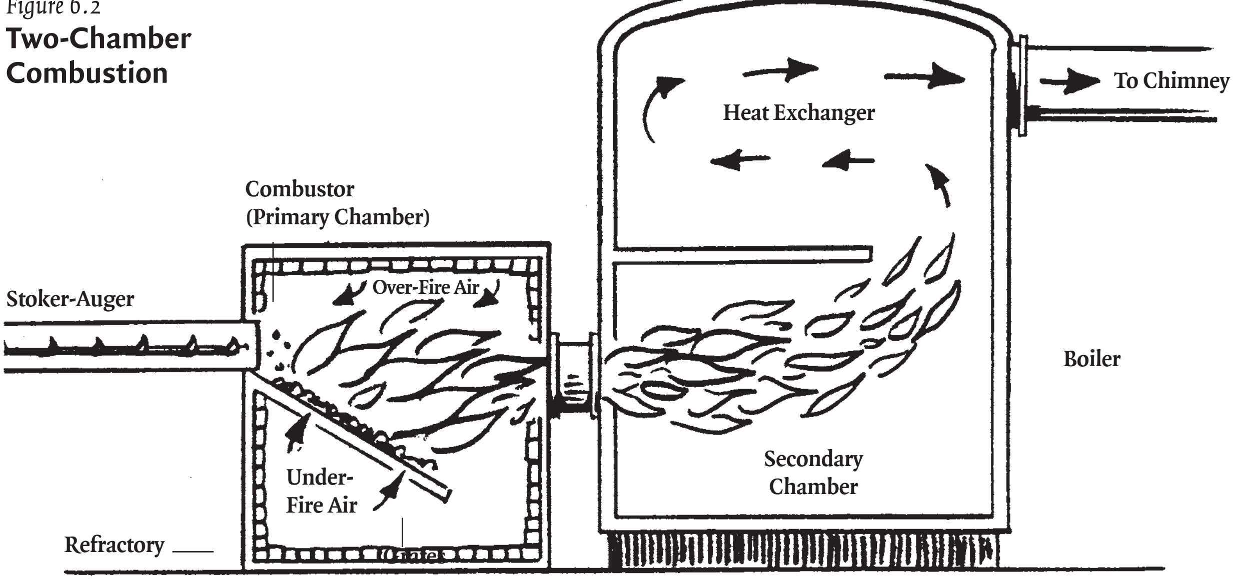
The combustor houses grates as well as the fuel and the air feed components (under-fire and over-fire), just like a direct-burn system. Hot gases from the combustor pass through the blast tube or directly into the combustion chamber of the boiler itself. In this way the boiler's combustion chamber becomes the secondary chamber of the combustion system.

Two-chamber systems burn both high-moisture and low-moisture biomass fuels and are frequently used specifically for high-moisture fuels like green softwood. Because the furnace volume of the combustor is relatively small, and because the chamber is enclosed on top with refractory, it is easy to achieve and maintain high temperatures in the primary combustion zone, even when the fuel is more than half water.

The combustor of a two-chamber system is generally built airtight, to limit the amount of oxygen available for combustion; too much excess air will cool the fire and reduce efficiency. Two-chamber systems are usually designed to prevent unintentional air (or tramp air) from entering the combustor with the incoming fuel. The control of primary and secondary air and the elimination of tramp air allow accurate control of the conditions of combustion in the primary chamber. Regulation of furnace temperature is particularly important, since sustaining high gas temperatures is critical to achieving complete combustion.

A potential advantage of two-compartment systems is that they can give a longer flame path, more turbulence (for mixing oxygen with combustible gases) and longer retention time of high-temperature gases. "Retention time" is a measure of the time it takes hot gases to pass from the point where the last combustion

Figure 6.2
Two-Chamber Combustion



air is added to the beginning of the heat exchanger. The longer the flame path and retention time, the more completely the gasified fuel carbon will be burned out. Complete combustion translates to higher efficiency and cleaner stack gases.

Two-chamber systems that produce very high gas temperatures in the secondary chamber need to have carefully matched heat exchangers, to be able to extract enough energy out of the hot flue gases. If the heat exchanger is undersized compared to the output of the combustor, the stack temperature will be too high and excessive energy will go up the chimney, reducing the system's efficiency.

The close-coupled gasifier is a variation on the two-chamber system, in which the combustion air in the primary chamber is restricted so that the wood gases produced are not allowed to burn completely in the combustor. Final combustion air is added at the blast tube or in the setting; this increases turbulence and produces high gas temperatures entering the secondary chamber.

Close-coupled gasifiers are characterized by low primary combustor temperatures (typically below 1,000°F), a relative absence of flame in the primary chamber, and high temperatures in the secondary chamber (typically 1,800°-2,200°F).

Chapter Seven

Economic Analysis of Wood-Chip Systems

This chapter provides the framework for determining whether a biomass system is cost-effective for a particular facility. In addition to describing the different methods of financial analysis, it goes into detail on the kinds of assumptions and data needed to do a life-cycle cost analysis.

For simplicity, this chapter focuses primarily on the analytical and financial aspects of burning biomass for space heating. However, the principles discussed are equally applicable to other biomass uses, such as providing industrial process steam.

Preliminary Feasibility

Before undertaking a rigorous economic analysis, potential biomass users may want to do a briefer, less formal feasibility study. Such a feasibility study might make sense in an area where institutional and commercial biomass-burning facilities are uncommon, or where the market for biomass is uncertain. A preliminary study could include the first four steps of the process outlined in “The Process of Analyzing and Installing a Wood-Chip System,” plus a preliminary economic analysis.

From an economic perspective, a preliminary study might look at the cost savings from installing a biomass system. In a very simple analysis, the fuel dollar savings could be compared to a rough estimate of system cost. For example, a system manufacturer might provide a preliminary estimate that the system, including building construction, would cost $300,000. If the oil heat currently used in a facility costs $15,000 per year, the fuel cost savings might be estimated at $6,000-7,500 per year, with a 40-50% reduction in fuel cost. It is clear that the preliminary estimate of cost-effectiveness for this biomass system would be less attractive than if the facility had a $50,000 oil heat bill — and could expect to save $20,000-25,000 per year with a wood-chip system.

The availability of capital might be another factor in a preliminary economic analysis.

Benefits and Costs

Many considerations are involved in selecting the appropriate heating system and fuel for a particular facility. These include the cost of each fuel/system option, the level of comfort provided by each, the likelihood of future fuel price increases or fluctuations, the environmental impacts of each option, and the effects that each would have on the local economy. Even if the fuel selection decision is based solely on cost considerations, it can require a significant level of investigation and analysis. In the end, the time and effort invested in a careful examination of the options can be overshadowed by the fuel cost savings and other societal benefits that an informed selection can deliver.

The principal economic advantage of wood-chip systems is that their fuel is considerably less expensive than competing fuels. The magnitude of this advantage depends on the local prices of biomass and of competing fuels. In the Northeast, electricity generally costs about seven to nine times more per unit of energy than wood chips; oil and natural gas cost roughly two and one-half times as much as wood chips.

Selecting biomass as a fuel can also provide several other, less quantifiable benefits. For example, the future price of wood chips can be predicted with more confidence than can the price of some conventional energy sources, such as fuel oil, because the price is based on local rather than global economics. This means that wood-chip systems offer greater security from future fuel price shocks. Also, as a locally

Cost-Effectiveness of Wood-Chip Systems

A school under consideration is characterized by two numbers: (1) the amount of oil, gas or electricity used for space heat (its heating consumption) and (2) the unit price of the oil, gas, or electricity. (With complex electric rates, it is important to select an average rate, including demand charges, that represents the cost of heating throughout the winter season.) These two characterizing numbers can be plotted to locate the school on the appropriate graph.

Each graph has three zones. If the school falls in the top zone (A) when plotted on the graph, it is likely that a wood-chip system would be cost-effective. If it falls in the bottom zone (C), a wood-chip system is unlikely to be cost-effective. The broad middle zone (B) defines the range of uncertainty for which a detailed analysis is required to get a sense of a wood-chip system's cost-effectiveness. In this zone, systems that cost more per MMBtu size will be less likely to be cost-effective, while those that cost less to install will be more likely to make economic sense.

These three graphs assume that there is no cost-sharing of the project capital cost — in other words, that the school district has to bear the full cost of the project. If cost-share is available as a grant from state aid or some other source, the economics (from the school's perspective) of installing a wood system can be much better than indicated by the graphs.

The lines separating the three zones on each graph are defined by the range of system costs for a given size plant. The system costs assumptions can be found in Appendix D. For an explanation of how system costs are influenced by the owner's decisions, see "System Sophistication and System Cost" on page 61.

produced, renewable fuel, wood chips can offer both environmental and local economic benefits that other fuels cannot match. Although generally left out of financial analyses and not discussed in great detail in this chapter, consideration of these issues can be a very important part in the fuel selection decision. These non-economic issues are discussed in Chapter One and elsewhere in this guide.

The principal disadvantage of wood-chip systems is that the up-front costs to install and house the necessary equipment are usually significantly greater than the initial costs of oil, gas, or electric systems. However, the magnitude of this greater first cost is extremely site-specific: it depends on the use for which

Figure 7.1

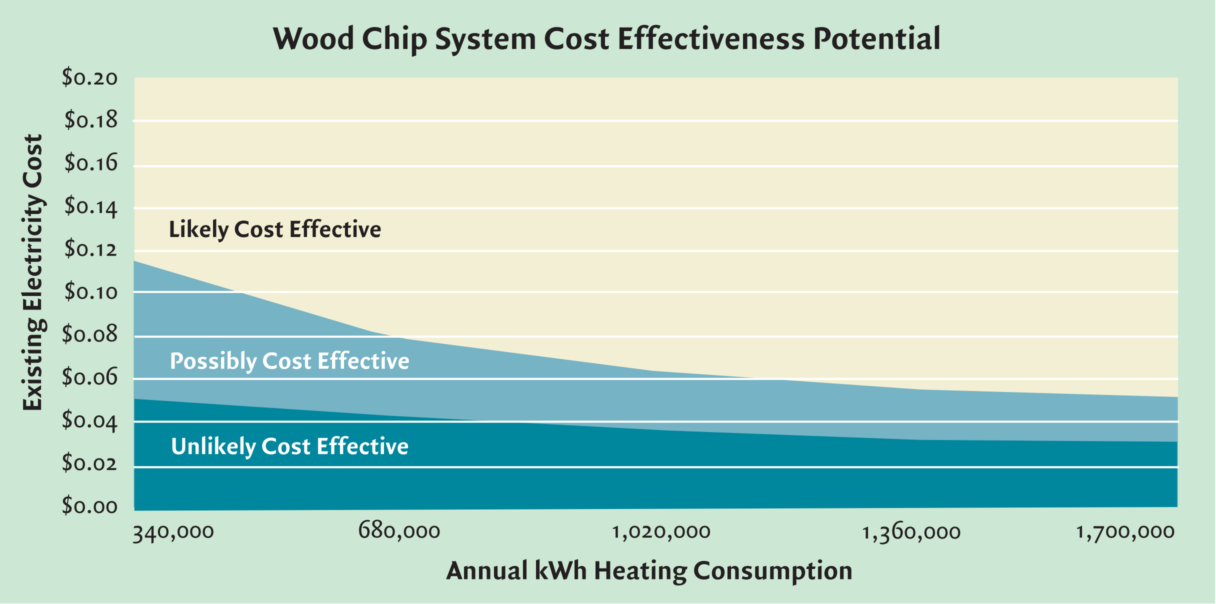
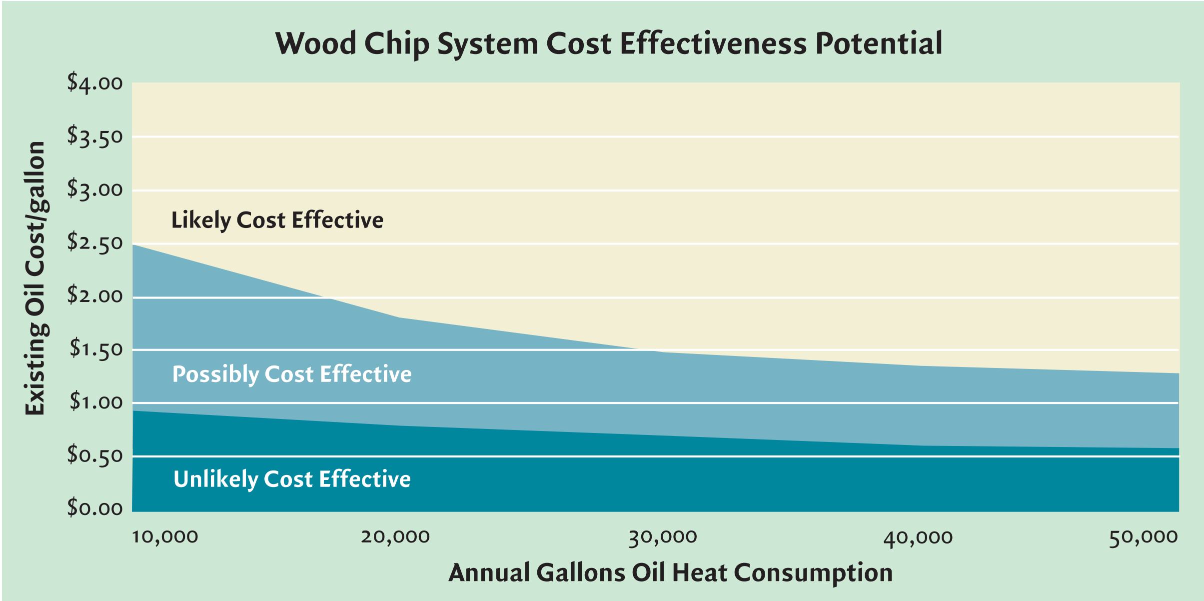


Figure 7.2



the wood-chip system is being considered, the nature of the competing fuel system being considered, the configuration of the building into which the wood-chip system will be installed, and the desired level of system automation.

This tradeoff between high initial costs and low annual costs is at the heart of any financial analysis of a wood-chip system's cost-effectiveness. Many factors can affect an analysis of this tradeoff. This chapter identifies the various issues that should be addressed in such an analysis, and briefly discusses the best analytical framework — life-cycle costing — for determining whether a wood-chip system is the least expensive option available in the long run.

When Are Wood-Chip Systems Cost-Effective?

The simple answer to this question is that biomass heating systems are almost always worth consideration. As a general rule, they are most cost-effective:

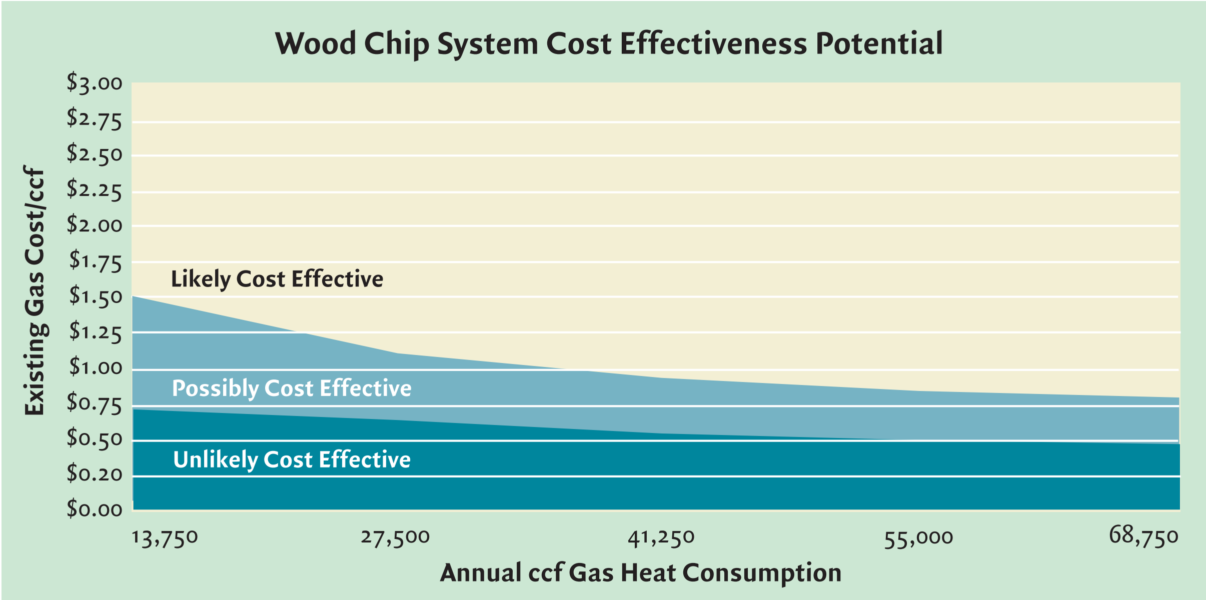
- when space-heating electricity and oil prices are relatively high,
- when energy consumption is relatively large,
- when the competing fuel is electricity rather than oil or gas,
- when they are an alternative to another new system, rather than a replacement for a system currently in use, and
- when the facility has a hydronic (hot water or steam) heat distribution system already in place.

Experience in the Northeast[1] suggests that, under the right conditions, wood-chip heating systems can be cost-effective for almost any level of heating energy consumption and at a wide variety of electricity, oil, or natural gas prices. Wood-chip heating systems have been demonstrated to be cost-effective for both large and small schools and businesses, for both high and low levels of energy consumption, as an alternative to electric and oil systems in both new construction and conversions, and for buildings with and without existing hydronic heat distribution systems. Wood systems compete very well with liquid propane gas (LP) and with natural gas when gas prices are high.

In most cases, wood-chip systems have resulted in large energy cost savings. However, that does not mean they are always cost-effective, nor does it guarantee that they will be cost-effective for a particular facility. It is very difficult to generalize about the cost and cost-effectiveness of these systems. The bottom line is that a wood-chip system's cost and its cost-effectiveness are very site-specific and can usually only be determined after thorough analysis. The cost of the analysis is generally low compared to its value as a decision-making tool.

The general cost-effectiveness of wood-chip systems in schools, compared to electric heat and to oil heat, is illustrated in Figures 7.1, 7.2 and 7.3. A school is used in the example because of the availability of data on the economics of school biomass heating. Keep in mind that these graphs give only a rough idea of cost-effectiveness, and cannot be substituted for a careful

Figure 7.3



analysis of the question. The data and assumptions used to develop these graphs are found in Appendix E. The cost-effectiveness criteria of these graphs were based on life-cycle costing.

Figure 7.1 shows the electricity price and level of annual heating energy consumption at which it might be cheaper to install a new wood-chip system in a school, rather than continue with an electric resistance heating system. It illustrates two important points.

First, the cost-effectiveness of wood-chip heating systems is very site-specific and difficult to predict, particularly for small schools — as evidenced by the breadth of zone B on the left side of the graph. For a school consuming about 340,000 kilowatt-hours (kwh) for heating each year, a wood-chip system is probably cost-effective at electricity prices greater than 16.5 cents/kwh, probably not cost-effective at electricity prices less than 5 cents/kwh, and it may or may not be cost-effective in between. This is not a very enlightening conclusion, since few schools in the Northeast face electricity prices either less than 3.5 cents/kwh or greater than 16.5 cents/kwh.

Second, Figure 7.1 demonstrates that wood-chip systems are more cost-effective at higher levels of electricity consumption. For a school consuming in excess of 1,000,000 kwh/year for heating, a wood-chip system is likely to be cost-effective at electricity prices greater than 10 cents/kwh, and may be cost-effective at prices as low as 4.0 cents/kwh. Most schools in the Northeast pay more than 7.0 cents/kwh for electricity, right in the middle of the range in which a wood system might be cost-effective.

Finally, Figure 7.2 suggests that given current oil prices in the Northeast, it is less likely to be cost-effective to convert from oil to wood chips than it is to convert from electric heat to a new wood-chip system.

Figure 7.3 provides a similar analysis for natural gas. It shows that for schools with a low gas usage for heat (less than 15,000 ccf/year) and that pay less than 75 cents/ccf, wood-chip systems are highly unlikely to be cost-effective. There is not a high likelihood of a cost-effective conversion from natural gas to wood until the fuel price rises above $1.25/ccf. When gas consumption for heat is above 50,000 ccf/year and gas prices are about $1/ccf, there will be some cost-effective opportunities.

Be careful about drawing definitive conclusions from these graphs; they are products of a number of simplifying assumptions that may or may not be applicable to any specific situation. For example, the graphs compare the cost of a new wood-chip system with the cost of continuing to operate an existing oil, gas or electric heat system. If you are building a new facility and are comparing a new wood-chip system with a new oil, gas or electric system, the wood-chip system will look more cost-effective than these illustrations indicate.

Despite these limitations, Figures 7.1, 7.2 and 7.3 provide useful insights into the potential cost-effectiveness of wood-chip heating systems. They confirm that at prevailing electric, oil and natural gas prices, wood-chip systems can be cost-effective for almost any level of energy consumption. Although cost-effectiveness is indeed site-specific, it can also be system-specific. This means it may be possible to custom-design a system that meets both your energy needs and cost criteria (for example, by accepting a lower level of automation), even if a "standard" system would not be cost-effective.

Conducting both a thorough engineering assessment and a thorough cost analysis for your specific situation is very important.

Principles for a Detailed Cost-Effectiveness Analysis

There are two general questions to answer before analyzing the potential cost-effectiveness of installing a wood-chip system. The first is, What kind of analytical method will be used? The second is, What are the assumptions, and what data must be considered? You should know the answer to these questions regardless of whether you plan to do the analysis yourself or to hire a consultant to do it.

Different methods can be used to study the cost-effectiveness of an investment such as a wood-chip heating system. The three most common are (1) simple payback, (2) first-year cash flow, and (3) life-cycle costing. As the following discussion demonstrates, the third option, life-cycle costing, is the only method that provides a thorough assessment of whether it is cost-effective to install a biomass heating system.

1. Simple Payback

Simple payback is the number of years it takes to recover the initial investment, based on the size of the investment and the first-year net cost savings — including costs for energy, operating, and maintenance. For example, if a system costs $300,000 to install and it saves $30,000 a year in energy-related bills, its simple payback is ten years.

This calculation is a useful tool for obtaining a quick, rough indication of the benefits a project may provide. Unfortunately, it has little application beyond that. It cannot tell whether a project is cost-effective, because it ignores several critical factors, including the cost of capital (the interest rate you would pay for a long-term loan), the magnitude of expected future energy savings, and the costs of future equipment replacement for both the wood-chip system and the alternative fuel system to which it is being compared.

Although it is tempting to pick a maximum simple payback (say five, 10, or 15 years) for which an investment is cost-effective, this approach is shortsighted because it fails to consider the future. One of the competitive strengths of biomass fuels is the realistic expectation that their prices will do better in the long-term future than those of competing fuels.

2. First-Year Cash Flow

First-year cash flow is simply a determination of whether the project's cash outflow in the first year (usually just the first year's loan payment) is greater than the first-year fuel savings (and any other savings) that the project generates. For example, with a 10%, 10-year loan for $250,000, which translates to annual loan payments of roughly $40,000 and annual energy saving of $50,000, the first-year cash flow is a positive $10,000.

This type of analysis has some benefit compared to simple payback analysis, since it does include the cost of capital — but it, too, has significant limitations. If the first-year cash flow is positive, as in the example just presented, then the project will be cost-effective. Unfortunately, however, no definitive conclusions can be drawn about the cost-effectiveness of an investment for which the first-year cash flow is negative.

A wood-chip system investment with a negative first-year cash flow could be very positive in the long term under two different sets of conditions. If the competing fuel price inflates faster than the wood fuel price, the annual savings might increase rapidly enough to create positive cash flow in future years. Also, the fuel cost savings in the years after the loan has been paid off may be dramatic enough to offset the short-term negative cash flows. Wood-chip systems can be expected to provide energy savings for more than 20 years (investments in boiler room and bin construction may last much longer), and loans are generally paid off in 20 years or less.

3. Life-Cycle Costing

Life-cycle cost analysis accounts for future changes in fuel costs of the biomass fuel and the competing fuels. It also considers the cost of financing; looks at differences in maintenance, repair, and replacement costs of the competing options; and takes into account the future value of the dollar.

Appendix E contains detailed information on life-cycle cost analysis.

There are two key principles to life-cycle costing. The first is that all project costs and all project benefits are analyzed for each year of the project's entire life. The second is that less importance is attached to long-term benefits and costs than to short-term benefits and costs, both because the value of future dollars is reduced by general inflation and because there is a value, independent of concerns about inflation, to having money today rather than sometime in the future.

Quantification of the future value of the dollar is accomplished through the use of an annual discount rate. The owners' discount rate is the annual rate of return they might get if they invested their money elsewhere (i.e., in the bank, a treasury bond, stocks, or another project) for the same length of time that they expect the wood-chip project to last. The higher the discount rate, the less value is attached to future benefits and costs. For public institutions, discount rates for energy investments are set by the individual state energy office, based on Department of Energy figures. Private facility owners considering a wood-chip system investment can use these or set their own discount rates.

Defining the Biomass Project and Its Costs

Whether a biomass system is considered for a new building or for converting the heating plant of an existing building, the financial analysis requires that the full scope of the project and the cost of all the project components be determined. The total biomass project usually involves more than purchasing and installing the mechanical components of a chip-burning system.

Cost components of a biomass installation may include the following:

- cost of the complete wood-chip handling and combustion system, including installation and any optional system components;
- construction costs for the chip storage facility, including bin loading doors;
- site costs (driveway for fuel deliveries, site grading, etc.);
- construction cost for boiler room space to house the wood boiler and its ancillary equipment (including general wiring);
- cost of emissions control equipment, if needed;
- cost of a masonry or an installed pre-fabricated chimney;
- professional costs - for engineering, architectural design, and project management; and
- costs to connect the piping and controls of the wood system to those of the backup system.

Other related costs that may not be considered as direct wood system costs include:

- any necessary costs for converting the distribution system (for example, removing electric heat and installing circulating hot water piping);
- costs of the backup fuel storage and combustion systems;
- costs for identifying the presence of asbestos that might be disturbed during the installation of the wood-chip system; and
- costs for spot removal of small amounts of asbestos in an existing boiler room.

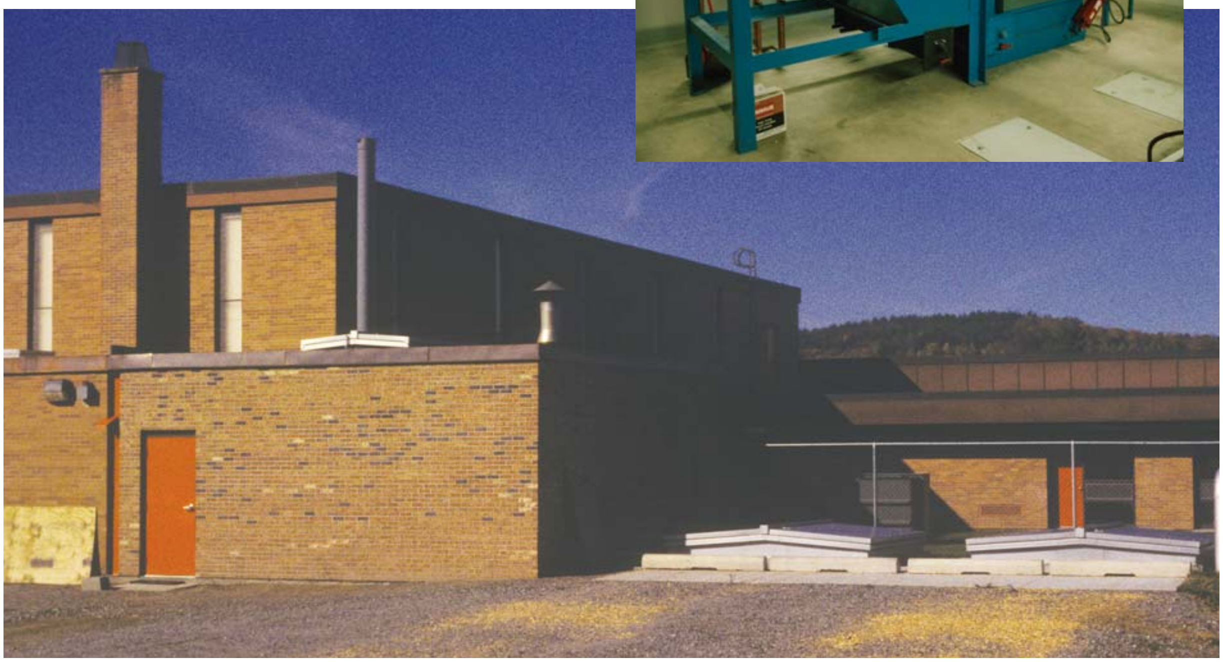
When deciding which of these cost components to include in the financial analysis you should ask the critical question, What are all the elements necessary to achieve the projected savings?

As an example, if a building is now heated by electric resistance baseboard, then the projected savings for a wood-chip conversion cannot be achieved without removing the electric heat and installing a full hot water distribution system. In this case the design and installation of the backup fuel system and the new heat distribution system should be included in the analysis of the wood-chip project. Alternately, the conversion could be considered as a basic modernization measure that would not be included in the wood system cost analysis.

If a building with suspected asbestos insulation on heating pipes throughout the structure is considered for conversion to a wood-chip system, the cost for determining the extent of needed asbestos removal might be counted as a wood system cost. However, if extensive asbestos removal is required, the removal cost would probably be considered a basic health and modernization measure and might not be included in the wood project definition.

If a wood-chip system is regarded as an alternative to an oil or gas system in new construction, the incremental cost of making the boiler room large enough to house the wood-chip boiler should be counted as a cost of the wood-chip system. The base cost of a boiler room only big enough to house the oil or gas system would not be considered a wood system cost, since it would have to be constructed anyway. By the same logic, the cost of the backup system to burn oil or gas would not be a cost for the wood-chip system.

Berlin Elementary School, Berlin, Vermont
System Size: 1 MMBH
Manufacturer: Sylva Energy Systems
Photo at left shows boiler room addition to school and ground-level loading doors (to right of boiler room). Photo at right shows combustor (background) and setting (foreground). Boiler is located above setting.



Life-cycle costing also recognizes that different costs may inflate at different rates over time. For example, competing fuels can be expected to inflate in price at different rates. Appropriate fuel price escalation rates can be obtained from a variety of sources, including state energy offices, utility regulatory bodies, and local utilities.

When using inflation rates and discount rates, you should be consistent in applying either real or nominal rates. Nominal rates include the rate of general inflation; real inflation rates do not. For example, if oil prices are expected to increase at a rate 2% greater than general inflation and general inflation is 3%, then the real oil price inflation rate is 2% and the nominal rate is 5%.

Once you have determined an appropriate discount rate and inflation rates, you can use life-cycle costing to make judgments about the tradeoffs between benefits and costs incurred at different points in time. Simple payback and cash flow analyses cannot do this. Life-cycle costing also enables you to evaluate on a year-by-year basis the full range of benefits and costs expected to be incurred over time.

The following section lays out some of the details associated with performing a life-cycle cost analysis of a potential biomass energy project. Software for doing life-cycle cost analysis is available from a number of sources, including the Building Life-Cycle Cost (BLCC) computer software by the National Institute of Standards and Technology (NIST). Prospective users of commercial software for life-cycle cost analysis should make sure that the methodology used meets their particular objectives.

Life-Cycle Cost Assumptions and Data Requirements

Choosing the right method for analyzing a prospective investment in a biomass heating system is the first step in a good economic analysis. The second step is using good assumptions in your analysis. While particular software programs may require more information, generally the important parameters involved in doing a life-cycle costing analysis of a wood-chip heating system are:

- initial system equipment/installation costs (including any building construction);
- costs for system design and project management;
- the life of the basic wood-chip system equipment;
- the life of any required building construction (boiler room and fuel storage bin);
- future wood-chip system equipment replacement costs (if selected parts will have to be replaced before the basic system needs to be replaced);
- resale or salvage value of any existing equipment that is no longer needed after the biomass system is installed;
- costs associated with the backup fuel system;
- annual wood-chip system maintenance and repair costs;
- the projected volume of wood chips required annually;
- the projected volume of backup fuel required annually;
- the projected electric use and first-year costs associated with running the wood-chip system;
- the current price of wood chips, backup fuel, and electricity (energy and demand);
- annual fuel price inflation rates for wood chips, backup fuel, and electricity
- timing and amount of financing costs (principal and interest);
- amount of grants that will offset the installed cost;
- annual general inflation rate; and
- the owner's discount rate for the investment.

The analysis will give the life-cycle cost of installing the wood-chip system. This needs to be compared to the life-cycle cost of not installing the wood system, by characterizing the "do-nothing" option in the same way that the wood system installation was characterized. If you are considering the installation of some alternative fuel system, you should analyze its costs in the same way that you analyzed the wood-chip system. The option with the lower life-cycle cost will be the better financial investment.

It is important to take care in developing assumptions and collecting useful data in each of these categories. Some will be easy to develop. For example, if you are considering installing a wood-chip heating system to replace an oil heating system, you will already know the price you are paying for oil and you probably have a good idea what it is costing to maintain the system.

Other assumptions will be more difficult to determine. For example, unless you have significant in-house expertise, determining how much it will cost to install a complete wood-chip heating system (including any necessary building construction) will probably mean getting an estimate from an engineer or consultant specializing in biomass systems or from a wood-chip system manufacturer (see "Defining the Biomass Project and Its Costs" on page 45). For the estimate to be useful, you will need to have a sense of the level of automation and sophistication you expect from the system (see "System Sophistication and System Cost" in Chapter Ten). It may be wise to analyze the life-cycle costs of two very different approaches to system sophistication and features.

Each of the assumptions you make will affect the outcome of your analysis. However, the results will be more sensitive to some assumptions than to others. Thus, once you have set up the basic framework for analysis, it may be worthwhile to determine which assumptions are most important, and ensure that you are reasonably comfortable with those particular numbers.

In addition, if you feel uncertain about one or more of your assumptions, it may help to look at how changing those assumptions affects the bottom line of your analysis. This sensitivity analysis is usually relatively easy to do (particularly if a computer program is used), and can give you confidence in your final decision.

For example, you may be confident about all the other assumptions you have used but uncertain about the appropriate oil and natural gas price inflation rates. If so, you could do your analysis several different times, using several different inflation rates that you believe to be plausible. If the wood-chip system is cost-effective under even the lowest of those rates, you can be sure that the system will save you money. If the wood-chip system is cost-effective under some plausible oil or gas price inflation rates but not under others, then you may want to spend more time to evaluate the assumptions.

Once your economic analysis is complete, you must make a decision about whether to install a biomass system. The economic analysis will be an extremely important factor in that decision, as will a number of noneconomic considerations. The decision-making process is discussed in Chapter Ten.

[1] Based on interviews with system operators, owners, and business managers as a part of the development of this guide.

Chapter Eight

Information Resources and Assistance for the Building Owner

Reading this guide may be the first step for a building owner in moving along a path that could lead to the purchase and installation of a wood-chip system. As the level of inquiry becomes more focused, a number of questions arise:

- Is a biomass system cost-effective for this facility?
- Is a wood-chip system an appropriate match with our maintenance staff?
- What type of wood fuel would it burn, and who would supply it?
- Should we install a simple, low-cost system or a more sophisticated and costly one?
- Can our in-house staff do the work of specifying and procuring the biomass system we want, or do we need to hire a specialist?

This chapter provides guidance in answering these and other questions.

The level of information required and the complexity of the process of making decisions will vary from facility to facility. For a public entity such as a school, the process may be long and may involve many players and information resources. For a small commercial establishment, such as a medium-sized greenhouse, the owners may get enough information from their own assessment of the savings, and perhaps from the successful example of a nearby wood-chip burner in a similar setting.

Your state's representative of the Northeast Regional Biomass Program (NRBP) is a very important first resource, both for support and for a wide range of information about burning biomass. See Appendix A for a state-by-state list of NRBP contacts. The NRBP representatives will be knowledgeable about other specialists — foresters, wood energy engineers, consultants, and so on — in the public and private sectors. The NRBP representative will also be able to supply the names of system manufacturers active in the market.

Feasibility and Economic Analysis

Building owners and facility decision-makers should use a level of economic analysis (preferably life-cycle, cost-based) that is consistent with what they would use for any other investment of a similar size. The smallest, simplest wood-chip systems rarely cost less than $50,000 (including building construction); the total cost of school systems is usually $150,000 to $350,000, and in the largest installations considered here, a complete biomass system may cost $500,000 or more.

The feasibility and economic analysis for a wood-chip system can be done by the same people who would perform a similar analysis for any other energy cost-saving measure. An NRBP contact may give welcome assistance, helping owners carry out in-house studies for small facilities or preliminary studies for larger facilities. If the technical capability to do the necessary level of analysis does not exist in-house, building owners usually turn to energy consultants or engineering firms that specialize in energy studies.

In-state professional engineers who specialize in energy studies of schools and hospitals can be identified with the assistance of your state's energy office (see the state-by-state listings in Appendix B). Your state's NRBP contact may be able give you names of consultants or engineers who specialize in wood-chip installations. The NRBP contact may also know of energy service companies that include feasibility studies of biomass heating plants in their scope of services. An energy service company (ESCO) may be interested in providing a full range of services — doing the study, providing third-party financing, and doing the engineering and project management.

The entity or individual that does your feasibility study does not need to have prior experience with wood-chip systems, although such experience is desirable. For an analyst who does not have prior biomass experience, here are some key pieces of information that must be developed from reliable and knowledgeable sources:

- local availability of biomass fuel, fuel type (including moisture and Btu content), and cost;
- a conservative but realistic number for wood system seasonal efficiency;
- an idea of the level of biomass system automation and sophistication of controls appropriate for the facility;
- an estimated cost for a complete biomass installation, including any building construction (the chip system budget should be based on estimates from more than one system supplier); and
- Realistic assumptions about maintenance costs for the wood system and for competing systems that burn conventional fuels.

Before you hire an analyst who lacks previous knowledge of biomass systems, you should discuss with him or her the process proposed for gathering the necessary information. It is important that the relative treatment of biomass and conventional fuels not be biased by the analyst's knowledge base or predisposition.

Technical Information on Wood-Chip Systems

At some point in the development of any wood-chip installation, someone representing the owner needs to become knowledgeable about biomass systems in general and about the specific choices that are available. For a small commercial or agricultural facility, the business owner is often the appropriate person to do this. For a school, it might be one or more school board or facility committee members, the head of maintenance, the principal, the business manager, or an interested person from the community. For a hospital or a government facility, it might be a staff engineer or a technical resource person from within state government.

Unless the owner hires a professional engineer or consultant who specializes in wood-chip energy projects, the owner's representative will need to find reliable sources for the necessary technical information. This guide is intended to provide a generic technical base of information on biomass systems and associated issues. The information in this book can be augmented by phone interviews with other similar facilities that burn biomass, and by site visits to see systems in operation and to talk to both owners and operators. Your NRBP contact or state forester should

Emory E. Hebard State Office Building, Newport, Vermont
System Size: 2.5 MMBH
Manufacturer: Messersmith Manufacturing
The wood system was installed during the construction of this new state office building. The fuel storage bin is in the basement, with chips delivered to sliding doors that are architecturally integrated into the exterior design of front of the building.

Tractor-Based Storage and Handling System. The photo at right shows loading the storage building at Hollewand Farm, Pereau, Nova Scotia. This pig farm has a 1 MMBH system by Dumont Stoker.

be able to help you identify good people to talk with and good sites to visit.

System manufacturers are a very valuable source of technical information. Their job is to produce and install systems that work reliably. Manufacturers with significant numbers of projects to their credit, installed over a number of years, can offer insight into which approaches work and which ones don't. To gain a broad technical view, it is important to get information from more than one manufacturer, since the competing firms have different strengths and weaknesses for different applications.

Project Management for Installing a Biomass System

Once the decision has been made to install a wood-fired system, someone has to do the nuts-and-bolts tasks associated with identifying the system characteristics required, writing the specifications, selecting a manufacturer or installer whose system meets those characteristics, writing a contract for the supply and installation, and overseeing the installation to make sure the contract terms are met. This person serves as the owner's project manager. The project manager may also play an important role in arranging financing, coordinating the overall scope of work, and overseeing communication between the owner and other parties.

The project manager for the biomass installation can be the person or entity that is the owner's designated technical resource on biomass, as discussed above. Or the owner may engage an architect, engineer, or professional project manager, particularly if the installation of the biomass system is a part of a larger project. A biomass project usually involves construction of a storage bin and possibly a new boiler room; it may also be part of the expansion of a building or of the construction of a new facility. If the project manager does not have technical background in biomass systems, it is important that the owner's technical resource person on biomass continue to have a role in project management.

In-House and Volunteer Assistance

Facility owners and decision-makers may be able to reduce project costs and build project support by relying heavily on in-house staff or, in the case of public institutions, on volunteer assistance. Volunteers may, for instance, be willing to spend many hours researching and learning about an interesting technology such as wood-chip burning. Volunteers who are technically inclined may be able to go into greater depth and achieve a broader understanding than might hired engineers working under budgetary constraints.

Communication between in-house staff resources, or volunteers, and the owners or decision-makers is very important. These designated human resources should fill the role of collecting information, clarifying and condensing it, and presenting it to those who are responsible for making decisions.

In project management it is important not to have too many players, and to maintain a clear chain of command from the project manager to the decision-makers. Project management should be done by technically qualified, experienced persons. All input from volunteer and in-house resource people should be channeled through the project manager. Using a volunteer committee to provide project management can lead to fragmented decision-making and unclear directions to the contractor.

Chapter Nine

Finding Capital to Pay for a Wood-Chip Heating System

This chapter identifies options for financing wood-chip system installations. It also presents case studies of how two different facilities — one in New England, the other in eastern Canada — analyzed, financed, and installed their biomass systems.

Financing is an essential and sometimes difficult part of any biomass project. In deciding whether to install a wood-chip heating system, one of the first questions to consider is how to obtain capital for the project. Institutions, non-profits, or managers of public buildings need to explore the possible sources of financial assistance (such as government grants) and how to raise money to pay for the portion of the project that cannot be financed with grants. For private, commercial, or industrial facilities, grants are less available and the owners may need to rely completely on company funds or debt financing.

Grants for Biomass Projects

In recent years, some states in the Northeast have had grant money available for public schools that might be used to study and install renewable fuel energy systems. In general, these grants have fallen into two categories. The first is state aid, through school construction aid or similar grant programs. The second is "green schools" initiatives that are generally funded by state renewable energy funds.

1. State Aid for School Construction Projects

The availability of state school construction aid varies from state to state. In Vermont, which has the most school wood-chip systems in the Northeast, schools that want to invest in a wood-chip system may be eligible for aid through the state Department of Education. Under that program, the state provides up to 50% of the eligible cost of installing a wood heating system. Information on state education aid programs in any state can be obtained by contacting your state Department of Education.

2. Green Schools Programs

In recent years a number of states have created "green schools" programs to encourage energy efficiency, the use of renewable energy, and construction that uses environmentally friendly building materials in public schools. These programs often make grants available to schools from state renewable energy funds, and may encourage schools to consider wood heating as a "green" practice.

However, since most renewable energy funds are capitalized from levies on electric bills, they may only apply to renewable energy systems that produce electricity. Because wood-chip systems that produce electricity at this scale are not currently available on the market, there may be limited opportunity to get capital for a wood system from your state's "green schools" program.

Other Grants for Public and Private Facilities

Although no other regionwide grant programs have been identified, individual states may have grant moneys that could be used for biomass system installations. For example, a public housing authority received two grants from the State of Vermont Department of Public Service and the Vermont State

Economic Opportunity Office to put a wood-chip system in a low-income housing development in the early 1990s (see photos on page 65; this wood-chip system has just completed its eleventh successful year of operation).

Grant programs to help private businesses pay for biomass systems may be limited. However, it makes sense for interested businesses to contact local or state economic development agencies to determine whether grants are given to businesses for projects — such as biomass heating systems — that add jobs to the local economy. Wood chips are usually purchased from in-state producers, so a thriving wood-chip market means local jobs. Oil, gas, and the primary fuels for electricity generation are generally produced outside the northeastern states.

Other Financing for Biomass Systems

Whether or not some grants are available, you will probably have to finance a portion of the cost of installing a wood-chip system. Public institutions such as schools usually issue bonds to raise this capital; private businesses usually either use internal financing or obtain a loan or line of credit from a commercial bank. These are fairly straightforward processes. Several other approaches, as discussed below, can also be taken to procure financing.

1. Loan Guarantees

One possible form of financing is a variation on private loans. Private businesses may be able to obtain a loan that is either subsidized or guaranteed by a state or federal agency. These subsidies reduce the effective interest rate of qualifying loans to some level below the normally available interest rate.

Small firms may qualify for guarantees from the federal Small Business Administration (SBA). SBA guarantees make it easier to obtain financing from commercial banks. To qualify for an SBA-guaranteed loan, you must document your firm's financial stability. In most cases, businesses must also contribute at least one-third of the total project cost. In exchange the SBA requires your lender to cap the interest rate according to a formula based on the prime rate.

2. Third-Party Financing

Another approach to financing for both public institutions and private businesses is to obtain financing from a third party — neither the facility owner nor a traditional lender.

Wood-chip installations and other energy-saving measures are sometimes financed by third parties under a shared-savings approach. Under this scheme, a third party agrees to pay for the installation of the wood-chip system from its own sources of capital, in exchange for regular payments from the facility owners. Payments are usually made out of the energy cost savings, which are thus "shared" by the owners and the third-party financier.

Payments to the third-party firm are enough to cover its financing costs and the costs of any other services it has been contracted to provide. Under some arrangements, the third-party financier might provide additional services, such as supply of the biomass fuel, equipment maintenance, and technical support. Third-party payments also include a profit that is acceptable to both parties.

To summarize, under the third-party approach the financier is paid for project costs it has assumed and then shares the remaining energy savings with the facility owners. The disadvantage of this approach is that the owners must share the net benefits of the project for a certain period. The advantages are that the owners do not have to raise the capital to pay for the

Trucks with a self-unloading or live bottom floor are often used to unload chips into a below-grade bin.

installation and do not incur the risk of assuming debt.

In cases where access to capital is a major barrier, third-party financing might be the only way to install a biomass system. The weakness of third-party financing is that energy service companies are most interested in financing energy measures with quick paybacks, and rarely fund projects with paybacks of more than seven years. Capital-intensive wood system projects are likely to have paybacks longer than this.

Third-party financing holds some promise for supplying capital for biomass system installations. A carefully structured third-party financing arrangement benefits both the facility owner and the financing entity. There are a few precedents for this approach. For example, an energy services company in New Brunswick provided third-party financing to install several wood-chip heating systems in hospitals in Canada, using shared-savings financing (see the following case study of Chaleur Hospital). Similarly, the non-profit Vermont Energy Investment Corporation of Burlington financed part of a wood-chip conversion of a public housing project in Barre, Vermont, using a form of shared-savings financing (see photos on page 65) to supplement grant financing.

Also, electric utility energy-efficiency programs have spurred the growth of energy service companies (ESCOs), which install efficiency measures on customer premises and in return are paid out of the savings. An ESCO active in your area might be interested in becoming the third-party financier of a wood-chip energy system. Your electric utility or state energy office should have information on ESCOs operating in your state.

3. Leasing

Lease financing from the equipment manufacturer is another mechanism available to building owners, either in the public or the private sector.[1] Leasing offers a number of advantages: low monthly payments compared to debt service on bonds and bank loans, up to 100% financing (no down payment), and a choice of lease types. Leasing also has some disadvantages, including limited tax benefits, no ownership of the capital equipment, and low availability of biomass system manufacturers willing to lease equipment.

Case Studies in Financing

1. A School Converts from Electric Heat to Wood Chips

In 1992 the Leland and Gray Union High School of Townshend, Vermont, converted from electric resistance heat to a wood-chip heating system. The project included removing the electric heat, installing hot water distribution piping throughout the building, constructing a chip storage bin, installing the wood-chip handling and combustion equipment (manufactured by Chiptec Wood Energy Systems), and installing an oil backup system. The installation of the new wood-chip system was the culmination of more than two years of analysis and planning.

In the late 1980s the school's $100,000 electric bill was its largest annual expense after employee salaries and benefits. Much of that expense was assumed to be attributed to the school's electric heat. The school hired an engineer to do a technical assistance (TA) study that examined several different fuel conversion options, including switching to coal, oil, LP gas, and wood chips. An federal grant paid for half of the $9,000 study.

Working with the engineer and the results of the TA study, the school quickly eliminated coal (because of concerns about air emissions and ash disposal) and LP gas (because the fuel cost would be substantially higher than oil). That left wood and oil.

Those two fuel options were studied from a number of economic perspectives, with the major emphasis on life-cycle costing. The simple payback method was also used, because Vermont's state aid program and the federal grant program available at the time required it in order to qualify for a grant for 30% of the installed system cost. First-year cash flow impacts were also studied as a means of demonstrating project benefits to the voters.

The final decision — to select a wood-chip system — was made on both economic and non-economic grounds. Although the wood-chip system was estimated to cost $100,000 more initially than the oil alternative, the added cost would be recovered over time from lower fuel bills. In addition, the school predicted there would be less uncertainty about the future price and availability of wood chips compared to the future price of oil. The wood-chip option was seen to be preferable both from an environmental perspective and as a stimulus to local economic development.

Once the wood-chip system was selected, the school board looked at bonding, third-party financing, and a bank loan as options for the non-grant money required to install the system. The school finally opted for a municipal bank loan, which was approved by the voters at Town Meeting. The variable rate bank loan had a seven-year term. It was originally projected at 6.25%, but falling interest rates brought the late-1993 rate down to 3.25%.

After the first year of operation, the wood-chip system was more successful than projected. During the public debate over the project, the school's business manager promised voters that the school's energy and maintenance cost savings would exceed its loan payments by $10,000 in the first year, based on reduced energy costs and the cancellation of a $7,000 annual maintenance contract on the electric heating system. With the help of low interest rates, the school's second-year cash flow was a positive $14,000, or $4,000 more than the original savings projection. (In the first year, savings were eroded by an electric-rate ratchet penalty.)

2. A Hospital Converts from Oil Using Third-Party Financing

During the 1980s, a number of hospitals in the Canadian Maritime Province of New Brunswick installed wood-fired heating systems. One of those projects — at Chaleur Hospital in Bathurst — was undertaken on a full "turnkey" basis, with third-party financing provided by Northeast Energy Services. This offers a classic example of a shared-savings approach to financing a biomass energy installation.

At the urging of an energy specialist in the New Brunswick provincial government, the hospital decided to add a wood-fired system to its oil-fired heating plant in an attempt to cut annual energy costs. The project, completed in 1986, was planned amid concern about high oil prices (which actually dropped sharply at just about the time the Chaleur system was installed). The oil-fired boilers remained available as a backup and to help during times of system peak demand. The wood-fired system, manufactured by KMW Energy Systems, was sized and installed to heat the hospital and a neighboring 125-bed nursing home.

Under the project's turnkey approach, the hospital arranged for Northeast Energy Services to design and install the wood-fired system, give technical and operating assistance, and provide a long-term supply of hogged wood fuel from local sawmills. Northeast Energy Services also provided all of the financial capital for the project, $784,000 in U.S. currency.

In essence, the project was set up on a lease-to-own basis, in which the hospital made regular payments over the life of its contract with Northeast in exchange for the services provided. The hospital's payment schedule was designed to be sufficient to cover all of Northeast's costs, plus a reasonable profit for the company. Because the payments were less than the energy cost savings, the hospital realized a net savings every year, including the contract period with Northeast. Once the term of the contract expired, the wood-fired system became the fully owned property of the hospital, with the hospital getting all the savings.

This project saved the hospital money in reduced energy costs, and has been a significant success. The shared-savings financing approach enabled the hospital administrators to undertake the project without having to raise the necessary capital themselves. As projected, the hospital saved more money in reduced energy costs than it paid Northeast Energy Services to cover construction, debt repayment, technical services, administration and profit.

Although successful from the hospital's viewpoint, from the perspective of Northeast Energy Services the project was not as profitable as originally estimated. The Chaleur shared-savings contract specified that the rate at which Northeast would be reimbursed for the wood fuel it supplied was a function of the prevailing oil price each year, and the oil price was not as high as was projected. Nevertheless, Northeast Energy Services abided by the terms of its contract and remained open to the possibility of pursuing similar projects in other locations.

[1] Curt C. Hassler and Kenneth D. Jones, Biomass Energy Systems: A Preliminary Investment Decision-Making Guide for the Small Business (Muscle Shoals, Alabama: Southeastern Regional Biomass Energy Program, Tennessee Valley Authority).

Chapter Ten

Putting Together and Implementing a Biomass Project

This chapter addresses the process of turning the idea of a wood-chip system into a reality. The first step, already discussed in detail in Chapter Seven, is to do an analysis of the cost-effectiveness of burning biomass. That study will be at the center of the decision-making process, which will consider a wide range of concerns: environmental considerations, staff interest, maintenance issues, economic development, public perception, regulatory requirements, access to capital, access to fuel supply sources, and more. Some of these issues are discussed below, and some are discussed in other parts of this guide. This chapter starts from the point at which a decision to install a biomass energy system is being made.

Decision-Making Based on the Financial Analysis

The energy and economic analysis discussed in Chapter Six will provide the basis for a decision on whether to install a biomass system. It will answer the question, Does this wood energy system have the lowest life-cycle cost compared to the other options? Whether or not the answer is a conclusive yes, decision-making can proceed from there to look at other related questions.

The final decision may well be made on factors that are not strictly economic, or that apply long-term thinking in ways difficult to quantify. In some cases, school boards and taxpayers have voted for wood-chip systems because they felt this was a sensible decision in favor of long-term environmental stewardship and resource use, even when installing an oil or gas system had more attractive short-term economic benefits. In some cases, decision-makers have recognized that a biomass system represents an infrastructure investment that will bring financial benefit as long as the building stands, even though the economic analysis may assume that components will last no more than 20 years. (One of the challenges of life-cycle cost analysis is to characterize adequately the cost components for those infrastructure improvements, such as concrete fuel storage bins, that last as long as the building.)

This guide has presented a number of reasons to install a biomass system, including:

- the dramatic reductions in fuel costs that can result from burning the least expensive fuel type (particularly after the finance period);
- the status of wood as a locally produced, renewable fuel;
- the flexibility of a boiler plant designed for solid fuels;
- the economic-development benefits of creating wood-energy production jobs and keeping fuel dollars in the local economy, instead of exporting them to other states or other countries; and
- the environmental benefits related to displacing high-sulfur fuels, and fuels that contribute to global warming.

To review other positive aspects of biomass systems, see “Beyond Economics” on page 8.

It is also appropriate to look squarely at the question, What are the reasons for not installing a wood-chip system? Decision-makers should be ready to look at:

- the impact on their maintenance staff (real and perceived);
- state air quality requirements of wood-chip systems in their size class;
- how they plan to dispose of ash; and
- other, similar facilities that burn biomass — not only the successes but also the shortcomings of their biomass systems.

To review other negative aspects of biomass systems, see "Concerns Associated with Biomass Fuels" on page 10.

Finally, the most important question will be which of these factors — economics, comfort, fuel price stability, environmental sensitivity, and local economic development — are most important to you. In particular, you may have to decide whether your interest in any of the less quantifiable factors is sufficient to warrant pursuing a course of action that is counter to the one suggested by the economic analysis. This is a decision that only you can make.

The decision whether to burn biomass fuel affords an unusual opportunity to take concrete steps toward building the kinds of energy-use structures that will serve our region well in a resource-constrained future. The debate over taking these steps can be interesting and enlightening. The rest of this chapter is concerned with the steps that follow the decision to proceed with installing a biomass system.

The Steps to a Successful Biomass Installation

When the owners of a facility undertake to install a biomass system, they will naturally want the finished product to meet their needs and expectations. Looking at the big picture, how can they do this? Here are the key ingredients of a successful installation:

1. APPROPRIATE PROJECT STRUCTURE

To get a system that will serve them well in the long run, owners must have access to unbiased information on their options. The project should be structured, through its use of human resources, to facilitate the supply of information and make possible intelligent decision-making. The project should also be structured so that the system purchased and installed is what the owners want and does what they expect it to do, as verified through system commissioning.

Camp Johnson, Essex, Vermont
Facility Type: National Guard base
System Size: 3 MMBH
Manufacturer: Chiptec Wood Energy Systems
Due to a high water table chips are stored on-grade in this building, then moved using a loader to a smaller indoor bin with automated fuel handling.

2. APPROPRIATE SYSTEM TYPE

A system can be either fully-automated or semi-automated. While a fully automated system will require minimal time on the part of operators, it will likely cost twice as much as a semi-automated system. For small facilities or ones with low heating bills, a fully-automated wood system may not be cost-effective, while a semi-automated system may provide attractive economics. The staff time involved with a semi-automated system should not be much more than for an automated system (see "System Sophistication and System Cost" on page 61).

3. APPROPRIATE SYSTEM FEATURES

The system should be selected with a level of sophistication and features that both assures the owners of efficient, trouble-free operation and stays within the cost levels supported by the economic analysis.

4. APPROPRIATE SIZING

A properly sized system will give efficient combustion across the facility's range of load conditions. A system that is grossly oversized may run efficiently only at the greatest load, and may be difficult to keep running properly the rest of the time. A system that is sized too small will result in excessive use of the backup fuel system and in additional cost.

The Importance of the System Operator

The person who will actually be responsible for keeping the biomass system operating every day is a very important player. The long-term success of the biomass project depends in large part on how well this person likes the system, and how comfortable he/she feels running it.

If the operator finds the system an imposition, a hassle, or a burdensome responsibility, it is unlikely that the system will function well. With an uninterested or hostile operator, systems tend not to get cleaned regularly - resulting in ash buildup and increased fuel consumption. If an oversized wood chip jams an auger, the operator plays a key role in restarting the fire. An uninterested operator may leave the system idle and let the backup fuel system take over. In either of these scenarios, the value of the investment in the wood system is degraded, and the anticipated energy savings may not materialize.

The potential system operator should be involved at the earliest point. It is particularly important that the operator be included in site visits to existing biomass-fired facilities and have the opportunity to talk to the system operators. The operator or chief of maintenance should be consulted by the project team on issues related to the daily operation and convenience of the biomass system.

5. EASE OF MAINTENANCE

For a system to be successful, it must be easy to operate and should match the capabilities and interest level of the operators.

6. HIGH-QUALITY FUEL

A high-quality wood-chip fuel is one that has uniformly sized chips, has few or no oversized chips, contains wood species that the system is designed to burn, has not been subject to precipitation or added moisture, and contains no rocks, gravel, or other foreign matter. The greatest problems that biomass-burning facilities encounter come from fuel that does not meet these criteria. In particular, oversized chips that regularly shut down the fuel handling system can make all the difference between an installation's success or failure.

The characteristics listed above are all specific to the biomass system. At the same time, the owners should look at integrating other energy efficiency measures. Such measures might include increased insulation levels, better windows, reduction of air infiltration, better controls for the heat distribution and electrical systems of the building, and efficient lighting upgrades. These measures will reduce the load on the building and could reduce the size of the biomass system required.

Assembling the Project Team

The project team is composed of the people who will research options, make decisions, and oversee the installation of the wood-chip system. For a small commercial or agricultural facility, the team may consist only of the owner and a heating contractor. For a large facility such as a government building or a hospital, the project team may have a fairly large and diverse membership.

If the facility is a school or other public institution with a governing board, at least one board member should be on the project team. Institutions may also include one or more members of a facilities committee or other appointees of the board. It is important that at least one board member or board appointee be interested and committed to spending the necessary time to learn about wood-chip systems. This person will play a major role in informing the decision-making body.

For hospitals or large businesses whose professional staff has expertise in economics, business, or plant management, some of these staff members may become part of the project team. Their skills in analysis, procurement, project management, and plant operation can be valuable assets. The head of maintenance or the person who will be directly responsible for the operation of the wood-chip system is a key person to include on the project team, as discussed in "The Importance of the System Operator" above.

Along with these in-house resource people, it will be necessary for larger facilities to have professional assistance on the project team. If possible, this should include a project manager, engineer, or architect who has previous experience with installing wood-chip systems. The experience of a person who has seen many systems, built by different manufacturers for different kinds of applications, is very valuable.

If you do not hire a specialist with experience in biomass systems, the same technical role can be

Commonly Asked Questions About Burning Wood Chips

Q: Doesn't wood burning involve a lot of labor?

A: In an automated wood-chip system, the operator never handles the fuel. The wood chips are loaded into the bin automatically, and the fuel is handled by completely automated equipment in the building. In a semi-automated system, the operator will spend 15-30 additional minutes each day using a tractor to feed the day bin.

Q: Isn't wood a dirty fuel that will make a mess at our building?

A: The wood chips are stored in a closed bin and burned in the boiler room, in a sealed combustion chamber. They never get out onto the grounds or into the rest of the building.

Q: Isn't there a danger that a large store of wood chips will catch fire?

A: Green wood chips are close to half water by weight, and it is next to impossible to set them on fire outside the controlled conditions of the combustion chamber.

Q: Will big trucks be coming and going every day?

A: Depending on the season and the size of the building, chip deliveries might be as infrequent as one truckload every two months, or as frequent as two loads per week. (A 10 MMBtu system might require one load per day during midwinter.)

Q: Is a wood-chip system noisy?

A: The building occupants usually never hear the wood-chip system unless they go into the boiler room.

Q: Why should we experiment with an unfamiliar technology?

A: Burning wood chips and other forms of biomass for heat has been common in the wood products industry for decades. In the last 25 years, wood-chip systems have been successfully installed in hundreds of buildings, including schools, hospitals, government facilities, greenhouses, commercial buildings, hotels, and motels. The technology is well-proven, and there are a number of manufacturers with successful track records.

Q: Won't the system make our building look like a sawmill or a factory?

A: With careful attention to design, the wood-chip system will blend in with the building. The casual observer won't know it is there.

Q: Will the wood smoke be an air quality problem?

A: Automated, commercial-sized wood-chip systems burn much cleaner than the most modern home wood or pellet stove. They produce no creosote and practically no visual smoke or odor. In most cases, institutional wood-chip systems easily meet state air quality standards.

Q: Will the system produce airborne wood ash that will fall over the neighborhood?

A: No. This has not been a reported as a problem in the neighborhoods of institutional and commercial wood-chip burners.

Q: Are the wood ashes toxic? Where and how are they disposed?

A: Wood ash from institutional and commercial heating plants is not toxic. In fact, it is an excellent soil additive for agricultural use. It can safely be put on gardens or disposed at a landfill.

Q: Burning wood creates carbon dioxide. Won't that cause global warming?

A: All fuels contain carbon and create carbon dioxide when they are burned. Unlike the burning of fossil fuels, when wood is burned CO_2 in the exhaust is off-set by CO_2 absorbed from the atmosphere by living trees. As long as sustainable forestry practices are used when harvesting the trees, there is no long-term increase of carbon dioxide in the atmosphere from burning wood.

Q: Will wood smoke cause acid rain?
A: The major sources of acid rain are sulfur dioxide and nitrogen compounds in combustion reactions (known as SOx and NOx). Unlike fossil fuels, wood has practically no sulfur and so produces virtually no SOx when it burns. Wood combustion does create NOx, but at levels comparable to fossil fuel combustion.

Q: Aren't oil and natural gas so cheap that it doesn't make sense to burn wood?
A: Depending on local market conditions, this is sometimes true for cordwood - but it is not true for wood chips. Wood chips generally cost about half as much as natural gas and no. 2 fuel oil, even at very low bulk prices for oil. Most dollars spent on oil and gas leave the Northeast, while wood dollars stay in the state economy, creating an additional economic benefit.

Q: If everybody starts burning wood chips, won't the price go up sharply?
A: The price of all fuels can be expected to go up over time. However, wood-chip prices are not directly connected to the world energy market. Wood is also a locally produced renewable fuel. For these reasons, it can be expected to increase less in price than the other fuels. Wood prices paid by schools have increased gradually at about 1% a year over the last fifteen years.

Q: Is there enough wood to heat this facility in the long term?
A: All 11 states of the Northeast have a large excess capacity of biomass available now, with an even larger reserve of unmanaged woodland that could be tapped on a renewable basis for energy production.

filled by a mechanical engineer or a project manager experienced in boiler installations. In many cases the installation of the wood system will be done under a general contract that will also include either mechanical work or building construction or both. These cases will already involve a project architect or mechanical engineer who will be able to oversee the wood system installation in addition to having other responsibilities.

Structuring a Typical Conversion

A typical conversion from electric heat to a biomass system might be structured as follows. A mechanical engineer is hired by the owner to design the boiler room equipment and the distribution piping throughout the building. This engineer is also responsible for advising the owner in the selection of the wood system manufacturer, and for designing the piping and controls connections between the wood-chip boiler and the backup boilers.

After the system manufacturer is selected, an architect is hired to work with the engineer and manufacturer to design the boiler room and the storage bin. There may also be a structural engineer, as a subcontractor to the architect, to design the concrete work (drainage, footings, slabs, walls, and reinforcement) for the fuel storage bin and boiler room. An electrical engineer will usually be involved in the overall project, and may have some responsibility associated with the biomass system.

If the biomass conversion is from an oil, gas, or coal system with hot water or steam distribution, there will be little mechanical design work outside the boiler room. In this case the mechanical engineer's role will focus more on the selection and installation of the biomass system. In new construction or in cases where there is an expansion of the existing building, the architect is likely to be in the lead role, with the mechanical engineer acting as a subcontractor.

If a biomass specialist is on the project team, that person will either work directly for the owner or be a subcontractor to the architect or mechanical engineer. It will be the specialist's responsibility to oversee the wood system specification and selection, as well as to work with the engineer and architect in putting together the pieces associated with the system: the piping and controls interface between the wood and backup systems, and the design and construction of the boiler room and storage bin.

In smaller, simpler jobs where an architect and a mechanical engineer would not normally be employed, such as an installation in a small commercial greenhouse, all elements of the design work can be handled on a performance specification or design/build basis by the owners or their representative. Under this design scenario, to be discussed in more detail later, the owner hires a biomass system installer to produce a working system on a turnkey basis. The system specifications and contract documents must be carefully written, to protect the interests of the owners and to give responsibility for installing a fully operative system to the system manufacturer or installer with whom the owner contracts.

Environmental Review and Project Permits

At the earliest stage, it is important to research all state environmental requirements for your project and to apply for necessary state and local permits. The principal area of environmental concern will be compliance with the specific requirements of your state's air quality regulations. In some states, compliance with air quality standards is no problem for biomass burners, while in others it may be necessary to go through a permitting process.

Projects that are the first of their kind can be expected to have a more difficult time in environmental review than those in areas where institutional wood burning is well-established.

See Chapter Three for more information on system features that address air emissions. Ash disposal is unlikely to be a problem for all but the largest biomass burners.

Public Involvement, Public Education

For public institutions such as schools, hospitals, or government buildings, public involvement is a key part of a biomass project. For schools, the taxpayers may be required to vote on appropriating funds for a wood-chip system, making public education and public involvement particularly important.

For small systems in the commercial or private sectors, the installation of a wood-chip system may not require an air quality permit and may attract little if any attention. Nonetheless, the owners should educate themselves thoroughly on wood-related issues that may be of interest to neighbors, such as the levels of truck traffic and stack emissions (smoke and odor). Adjoining property owners may wish to discuss these issues, and it is in the owner's interest to be proactive in providing information.

In many cases, the idea of burning wood chips or other biomass to heat a large building may be unfamiliar to the public, who should therefore be expected to have concerns and questions. Some of these concerns may be based on the public's experience with home wood burning, some on a sophisticated understanding of the global warming question, and others from fear of something new. Regardless of whether the questions and concerns are based on misconception or valid fact, the public deserves well-researched answers.

Almost all the critical questions raised in the early stages of public decision-making on wood-chip systems become nonissues when the public is presented with factual information in a thoughtful, well-organized manner. The earlier the public is brought into the process, the better. For public institutions, this process should start while the feasibility study is being done. That way, as soon as there is a demonstrated economic case for installing a wood-chip system, the decision-makers will be ready to make that case.

The Northeast Regional Biomass Program has made an excellent video, "Heating Schools with Wood Chips" (produced by the State of Vermont Department

Union 32 Junior-High School, East Montpelier, Vermont. 4.5MMBH
Manufacturer: Messersmith Manufacturing
Installation of a tall stack.

System Sophistication and System Cost

Data on the installed cost of biomass heating systems in 45 facilities, collected as part of the development of this guide, show a wide range of system costs per MMBtu of system size. For example, semi-automated greenhouse biomass systems typically cost about one-third as much as fully-automated systems of the same size in schools or hospitals.

There appear to be three major reasons for this divergence in system costs. First, tractor-based semi-automated systems, which use a tractor or front-end loader to move fuel from the storage bin to a day bin are inexpensive to build. The fuel storage facility can be of simple, low-cost construction, compared to below-grade fuel bins. Further savings come from eliminating some of the fuel handling equipment and controls, particularly if the facility already owns a tractor suitable for this purpose. See photos below for an example of a low-cost tractor-based system.

Second, a farm or greenhouse will typically make the most of its own in-house resources to design and build the storage facility and boiler room. (There may already be a suitable building space for on-grade fuel storage or available space for the boiler room.) Staff may also be used to install the biomass system. In contrast, a school, hospital, or public building will typically use architects and engineers to design buildings that are built by contractors at considerably higher cost.

Third, the level of control sophistication and additional features has an impact on cost. A system utilizing simple on/off controls and no exhaust gas cleaning equipment costs substantially less than a system with more sophisticated microprocessor controls and added features. Attractive features like automatic ash removal or soot cleaning, moving grates, and more complex combustion chamber geometry translate into higher costs. The technical and maintenance benefits of these various features are discussed in Chapter Three.

Decision-makers need to be aware of the cost implications of the various system features early in the development of a project. These implications include not only first costs but operating costs as well. There can be a tradeoff between lower first costs and higher operating costs, although many successful lower-cost systems do not have high operating costs.

It is good to discuss system sophistication and cost in the framework of the economic analysis when a project is being put together. For example, a comparative life-cycle cost analysis for a particular project (see Chapter Six) can be performed for both a sophisticated, more costly approach and a simple, less costly system.

of Public Service), for use by decision-makers and in public education. The video is available through state NRBP representatives.

The following section of the guide lists a number of common questions about wood-chip systems that are likely to be asked in a public forum, and gives the outline of answers to each. Many of these questions are also covered effectively in the video mentioned above.

Selecting a Wood-Chip System: Performance Specifications

The first step in selecting a wood-chip system is deciding what you want and need for your facility. Here are the key questions to answer:

- What kind of biomass fuel will be burned? Who are the likely suppliers? What kind of truck will be used for delivery, and what is its capacity?
- Will the fuel handling system be fully automated, or will a tractor be used for loading a day bin from a fuel storage pile?
- How big should the fuel storage bin or shed be?
- What is the best location for the boiler room and fuel storage bin?
- How important is it that the building construction for the boiler room and bin be carefully designed to fit in with the style of the existing building?
- How should the bin and its loading doors be configured for ease of delivery?
- What is the peak heating load of the facility (in million Btus per hour), and what is the annual heating load (in million Btus)?
- What fuel will be used for backup?
- How should the wood system be sized, compared to the peak heating load? How should the backup system be sized? (See "Sizing the Biomass System"

on the next page.)

- Should the system be of a simple low-cost design with few extra features, or is a more sophisticated and more costly system with added features desirable? (See "System Sophistication and System Cost" on page 61 and "Considerations in System Selection" in Chapter Four.)
- What gauges or level of instrumentation is required?
- What level of spare parts for the system should be supplied by the manufacturer?
- How can the system be configured to give the best possible match with the existing maintenance capability?

The answers to these questions then need to be formalized in a performance specification, a written document that tells bidding system suppliers what is required. A performance "spec" says what the installer's system must be able to do, but it does not

Sizing the Biomass System

How big should the biomass system be? How do you determine the "correct" Btu output - and how should the backup system be sized? These are critical questions, and the answers depend on the owner's objectives for operating the plant.

There are two lines of thinking on this issue, and they lead in opposite directions. Although this discussion is fairly technical, it is important for the owners to understand and, under the advice of a mechanical engineer, to decide how the biomass system is sized. The starting point is an accurate number for the peak heat load of the facility (including domestic hot water). This number is usually provided by a mechanical engineer, based on ASHRAE load calculations.

No matter what the objective, gross oversizing of the biomass plant should be carefully avoided. There is a natural tendency to design heating plants that are oversized. But if the wood system is grossly oversized, whether unintentionally or by design, it will not run well, will burn too much fuel, and may produce smoke in low-load conditions.

The owner's primary objective may be to minimize backup fuel use. In this case the system should be sized to meet, or nearly meet, the facility's full heat load. In the coldest weather, or the period of greatest load, the system will be running almost constantly at full output. The backup fuel system would not be needed to meet the load, except perhaps for very brief periods. But since peak load conditions usually occur only a small fraction of the time, the rest of the time the system may run less efficiently.

A system with multiple firing rates or modulating fuel feed will do better in low-load conditions than will a simple on/off feed system. For these systems, oversizing is less of a problem, since the system will run efficiently over a wide range of load conditions throughout the heating season.

The opposing objective is to try to minimize capital cost by installing an undersized system, compared to the peak heat load of the facility. In this way the wood system will run at its maximum output more of the time. The drawback is that the backup fuel system will be needed to boost heat output during the peak load periods. Depending on the level of undersizing, this can result in either a minimal backup fuel use or a significant and costly backup fuel use. Experience over the last fifteen years shows that significantly undersizing the system my not save much capital cost and may significantly increase the usage and cost of backup fuel.

Sizing the system can be complicated by the possibility of future building or load expansion. When making sizing decisions, the owner needs to have a realistic discussion about the likelihood and magnitude of possible future expansions of the load on the heating plant. There needs to be a coherent strategy that addresses two questions: How will the system run if we do not expand our load? and, How will we be able to modify the system if our load does increase?

For a system with a winter seasonal heat load, peaking in midwinter and dropping sharply in the fall and spring, the use of more than one biomass boiler can give efficient operation in almost all conditions and still meet the entire heat load with no need for burning backup fuel. The larger of the two wood boilers would be used in the winter season and the smaller wood boiler could provide efficient operation in warm months. This approach can be attractive for a large facility with a high summer demand for domestic hot water that could be met by the wood system.

It is common to size the backup system to meet the full design load of the facility. In this way the backup say exactly how it should do that. Since the installers are in the business of building successful systems, they do not need to be told how to make their product. The performance spec does, however, give them guidance on the kinds of features and the level of performance the owner wants. Of course, the performance spec will be very specific in certain areas, such as system sizing.

In the size range considered in this guide, systems are typically installed on a turnkey basis, in which a single system supplier takes responsibility for the entire fuel handling and combustion package. In such installations the owner or the owner's representative plays a major role in determining how the system is configured, and so needs to be well-informed about how biomass systems work.

The content of the performance spec is critical in producing a biomass system that will operate efficiently with minimal problems for many years. The art of writing a good performance spec is knowing how much detail or specificity is needed to convey the owner's intention and to protect the owner's interest in getting a good, workable system. There is a danger in overspecifying the job, because that may relieve the installer of the responsibility for the workability of all aspects of the system. But there is also a danger in underspecifying, because without enough direction the installer might give the owners more or less system than they expect. The specification should allow bidders to propose alternate approaches and additional features.

At the high end of the size of systems considered in this guide (about 10 MMBtu or larger), it is common practice to hire an experienced biomass system engineer to design and specify fully all aspects of the system. In projects using this design specification approach, the biomass engineer takes responsibility for assembling the pieces and producing a system that works. When there is a design engineer, the owner is relieved of much of the technical burden of researching systems and making decisions on system components. That process is quite different from the turnkey performance spec approach advocated for most systems in the size range considered in this guide. In turnkey projects the major responsibility for a workable system lies with the turnkey contractor, with many key decisions being made by the owner.

Selecting a Wood-Chip System: The Bidding Process

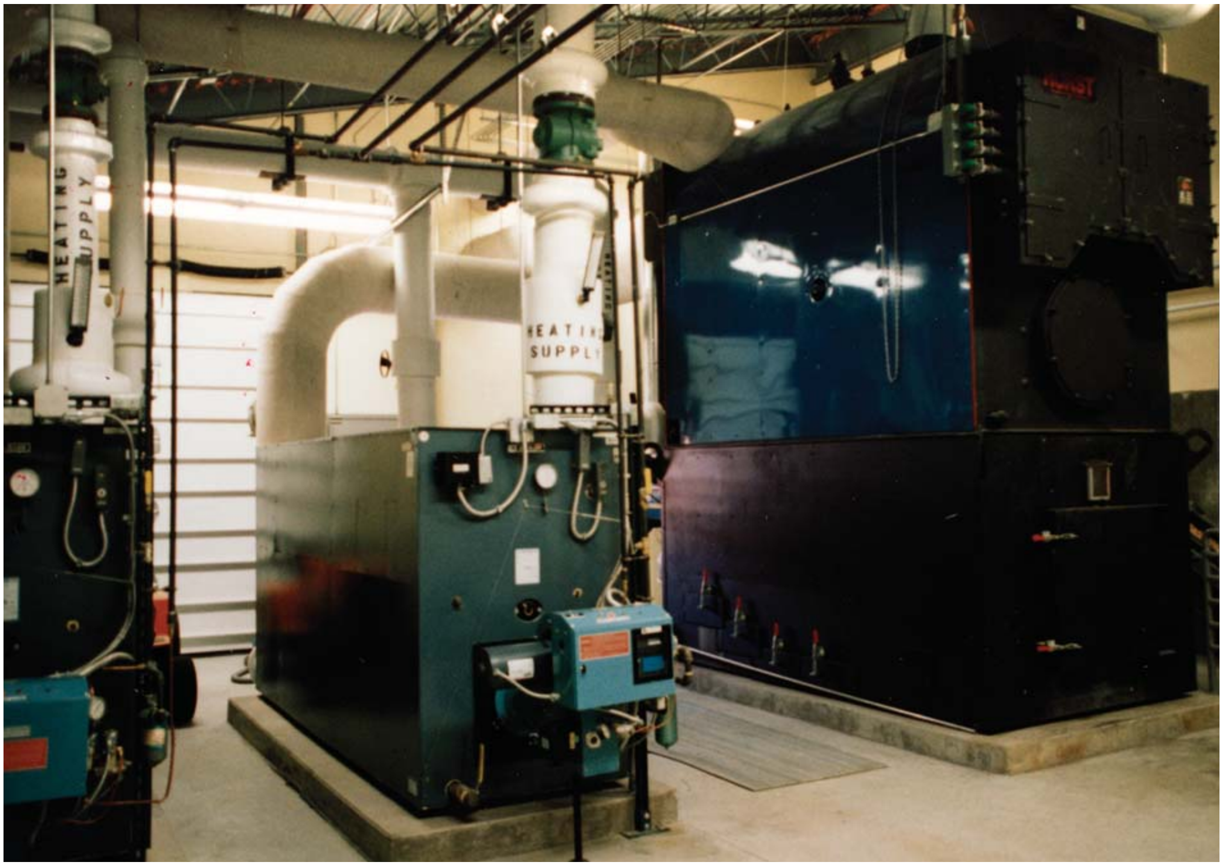
Once the owners have clarified in a performance spec what they want from a biomass system, they can take two approaches to selecting a system: competitive bidding and informal bidding.

Under competitive bidding, the performance spec becomes the basis for bid documents used to solicit bids from a number of system suppliers. Each one must submit a bid that meets the specifications. Because these are performance specs, all bidders have the freedom to configure their proposals to the strengths and individual characteristics of their systems, within the bounds of the requirements of the spec. Each

system will always be able to take over completely if the biomass system goes down for any reason. If, however, the owners have a strong commitment to operating the biomass system as the primary and only system in normal conditions, and are willing to put in place routines that will correct any system problems when they develop, it then becomes less important for the backup system to be sized to the full load. Fuel storage tanks for backup oil systems can be much smaller - and less expensive - than they would be if oil or propane were the primary fuel.

Some facilities with daily maintenance staffing run biomass systems with no backup. This can be done if four conditions are met. First, the biomass system's output must be able to meet the full peak load. Second, the manufacturer's system must have an excellent track record for smooth, reliable operation. Third, there must be a completely dependable biomass fuel supply. And fourth, the operator must be readily available to get the system going again if it shuts down for any reason. Facilities without 24-hour staffing can accomplish this by using an automatic paging or dialing system that can sense trouble in the system and call the system operator.

Any building owner considering installing a biomass system without a backup needs to look carefully at the capital and operating costs associated with both approaches (with and without a backup system). While money can be saved by not putting in backup burners and boilers and by making the boiler room smaller, staffing the system to avoid shutdowns may add to the owner's labor costs.



Wood-chip Boiler Room:
This shows the wood boiler (on the right) and two backup oil boilers, the smaller of which is for warm-month use. The oil boilers are sized to handle the entire load of the school so that if the wood system is unavailable for any reason, the oil boilers will provide full heating capability. The oil boilers come on automatically whenever needed.

manufacturer's proposal will demonstrate how that system will meet the specifications and at what price. The performance spec allows systems that are quite different to compete on a level playing field.

Under informal bidding, the owners (or their representative) study the systems on the market, visit existing installations, and then select the manufacturer or installer they want to use. The performance spec then becomes both the tool for telling the supplier exactly what is required and the basis for the supplier's price proposal. The informal approach to system selection is sometimes used in locales where one manufacturer dominates the market. It is easy for a prospective buyer to look at a number of successful systems in operation in a given area, all by the same manufacturer, and say, "We'll take one just like that."

The major strength of competitive bidding among a number of suppliers is that it tends to keep a downward pressure on costs. To be effective, however, competitive bidding requires carefully written performance specifications. The strength of informal bidding is that it is very simple. Its weakness is that the price advantages of competitive bidding on system cost may be lost.

Another important advantage of competitive bidding is that it tends to promote innovation and system improvements. Manufacturers who operate in a competitive environment are more likely to build in improvements that will make their system more attractive than the competition's. Competitive bidding also puts the owner squarely in the driver's seat in terms of deciding what features will be installed.

Competitive bidding brings a dynamic element to

Green Acres, Barre, Vermont
Facility Type: 50-unit public housing development
System Size: 2.2 MMBH
Manufacturer: Messersmith Manufacturing
Bottom photo shows the maintenance building, which houses the boiler plant for 8 buildings of family rental apartments. The district heating system supplies heat in the winter and domestic hot water year-round.

the content of the performance spec. In the process of talking to prospective bidders and looking at examples of their systems, the owner or the consultant may pick up new ideas that can be incorporated into the performance spec. These ideas may be proprietary, in which case they would not be written into the spec and would strengthen the proposal of the manufacturer who owns them.

One variation on these approaches to system selection is to write the job specifications based on one manufacturer's system. If a single supplier is preselected in this way, the owner should be clear about the reason for the preselection. Using a spec based on one manufacturer's equipment makes it impossible for other manufacturers to have a fair chance to bid, reduces price competition, and limits the owner's options.

Whether the bid process in formal or informal, the owner should consider carefully the extent to which the selection decision is based on vendor marketing. It is important to give the competing vendors the opportunity to make marketing or sales presentations on their products, but it is also important to build in objective criteria that prevent the owner from selecting a system based on the strengths of a vendor's marketing approach.

Selecting a Wood-Chip System: Assessing Bid Forms to Make the Selection

It is best to solicit written bids by using a bid form. The bid form is structured to collect information and cover all the important areas of concern to the owner.

Using a uniform bid form also makes it easier to assess and compare bids from manufacturers whose systems may have significant differences. By studying the completed bid forms, the owner can ensure that each proposal meets the minimum requirements set forth in the specs, and can also see how the proposals received differ from one another.

A number of items might be included on a bid form. The level of detail required depends on the size and cost of the system and whether the installation is simple or sophisticated, with more features. Below are some areas that might be covered.

Bid Form Inclusions

• INSTALLATION LIST

It is important to get a complete installation list from each manufacturer, so that you can see how many systems similar to yours they have installed. Use the installation list to make reference calls, and be sure to talk to the system operator and possibly the business manager. You may request the installation lists before you write the specs, so that you can do research on available systems early in the process.

• FEATURES

Ask what features are included in each manufacturer's base proposal, in addition to the minimum requirements of the spec. Manufacturers should also be encouraged to submit alternate prices for additional features they think would enhance the system.

• TECHNICAL DETAIL

Each proposal should have enough information so that you can understand the basic elements of the system. What type of combustion system is employed? How do the controls work? Are the fuel feed rate and the combustion air supply rate fixed, or is there a staged or modulating control that responds to the load? Does the system include a flue gas particulate removal device?

• OPERATING PARAMETERS

How does the manufacturer say the system will perform? What are the anticipated furnace temperatures, stack temperature, excess air level, and steady state efficiency?

• ELECTRIC MOTORS AND PUMPS

Each proposal should have a list of all electric motors and pumps, with their horsepower and mode of operation (continuous or intermittent).

• SAFETY DEVICES

How is the system protected against burnback of fire along the fuel feed path to the storage bin? What other safety features does the system include?

• MAINTENANCE REQUIREMENTS

What are the required maintenance tasks? How frequently must each be performed, and how long does each take?

• FUEL FLEXIBILITY

What fuels will the system burn without adjustment? Which ones can be burned readily with manual changes to the controls? Which ones should be avoided?

• WARRANTY

The owner may specify the warranty requirements, but there may also be additional manufacturer warranties on certain components. The bid form should clarify all warranties supplied.

• PRICE

Each proposal should include the fully installed cost of the base system, meeting the minimum requirements of the specifications, and any alternate prices for additional features or alternate approaches.

Once they have received the bids and checked references, the owners will be ready to make a decision based on a careful consideration of all the information. However, there are some areas that warrant particular attention: those that impact the operating costs of each proposed system.

The number and size of electric motors and pumps can have a major impact on operating costs. Data on this electrical equipment can be used to predict each system's impact on electricity demand and consumption. When analyzed in the context of the electric utility rate, this will indicate the cost impacts on the electric bill of the competing systems. Because electricity is a much more expensive form of energy than biomass, demand charges from more or larger electric motors may have a greater impact on operating costs than will differences in wood combustion efficiency.

Look carefully at the maintenance tasks associated with each system. Maintenance time can be verified by talking to the operators of systems from the manufacturer's list of installations. The daily tasks should take no more than half an hour per day. A system that requires more time on a daily basis will not only incur extra maintenance cost but may be seen as an unwelcome burden by the operator.

Contracting and Project Structure

Once a system manufacturer has been selected, the owner is ready to prepare a contract for signature. The contract should include the performance specifications, any additional features agreed upon, the price of the job, the completion date and the payment schedule. The payment schedule should include retainage, so that the manufacturer is not paid in full until the system has been demonstrated to operate properly, as explained in the next chapter.

There are two options for structuring the contract for the biomass system. The first is for the owner to contract directly with the biomass system manufacturer or installer. The second is for the biomass system installer to become a subcontractor to a general contractor. The choice between the two approaches will depend in part on the overall scope of the project.

If the installation of the complete biomass system is the only work being done, then the owner is likely to contract directly with the system manufacturer. Any building construction (for the fuel storage bin and boiler room space) can be handled as a separate contract, or the system manufacturer may be interested in doing the building construction as well as installing its biomass equipment.

If the biomass system is part of a larger project, it is more likely that the biomass system manufacturer or supplier will become a subcontractor to the general contractor. Examples include the construction of a new building with a biomass heating plant and the conversion of an electricity or steam heated facility to a biomass system with a new hot water heat distribution system. In these cases, it is generally preferable to select the biomass system first, and then — having established the cost of the biomass system — require bidding general contractors to integrate the selected system and its cost into their bids.

CHAPTER ELEVEN

Operating and Maintaining a Wood-Chip System

This chapter covers a range of operational issues: getting the system installed and running in the first place, working out any problems during the first season, maintaining the equipment, and making repairs when parts fail.

Installation and System Commissioning

It is the contractual responsibility of the manufacturer or installer to supply and install the wood-chip system and to get it running properly. This process involves a number of steps, and must not happen too quickly. Once the installer has successfully fired up the system, the owner needs to be convinced that all the specified components are in place and that the system is performing as the manufacturer (and the contract) said it would. This process is called "commissioning" the system.

The term contractor is used here to refer to the entity with whom the owner has formally contracted to install the wood-chip system. The contractor may be the manufacturer of the biomass system or a general contractor who undertakes to install it. In the second case, the system manufacturer becomes a supplier of equipment. In any case the primary legal responsibility for the system's operating properly lies with the entity with whom the owner contracts.

The main tool that the owner has in commissioning is the operating parameters the system manufacturer provided during the bid process: Btu output of the system, turn-down ratio, furnace and stack temperatures, excess air levels, and steady state efficiency.

While measuring temperatures and determining the excess air level are simple, measuring steady state efficiency is more complicated. Rigorous calculation of steady state efficiency involves determining the moisture content and calorific value of the fuel and testing the ash for unburned carbon, as well as taking measurements of the stack gases.[1] Depending on the cost and size of the system, the owners may or may not require the contractor to demonstrate that the stated steady-state efficiency has been achieved. If efficiency verification is required, that must be stated in the bid documents so the contractor can build it into the price.

For commissioning, the fuel used must match the fuel specifications as detailed in the system installation contract. If the fuel specifications include different types of fuel (for example, hardwood and softwood, or mill chips and whole-tree chips), it is most common to use the anticipated regular fuel type at the beginning. The system can be tested later on other fuel types, if desired by the owner.

Commissioning should take place during full-load conditions. A system that is commissioned to run well in early October may not run properly in mid-January. Its ability to heat the facility during the coldest weather cannot be known until mid-winter. If the system is installed outside the midwinter heating season, there should be provision for the contractor to return and readjust the system to optimize performance during full-load conditions. An important but difficult part of commissioning is to demonstrate that the system output under peak conditions is equal to the requirements of the contract. This can only be determined during mid-winter conditions. Some of the contract cost should be held back until the system is demonstrated to meet the required output and all other conditions of the contract have been met.

The other important part of the startup process is operator training. It is imperative that the operator be fully trained in operating, maintaining, and trouble-shooting the system. The required time allocated for operator training should be specified in the bid documents, and the training must be done before the contractor leaves the site after initial startup. The contractor must also provide maintenance schedules, manuals, product literature, and wiring diagrams to cover all the components of the system.

System Adjustments During the Warranty Period

The new owners of a biomass system should expect some things to go wrong in the first year. This is generally true for any large mechanical system during its initial year of full operation. It is important to use this warranty year to get all the bugs out of the system while it is still the contractor's and the manufacturer's responsibility. If the owner has been careful about specifying the system and if the contractor has done a good job, these adjustments will be minor.

At the end of the warranty period, the system should be operating smoothly with no outstanding areas of concern. If major areas needing improvement are identified that are not the responsibility of the manufacturer or contractor, then it is best to deal with these problem areas immediately. It is to the owner's advantage to have the system running smoothly as soon as possible, rather than putting off the necessary improvements and keeping the system in a poor operating condition.

Ongoing Maintenance

The manufacturer should provide a list of the required maintenance procedures and recommended frequency of each one. Some of the most important maintenance tasks for most systems are:

- ash removal — grates (may be automatic);
- ash removal — under grates;
- boiler tube cleaning (see photo on this page);
- fly ash removal;
- cleaning of fire box and other heat exchange surfaces;
- lubrication;
- inspection of drive chains, belts and gearboxes;
- inspection of refractory;
- checking of safety devices; and
- checking and adjustment of fuel feed rates and combustion air.

The system operator will learn how fast ash builds up in key places, and may need to adjust the frequency of cleaning accordingly. Ash buildup in the heat exchanger, particularly the boiler tubes, can reduce efficiency dramatically. It should be carefully controlled by cleaning.

The system manufacturer's service representative should be hired to come back and tune the system, on all firing levels, once a year.

Maintenance Contracts

The system manufacturer, the installer, or an experienced contractor may be interested in providing ongoing maintenance on a contract basis. A maintenance contract may work well for facilities where the in-house staff does not have the time or the capability to handle the wood-chip system's maintenance. Maintenance contracts also have the advantage of building in regular oversight by someone

Lyndon Town School, Lyndon, Vermont
System Size: 1.2 MMBH
Manufacturer: Chiptec Wood Energy Systems
This system uses an above-grade metal silo and separate boiler house (which includes garage space). Silo is loaded from a receiving bin (on far left) using an inclined auger.

Boiler Tube Cleaning
Manual boiler tube cleaning shown at Calais Elementary School, Calais, Vermont (.5 MMBH system by Messersmith Manufacturing).

who has more experience with wood systems than the on-site maintenance staff.

The potential danger of using a maintenance contract that relieves the owner's maintenance staff of too much responsibility is that there may be no one working directly for the owner who is knowledgeable, interested, or invested in the system. It is important for the owners and their staff to remain committed to the system and its operation on a day-to-day basis.

A maintenance contract must clearly delineate which tasks are to be carried out by the facility's maintenance staff, and which are to be carried out by the maintenance contractor. Generally, the in-house staff will do the things that must be done on a daily basis, and the maintenance contractor will perform routine and preventive maintenance tasks that need to be done annually. Large systems should have more frequent regular servicing. The maintenance contract price may include the cost of routine supplies like lubricants, while parts replacement and larger repairs will be preapproved and billed on a time-and-materials basis.

Performance Monitoring and Record Keeping

It is important to know, from year to year, how well the biomass system is operating. On the simplest level this is the answer to the question, Does the system run regularly with no unplanned shutdowns? Shutdowns are a major nuisance to the operator and are usually fuel-related (augers jammed by oversized chips or frozen fuel in an above-ground bin). It is useful to keep a logbook for the biomass plant, with dated entries for fuel deliveries, system shutdowns and their causes, maintenance work, parts replacements, and repairs.

Beyond this, it is very useful to know how efficiently the plant is running and how much money it is saving. Records should be kept of the amounts and costs of both the biomass and backup fuel totals for each year of operation. The relative amounts of wood and backup fuel also give an important indication of how well the biomass plant is performing.

For systems that were converted from another fuel such as electricity, oil, gas, or coal, the annual biomass cost can be compared to the cost of the original fuel to see how much money is saved each year. (To give a more accurate picture of savings, the original conventional fuel consumption can be multiplied by the current fuel price.) This will serve as a check on the original projections on which the biomass conversion was based.

For large systems, if there are run-time meters on the backup fuel burners and on the biomass system, the run-times can be logged each day to give an immediate day-to-day picture of how much of the heat load is carried by the backup system at different times of the year. This serves as a useful check on the effectiveness of the strategy for use of the backup burners and for scheduling maintenance.

If the stoker auger of the fuel feed system has a revolution counter, this serves as an indicator of the amount of wood fuel fed into the boiler over time. By calibrating the feed auger, it can be calculated how much volume of fuel is fed to the fire for each revolution. If the density of the fuel and its Btu value are known, then the input Btu rate of the system can be calculated. This is very useful information for operators who want to monitor system performance closely.

Annual efficiency testing is a good idea for large systems. However, this can be very costly if the system does not have much instrumentation. With good instrumentation, the operator can collect needed data and send it to a lab along with a fuel sample and a bottom ash sample. The lab can then calculate the steady state efficiency without making a field visit. If this approach is used, it is important that an experienced combustion analyst be consulted for guidance on test methodology and data collection. A less expensive, but less accurate, approach is to have the wood system manufacturer's service representative do periodic efficiency testing with hand-held equipment.

[1] American Society of Mechanical Engineers, ASME Power Test Code, PTC 4.1. (New York: ASME).

Chapter Twelve

The Future of Biomass

This concluding chapter looks at the future of the biomass resource, its long-term availability, its various uses, and its possible future role in meeting local and global energy needs. Of course, we can only speculate on the future; but we can look at today's reality and make some intelligent guesses about what we may see tomorrow.

Biomass Supply and Demand

In the last ten years, great strides have been made in refining the technology for heating larger buildings with biomass. Much of this is due to the widespread use of automated wood energy systems in public schools in Vermont and a few other states. There is a growing interest from communities in the western states to use wood residues from fire-prone national forests to provide energy to public buildings. There are many successful examples of schools, hospitals, government buildings, commercial buildings, agricultural applications, and industries using biomass for heat. However, at the beginning of the 21st century these biomass-burning facilities are hardly the norm. While some states or regions have a growing number of institutional and commercial facilities using biomass, others have few.

Heating applications for wood chips and other forest residues, excluding cordwood, are a very small part of a larger market. This market is dominated by the use of wood residues for three purposes: making steam for dry kilns within the forest products industry, making paper, and generating electricity. In the Northeast, most suppliers of biomass to schools and other institutions sell most of their wood wastes to paper mills and power plants.

As more schools, hospitals, and businesses install biomass systems, the connections between biomass fuel suppliers and users will grow stronger. In many regions these links are now weak or nonexistent. In the future there are likely to be more self-unloading delivery vehicles available to serve the institutional and commercial markets for biomass. It is also likely that as the institutional/commercial market grows and becomes more competitive, biomass suppliers will adopt more of the customer service approach common to oil dealers.

In the future the level of biomass utilization for thermal energy will depend in part on how society allocates the available marketed biomass among uses for heating, electricity generation, paper manufacturing, chemical feedstock supply, and other applications. It will also depend on the sustainable yield from our forests.

We can expect to see better utilization of the forest resource in the future. Throughout the Northeast there are very large inventories of unmanaged, poor-quality timber stands. To improve overall forest health and provide greater economic return to forest land owners, there will be an increased pressure to cull, harvest, chip and remove low-grade trees. This could result in a much greater supply of chips to meet the needs of the growing market for institutional biomass heating.

Trends in Biomass Burning

A number of trends already underway in biomass combustion technology will continue to make institutional and commercial wood burning more feasible in the coming years. These developments are occuring in the areas of improved combustion efficiency, cleaner air emissions, better operating characteristics of biomass burners, and better-developed wood fuel markets.

The challenge of institutional biomass heating plants in the 1980s was to develop integrated fuel handling and combustion systems that worked

Mount Wachusett Community College, Gardner, Massachusetts
System Size: 8 MMBH
Manufacturer: Messersmith Manufacturing
The separate boiler house shown on the left heats the main college building and a fitness center with pool. The system uses advanced emissions control equipment to meet stringent air quality standards. The tall stacks help reduce on-site air impacts to a negligible level.

smoothly in settings such as schools, hospitals, and commercial buildings. This process of taking wood combustion out of the sawmill and putting it into public buildings has been successful, as evidenced by the scores of facilities now burning wood chips and other forms of biomass.

In the early 1990s, the question of combustion efficiency in our existing institutional and commercial biomass systems was explored through testing in the Northeast and eastern Canada. Manufacturers and engineers involved in the next generation of installations have integrated the lessons learned from these tests into the system designs. The result has been more routine combustion testing and tuneups by manufacturers, better efficiency and cleaner emissions.

Although stack emissions have not been a problem for most existing institutional and commercial biomass burners, emissions from wood systems are an area of growing concern on the part of environmentalists and the general public. Large utility, sawmill, and industrial wood boilers are tested regularly for air emissions, but plants in schools and businesses are small enough that air quality regulators have not spent much time testing and gathering data about them. More precise, clearly articulated and broadly available information in this area is needed.

Over the last ten years, vendors have made numerous small changes to their systems that have significantly improved reliability and made operation smoother for users. Problems with bin unloading equipment and fuel conveyors have been addressed and largely solved. Control panels have been improved so that they carry out more sophisticated functions while remaining simple for the operator to use. Daily maintenance time has been reduced to less than 30 minutes in most cases. All parties have listened to and acted on what operators have been saying: that larger bins make life much easier for the user, compared to bins that only hold only one truckload of chips.

Fuel supply is an area that continues to require ongoing vigilance, on the parts of both users and state officials. Users rarely have the luxury of long-term, stable relationships with a single chip supplier without the need for yearly reassessment. When users regularly stay on top of chip prices and the competitive fuel market, prices tend to stay low. Having said that, users find that keeping a stable relationship with a single, reliable fuel supplier is an invaluable asset.

Users have learned that mill residue chips provide the most trouble-free operation. They tend to prefer mill chips over fuel chipped in the woods. However, in some regions mill chips may be hard to find at a reasonable price. Bole-wood chips from logging operations have been used successfully in many cases. The critical factor is that the supplier of forest chips be very interested in serving the institutional market and be committed to producing a uniform quality chip similar to a mill chip. If a forest chipper slips into delivering school customers loads with too many oversized chips, they will quickly lose the confidence of their customers and their business.

State forestry and education officials can play a critically important role in helping to create and maintain a stable fuel market for school users. Vermont's energy office, in partnership with the state forestry agency and the school superintendents' association, created a support program that has benefitted schools with wood energy systems. Each year a meeting is held for system operators to discuss issues of concern and share information about fuel supply and other matters of common interest. The state collects and shares data on wood fuel prices, energy consumption and fuel supply, so that all users (and others) can see who is supplying who at what price and can compare their fuel consumption with other schools on a square-foot basis. The state initiative also helps to link individual schools with fuel suppliers and to solve short-term fuel supply problems.

New Uses on the Horizon

In the future we may see more use of biomass in heating plants, both for smaller commercial facilities and for applications larger than those discussed in this guide. On the large side, using biomass to fuel "district heating" plants is becoming a recognized option, economically viable in some settings.

District heating is the use of a central boiler facility with buried piping that serves the heating needs of a number of nearby buildings. District heat systems have been common in settings such as college and university campuses for many years. Since one of the drawbacks of biomass heating plants is their relatively high capital cost, it makes sense to have one plant provide heat to a number of buildings.

Large district heat systems that burn biomass are fairly common today. A number of colleges in the Northeast and elsewhere currently have biomass-fired district heating systems. St. Paul, Minnesota, has a very large urban-district heating and cooling system that burns biomass, as do the complexes of government buildings in Montpelier and Waterbury, Vermont. The St. Paul system uses hot water to distribute heat, while the Vermont state district systems (and most older campus systems) use steam as the medium.

In Scandinavia, district heating is widely used and the technology is highly developed. The capital of Prince Edward Island, Charlottetown, has a 20-year-old modern Scandinavian-style downtown hot-water district heating system that burns whole-tree chips and other forms of waste biomass.

Small district heating systems are also common in settings where one plant may heat two or more adjacent buildings. Examples include schools with two or three buildings on the same property, and hospitals with plants that also heat nearby medical office buildings or nursing homes.

A first-of-its-kind district system was installed in 1991 to provide low-cost wood-chip heat to nine buildings of a 50-apartment, low-income family housing project in Barre, Vermont. This system now has over a decade of reliable operation, with a monthly fuel cost of $26 per apartment for all heat and hot water, averaged over ten years. In 2003, the first school wood energy system in the Rocky Mountains was installed to serve a three-school campus in western Montana.

On the small side, expect to see an expanded use of semi-automated systems to serve smaller schools and commercial buildings. Fully automated systems have proven to be economically viable in large schools, but the high capital cost sometimes puts them out of reach of smaller schools, facilities with less access to capital, and those that expect a quicker return on investment.

Gasification: Promise for the Future

Gasification of biomass is an exciting technical development that promises to open up new and more efficient uses of wood chips and other forest fuels.[1] A gasifier is a pre-combustion device that cooks the wood fuel in an oxygen-starved environment, producing unburned combustible gases. These gases are then cooled and cleaned to produce a medium or low Btu content gas, which can be used much like natural gas or liquid propane gas. The resulting bio-gas can be stored, transported, and used in applications remote from the gasifier that produced it.

Potential uses for bio-gas include combustion for heating and steam production, and fueling internal combustion engines for a variety of applications. Bio-gas can also be used as a feedstock for chemical processes, and it may replace petroleum-based feedstocks in some cases.

More importantly, biomass gasifiers are expected to lead to a dramatic increase in the efficiency of burning wood to produce electricity. Currently, the only commercially available way to produce electricity from solid biomass fuel is to burn the wood fuel to create steam for a steam-turbine driven generator. The overall efficiency of this process for steam-based electric production is very low and the maintenance cost is high. Wood gasifiers promise to produce electricity at a higher efficiency, with lower emissions and with less expensive operating costs, compared to a steam boiler approach. System efficiency can be further boosted when the gasifier is in a combined-heat-and-power (CHP) application. With a gasifier CHP system, it is easier to capture and use the waste heat than with a steam CHP system.

Gasifiers for power and CHP applications are currently under development in a wide range of sizes. Smaller gasifiers will initially be used to fuel internal combustion engines to drive electric generators. Heat can be extracted from the engine coolant and the engine exhaust to provide hot water as a useful byproduct. Large wood gasifiers will produce bio-gas fuel for combined-cycle gas turbine systems for power and thermal energy production. In this application, burning bio-gas turns the blades of a combustion turbine to drive an electricity generator. Hot exhaust gases are captured to create steam that in turn drives a steam-turbine power generator. Thermal energy is captured from the steam turbine outlet to provide either low-pressure steam or hot water. Both small-scale and large-scale biomass gasification will significantly out-perform wood-burning steam systems for power production.

Further in the future, product gas from biomass gasifiers will be used in microturbines and in fuel cells. These technologies will further increase efficiency and reduce emissions in producing power and heat from biomass.

[1] There are two major categories of gasifiers, and numerous sub-categories of each. The first category, close-coupled gasifiers, refers to combustion appliances that produce heat by separating the combustion process into two stages in connected, adjacent, combustion chambers. Among close-coupled gasifiers there are variations: small combustors that fire into residential-sized boilers or furnaces; a class of small cordwood boilers; and the two-chamber, commercial-sized gasifiers discussed in Chapter Six. In the second category are those gasifiers that produce bio-gas, which can be used in a variety of applications. This section of the guide discusses the second type of gasifier.

Appendix A

Northeast Regional Biomass Program State Offices and U.S. Government Contact

Connecticut
Department of Environmental Protection
Office of Pollution Prevention
79 Elm Street
Hartford, CT 06106-5127
(860) 424-3022
(860) 424-4081 (fax)

Delaware
Delaware Energy Office
146 S. Govenor's Ave.
Dover, DE 19901
(302) 739-1530

Maine
Policy Development
State Planning Office
State House Station 38
Augusta, ME 04333
(207) 287-4315
(207) 287-8059 (FAX)

Maryland
Maryland Energy Administration
1623 Forest Drive
Annapolis, MD 21403
(410) 260-7190
(410) 260-2250 (fax)

Massachusetts
Renewables Office
Division of Energy Resources
70 Franklin Street, 7th Floor
Boston, MA 02110-1313
(617) 727-4732
(617) 727-0093 (fax)

New Hampshire
NH Dept. of Resource and Economic Development
P.O. Box 1856
172 Pembroke Road
Concord, NH 03302
(603) 271-2341 xt. 126
(603) 271-6784 (fax)

New Jersey
Division of Parks and Forestry
State Forestry
Department of Environmental Protection
P.O. Box 404
Trenton, NJ 08625-0404
(609) 292-2520
(609) 984-0378 (fax)

New York
Biomass Energy
New York State Energy Research & Development Authority
Corporate Plaza West
286 Washington Avenue Extension
Albany, NY 12203-6399
(518) 862-1090
(518) 862-1091 (fax)

Pennsylvania
Conservation & Agricultural Technology
Bureau of Plant Industry
Department of Agriculture
2301 North Cameron Street
Harrisburg, PA 17110-9408
(717) 772-5208
(717) 783-3275 (fax)

Rhode Island
Central Services
State Energy Office
Department of Administration
One Capitol Hill
Providence, RI 02908
(401) 222-3370
(401) 222-1260 (FAX)

Vermont
Department of Forests, Parks & Recreation
103 South Main Street, 10 South
Waterbury, VT 05671-0601
(802) 241-3698
(802) 244-1481 (FAX)

U.S. Government
Bioenergy and Weatherization Assistance Program
U.S. Department of Energy
Northeast Regional Office
JFK Federal Building, Suite 675
Boston, MA 02203-0002
(617) 565-9732
(617) 565-9723
www.eren.doe.gov/bro

Appendix B

Northeastern State Energy Offices

Connecticut
Energy Research and Policy Development Unit
Strategic Management Division
Connecticut Office of Policy and Management
450 Capitol Ave. MS#52Enr
PO Box 341441
Hartford, CT 06134-1441
(860) 418-6297

Delaware
Energy Office
Thomas Collins Building, Suite 1
540 South DuPont Highway
Dover, DE 19901
(302) 739-5644

Maine
Energy Conservation Division
Department of Economic and Community Development
State House Station No. 59
Augusta, ME 04333-0059
(207) 624-6000

Maryland
Maryland Energy Administration
1623 Forest Drive, Suite 300
Annapolis, MD 21403
(410) 260-7511
1-800-72ENERGY

Massachusetts
Division of Energy Resources
Department of Economic Development
70 Franklin Street, Seventh Floor
Boston, MA 02110-1313
(617) 727-4732

New Hampshire
NH BioFuels Project
NH Governor's Office of Energy and Community Services
57 Regional Drive
Concord NH 03301-8519
(603) 271-2611

New Jersey
Office of Clean Energy
New Jersey Board of Public Utilities
44 South Clinton Street,
PO Box 350
Trenton, NJ 08625-0350
(973) 648-3717

New York
New York State Energy Research and Development Authority
17 Columbia Circle
Albany NY 12203
(518) 862-1090

Pennsylvania
Pennsylvania Energy
Office of Pollution and Compliance Assistance
Department of Environmental Protection
PO Box 2063
400 Market Street, RCSOB
Harrisburg, PA 17105
(717) 783-0542

Rhode Island
Rhode Island State Energy Office
1 Capital Hill, 2nd Floor
Providence, RI 02908
(401) 222-3370

Vermont
Department of Public Service
Energy Efficiency Division
112 State Street, Drawer 20
Montpelier, VT 05620
(802) 828-2811

APPENDIX C

Wood-Fuel Energy Data

I. Energy Content

The energy content of wood can be characterized in a number of ways:

• **BTU CONTENT OF DRY WOOD**

It is generally accepted that the average energy content of bone-dry wood is 8,500 Btus/lb. ("bone-dry" is the state defined by a laboratory test in which a wood sample is heated until all the water is driven off; bone-dry is generally synonymous with oven-dry).[1]

Actual energy content of any sample will depend on the mix of species included in the sample (and other factors), and can only be determined by laboratory testing. Typical heating values of dry wood for common northeastern species are given in the table below.

Typical Dry-Sample Heating Values (GHV-DS)

Various Wood Species Common to the Northeast (in Btus/dry lb.)[2]

	Average	Low	High
Hardwoods			
Ash, white		8246	8920
Birch, white		8019	8650
Elm		8171	8810
Hickory		8039	8670
Maple		7995	8580
Oak, red		8037	8690
Oak, white		8169	8810
Poplar		8311	8920
Softwoods			
Cedar, white		7780	8400
Hemlock, eastern	8885		
Pine, white		8306	8900

This energy content is called variously the gross heating value of the dry sample (GHV-DS), the oven-dry gross heating value (oven-dry GHV), or the oven-dry high heating value (oven-dry HHV).

• **GROSS BTU CONTENT OF WOOD ADJUSTED FOR MOISTURE CONTENT**

Fuel biomass, as it is delivered, is never bone-dry. As-delivered or as-fired wood can be characterized by its GHV-DS, its moisture content (or MC, expressed as a percent), and the resulting Btu content of the wood in the sample (GHV-AF). The Btu content of the as-fired wood can be calculated as follows:[3]

GHV-AF = GHV-DS x (1 - MC/100)

For example, if the dry-sample gross heating value is 8,500 Btus/lb. and the moisture content is 40%, the as-fired heating value is 5,100 Btus/lb.:

For a 1 lb. sample of green wood at 40% moisture,

weight of water = 1 x (MC/100) = .4 lb.
weight of wood = 1 x (1 - MC/100) = .6 lb

GHV-AF = 8,500 x (1 - 40/100) = 5,100 Btus/lb.

The following chart converts gross heating value from a dry basis (assuming 8,500 Btus/lb.) to an as-fired basis.

Moisture Content (MC)	Gross Heating Value (GHV-AF)
oven-dry	8500
25%	6375
30%	5950
35%	5525
40%	5100
45%	4675
50%	4250
55%	3825
60%	3400

The figure of 5,100 Btus/lb., or 10.2 MMBtu/ton, based on a GHV-DS of 8,500 Btus/lb. and a moisture content of 40%, is a good all-round figure to use for the energy content of biomass fuel available in the Northeast. For specific applications, the analyst can select different GHV and MC figures. For example, a more conservative approach (considering the variability of fuel actually available) might be to use a GHV-DS of 8,200 Btus/lb. and a moisture content of 45%, giving a GHV-AF of 4,510 Btus/lb. or 9.02 MMBtu/ton.

• **NET BTU CONTENT AVAILABLE FOR HEAT**

The amount of energy in a green fuel sample is reduced because only a fraction of the sample is wood (the remainder being water). The amount of useful heat made available from combustion is further reduced by other factors.

A certain amount of heat in the wood is required to vaporize the water in the sample. There is also "latent" energy that is not available for useful purposes, unless it is released by condensing the water vapor in the flue gases, which is not common practice in wood combustion.

When the GHV is reduced by subtracting the heat of vaporization and the latent energy of water vapor in the flue gases, the resulting heating value is called the net heating value (NHV)[4] or lower heating value (LHV).[5]

II. Wood Combustion Efficiency

Efficiency can be defined by the amount of useful heat output from combustion, divided by the heat input of the fuel. For efficiency calculations, the input fuel's energy content can be characterized either by its as-fired gross heating value (GHV-AF) or by its net heating value (NHV). For obvious reasons, there is a need to be consistent in the way in which efficiency is calculated.

In the United States, it is the standard to use the gross heating value (GHV-AF) for calculating steady state efficiency.[6] This convention has also been adopted by the Northeast Regional Biomass Program in its 1993 testing of biomass boilers in the Northeast.[7]

Green wood combusts with relatively low efficiency because it contains a large amount of moisture. GHV-based efficiency calculations look at the total heating potential of the wood, including the energy that is "wasted" in vaporizing water and in not condensing water vapor in the flue gases.

When efficiency calculations are based on NHV, which removes fuel moisture from the equation, efficiencies increase significantly compared to efficiencies calculated on a GHV basis. Some European manufacturers (or manufacturers with product lines based on European technology) report their efficiencies based on NHV. Prospective buyers must be sure that they know what heating value basis is being used when they evaluate the efficiency of different combustion systems.

1 Peter J. Ince, "How to Estimate Recoverable Heat Energy in Wood or Bark Fuels" (Washington, D.C.: Forest Products Laboratory, USDA Forest Service), p. 3; Wood-fired Boiler Systems for Space Heating, Publication EM 7180-2 (Washington, D.C.: Biomass Energy Program, USDA Forest Service, 1982), vol. 1, p. 3-1.

2 Wood-fired Boiler Systems, p. 3-4.

3 Wood-fired Boiler Systems, p. 3-2.

4 Wood-fired Boiler Systems, p. 3-2.

5 Georgia Institute of Technology, Technical Applications Laboratory, Industrial Wood Energy Handbook (New York: Van Nostrand Reinhold, 1984), p.9.

6 Ibid., p. 10.

7 Small and Medium-Sized Wood Energy Boiler Efficiencies, prepared by Commercial Testing and Engineering Company for the Northeast Regional Biomass Program, CONEG Policy Research Center, Washington, D.C., December 1993; ASME Power Test Code, PTC 4.1, (Atlanta: American Society of Mechanical Engineers), section 5.

APPENDIX D

Assumptions Used in Developing Figures 7.1, 7.2 and 7.3

These three graphs were developed by applying life-cycle costing to data for wood-chip systems replacing the heat energy supplied by existing oil, gas, or electric heat equipment. The high and low ends of data ranges define optimistic and pessimistic cases for the wood conversion, as represented by the lines separating the three cost-effectiveness zones of each graph.

A. BTU CONTENT OF FUEL

Wood chips . . . . 9,600,000 per ton
No. 2 fuel oil . . . . 138,000 per gallon
Natural gas . . . . 100,000 per ccf
Electricity . . . . 3,412 per kilowatt-hour

B. AVERAGE SEASONAL EFFICIENCY

Wood boiler 70%
No. 2 oil boiler 80%
Natural gas boiler 80%
Electric baseboard . . . . . 95% (at customer side of meter)

C. FIRST-YEAR CAPITAL COSTS FOR WOOD-CHIP SYSTEM

Existing Energy Consumption Replaced by Wood-Chip System	Wood-Chip System Cost Range
10,000 gallon/yr. oil or 14,000 ccf/yr gas	$100,000 – 250,000
20,000 gallon/yr. oil or 27,000 ccf/yr gas	$160,000 – 320,000
30,000 gallon/yr. oil or 41,000 ccf/yr gas	$180,000 – 360,000
40,000 gallon/yr. oil or 55,000 ccf/yr gas	$200,000 – 400,000
50,000 gallon/yr. oil or 69,000 ccf/yr gas	$225,000 - 450,000
340,000 kwh/yr. electricity	$200,000 - $500,000
680,000 kwh/yr. electricity	$320,000 - $640,000
1,020,000 kwh/yr. electricity	$360,000 - $720,000
1,360,000 kwh/yr. electricity	$400,000 - $800,000
1,700,000 kwh/yr. electricity	$450,000 - $900,000

Costs of replacing electric systems presented above are based on the assumption that hydronics conversion is necessary, and that the cost of the conversion doubles the capital cost of the project.

D. OTHER WOOD-CHIP SYSTEM ASSUMPTIONS

General equipment life: . . . . . . 30 years
Cost of equipment replaced
after 10 years . . . . 20% of first-year cost
. . . . (excluding hydronics)
Cost of equipment replaced
after 20 years . . . . 20% of first-year cost
. . . . (excluding hydronics)
Incremental maintenance cost . . $0
Fuel cost . . . . $25 - $30 per ton

OTHER ASSUMPTIONS:

General inflation rate(avg.) 2.3%
Oil price inflation rate (avg.) . . . . 1.9% - 4.0%
Natural gas price inflation rate . . (avg.)2.8%
Electricity price inflation rate. . . . (avg.)2.3%
Discount rate 6.4%

APPENDIX E

Sample Life-Cycle Cost Analysis: Generic Vermont School

This is a sample life-cycle cost analysis of a conversion from oil heat to a new wood-chip heating system in an actual 220,000 square foot high school in Vermont. The National Institute of Standards and Technology's (NIST) BLCC5 life-cycle cost analysis software was used.

a. Conversion Assumptions: Oil Heat to Wood-Chip Heat

I. CAPITAL COSTS

The wood-chip conversion involves four cost components:

Wood-chip boiler system	$350,000
Building construction	$150,000
Domestic hot water	$30,000
Engineering	$60,000
Total project cost	**$590,000**

The wood-chip system includes the boiler, combustor, chimney, all fuel handling and bin unloading equipment, controls, and the wood boiler chimney. The building construction includes constructing a chip storage bin and a boiler room large enough to hold both the wood chip boiler and a back-up oil boiler. Engineering costs are for developing specifications and for project management. The domestic hot water (DHW) line item is for a DHW storage tank that can be heated by the boilers.

II. FINANCING

While the actual societal cost for this project is $590,000, the cost born by the school district is the most important consideration for local decision makers. Therefore, state aid to education for capital construction projects was subtracted from the overall cost and finance costs were then calculated on this net project cost.

In Vermont, where this school is located, the state Department of Education provides construction aid to school districts for capital improvement projects. Each state has different construction state aid rules and regulations. This analysis assumes a 30% cost share from the state for all construction costs. The remainder of the construction costs is assumed to be borrowed by the school district from the state bond bank. Since the school receives a 30% construction grant from the state Department of Education, the school's share of the cost is reduced to $413,000. The financed and construction aid portions of the project's total cost are:

Total Construction Cost	$590,000
30% State Construction Aid	$177,000
Net Financed Cost	**$413,000**

Financing assumptions, based on the municipal bond market, are:

Interest rate	4.6%
Term	20 Years

Annual bond payments were then calculated using an amortization calculator.

III. ENERGY USE AND COSTS

The energy consumption costs for oil heat were extracted from a historical analysis of fuel oil bills. Current fuel oil costs were applied to give a first-year oil heat cost. Oil consumption was then used to project wood-chip consumption. Fuel cost and escalation rate assumptions are given below. All price inflation rates in the analysis include a 2.3% annual general inflation rate. The analysis uses a 5.6% nominal discount rate.

The life-cycle cost analysis of the wood system assumes that the wood system supplies 85% of the school's heat and the oil backup system 15%.

Current year oil price	$1.00/gallon
Current year wood-chip price	$28/ton
Annual wood-chip price escalation rate	2%
Annual oil price escalation rate	3%

iv. Operating, Maintenance and Replacement (OM&R) Costs

Operating costs for the existing heat system and annually recurring costs for the wood-chip system include routine servicing and parts, along with staff time for operating and maintaining each system. Non-recurring operation and maintenance costs for larger repairs, such as system upgrades and parts replacement, are taken into consideration at various intervals.

For example, the existing oil heat system costs include a substantial upgrade in year 15 and in year 20, when the two existing oil boilers will be 30 years old respectively. The wood system includes replacing the refractory in years 10 and 20, upgrades to the fuel handling system in year 15, and periodic general repairs and replacements to controls and other systems. These non-recurring costs were then annualized and averaged in over the analysis period.

v. Salvage Value

The analysis has been done on a 25-year basis. In fact, some significant components do not necessarily decline in value over time. For example the wood fuel storage bin and the additional space in the boiler room for the wood boiler do not lose their value. A true life-cycle cost analysis would take these values into account by including a salvage value for these types of items at the end of the analysis period.

However, these types of values have little monetary impact on a school budget. The asset value of property is not taken into consideration for most public sector capital investments. For a private sector building, salvage value may be an appropriate consideration in the analysis. For purposes of this life cycle cost example, assumptions about the salvage value of equipment or building improvements at the end of the 25-year study period were not are included in either the oil heat and wood-chip heat scenarios.

b. Results of Life-Cycle Cost Analysis

NIST BLCC software is set up to compare the life-cycle costs of each energy option. Each scenario is analyzed individually, and the net present value of the different options can then be compared. The option with the lowest net present value is the one that should be selected, based on economic considerations. This analysis looks at two options: retaining the existing oil heat system and installing a wood-chip system while leaving the oil system as backup.

The results of the analysis are given below. For each option, the present value of 25-year cash flows is given in four line-item cost categories, and as the total life-cycle cost.

The analysis shows clearly that the wood-chip conversion had a life-cycle cost that was much less than the keeping existing oil heat system. In 2003 dollars, it is worth almost $350,000 to convert from oil heat to wood heat.

First-Year Capital Costs for Wood-Chip System

Existing Energy Consumption Replaced by Wood-Chip System:	Wood-Chip System Cost Range
gal/yr Oil	
10,000	$100,000 - 250,000
20,000	$160,000 - 320,000
30,000	$180,000 - 360,000
40,000	$200,000 - 400,000
50,000	$225,000 - 450,000
kWh/yr Electricity	
340,000	$200,000 - 500,000
680,000	$320,000 - 640,000
1,020,000	$360,000 - 720,000
1,360,000	$400,000 - 800,000
1,700,000	$450,000 - 900,000

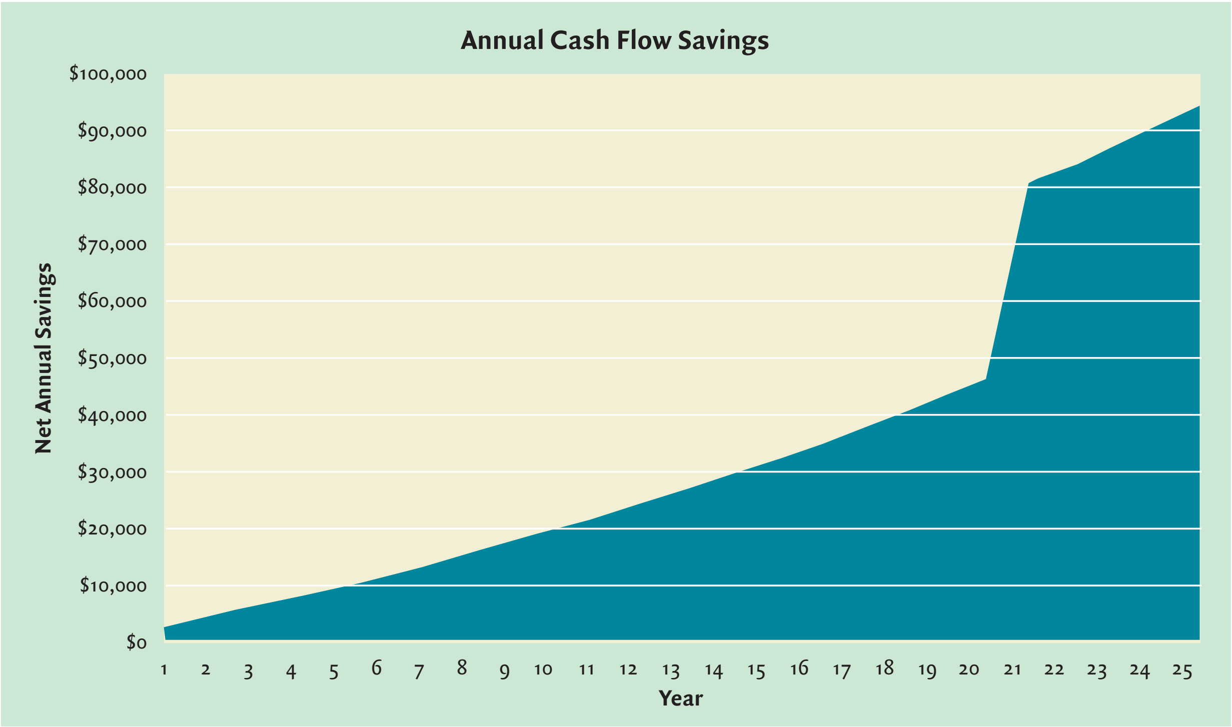
Cost Category	Base Case Oil Heat	Wood Chip Heat Alternative	NPV Savings
Capital and Finance – Related Costs	$0	$385,920	-$385,920
Energy Costs	$1,563,725	$812,602	$751,123
Recurring and Non-recurring O&M Costs	$99,832	$184,786	-$84,955
Replacement Costs	$69,366	$0	$69,366
Total PV Life Cycle Cost	$1,732,923	$1,383,308	$349,614

The wood-chip system was installed in late 2002.

The following table shows the nondiscounted 25-year cash flow impacts of the conversion from oil heat to a wood-chip system, from the school's economic perspective. Note that the cash flow analysis does not include grant money or salvage values at the end of the period. The financing payments shown include the costs for the total project, with both energy-related and building construction components, since they are both real costs associated with the wood conversion project.

Note that a positive cash flow is achieved in the first year. For this school district, the annual school budget went down the first year after installation a wood chip heating system even with the inclusion in the analysis of the bond payments. The savings increase over time and take a big jump in year 20, when the bond is fully paid off.

	Sum of All Oil Cash Flows					Sum of All Wood Cash Flows					
Year Beginning	Recurring O&M Costs	Non-Recurring O&M Costs	Energy Consumption	Replacement	Sum of Oil Costs	Recurring O&M Costs	Non-Recurring O&M Costs	Energy Consumption	Replacement	Sum of Wood Costs	Total Net Savings
June 2004	$4,473	$1,751	$85,273	$5,209	$96,706	$31,620	$8,237	$3,295	$50,978	$94,130	$2,576
June 2005	$4,575	$1,751	$87,728	$5,209	$99,263	$31,620	$8,426	$3,295	$51,706	$95,047	$4,216
June 2006	$4,680	$1,751	$90,273	$5,209	$101,913	$31,620	$8,620	$3,295	$52,460	$95,995	$5,918
June 2007	$4,788	$1,751	$92,914	$5,209	$104,662	$31,620	$8,818	$3,295	$53,242	$96,975	$7,687
June 2008	$4,898	$1,751	$95,658	$5,209	$107,516	$31,620	$9,021	$3,295	$54,057	$97,993	$9,523
June 2009	$5,011	$1,751	$98,526	$5,209	$110,497	$31,620	$9,229	$3,295	$54,919	$99,063	$11,434
June 2010	$5,126	$1,751	$101,500	$5,209	$113,586	$31,620	$9,441	$3,295	$55,814	$100,170	$13,416
June 2011	$5,244	$1,751	$104,559	$5,209	$116,763	$31,620	$9,658	$3,295	$56,723	$101,296	$15,467
June 2012	$5,365	$1,751	$107,701	$5,209	$120,026	$31,620	$9,880	$3,295	$57,646	$102,441	$17,585
June 2013	$5,488	$1,751	$110,918	$5,209	$123,366	$31,620	$10,108	$3,295	$58,577	$103,600	$19,766
June 2014	$5,614	$1,751	$114,240	$5,209	$126,814	$31,620	$10,340	$3,295	$59,534	$104,789	$22,025
June 2015	$5,744	$1,751	$117,682	$5,209	$130,386	$31,620	$10,578	$3,295	$60,524	$106,017	$24,369
June 2016	$5,876	$1,751	$121,225	$5,209	$134,061	$31,620	$10,821	$3,295	$61,534	$107,270	$26,791
June 2017	$6,011	$1,751	$124,873	$5,209	$137,844	$31,620	$11,070	$3,295	$62,568	$108,553	$29,291
June 2018	$6,149	$1,751	$128,636	$5,209	$141,745	$31,620	$11,324	$3,295	$63,628	$109,867	$31,878
June 2019	$6,290	$1,751	$132,512	$5,209	$145,762	$31,620	$11,585	$3,295	$64,709	$111,209	$34,553
June 2020	$6,435	$1,751	$136,501	$5,209	$149,896	$31,620	$11,852	$3,295	$65,813	$112,580	$37,316
June 2021	$6,583	$1,751	$140,603	$5,209	$154,146	$31,620	$12,124	$3,295	$66,938	$113,977	$40,169
June 2022	$6,734	$1,751	$144,828	$5,209	$158,522	$31,620	$12,403	$3,295	$68,089	$115,407	$43,115
June 2023	$6,889	$1,751	$149,187	$5,209	$163,036	$31,620	$12,688	$3,295	$69,269	$116,872	$46,164
June 2024	$7,048	$1,751	$153,677	$5,209	$167,685	$0	$12,980	$3,295	$70,474	$86,749	$80,936
June 2025	$7,210	$1,751	$158,295	$5,209	$172,465	$0	$13,279	$3,295	$71,706	$88,280	$84,185
June 2026	$7,376	$1,751	$163,052	$5,209	$177,388	$0	$13,584	$3,295	$72,966	$89,845	$87,543
June 2027	$7,545	$1,751	$167,959	$5,209	$182,464	$0	$13,896	$3,295	$74,256	$91,447	$91,017
June 2028	$7,719	$1,751	$173,007	$5,209	$187,686	$0	$14,216	$3,295	$75,576	$93,087	$94,599
Total	$148,871	$43,775	$3,101,327	$130,225	$3,424,198	$632,400	$274,178	$82,375	$1,553,706	$2,542,659	$881,539


Annual Cash Flow Savings
Net Annual Savings
$100,000
$90,000
$80,000
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Year

Appendix F

Biomass System Manufacturer List

The following system manufacturers all make biomass combustion systems in the 1-10 MMBtu size range, and have successful installations in institutional and commercial settings of the type considered in this guide. All listed manufacturers have installed or are actively interested in installing systems in the Northeast.

Inclusion on this list does not constitute an endorsement of a manufacturer's equipment by either the Biomass Energy Resource Center, the Northeast Regional Biomass Program, the Coalition of Northeastern Governors, or the USDA Forest Service. Similarly, omission of a manufacturer does not imply any criticism of that manufacturer's capability or equipment.

Biomass Combustion Systems Inc.
16 Merriam Rd.
Princeton, MA 01541
(508)393-4932
www.biomasscombustion.com

Chiptec Wood Energy Systems
48 Helen Avenue
So. Burlington, VT 05403
(802) 658-0956
www.chiptec.com

Grove Wood Heating, Inc.
Pleasant Grove, Prince Edward Island
Canada C0A 1P0
(902) 672-2090

KMW Energy Systems, Inc.
150 White Oak Road
London, Ontario
Canada N6E 3A1
(519) 686-1771

Messersmith Manufacturing, Inc.
2612 F Rd.
Bark River, MI 49807
906-466-9010
www.burnchips.com

Glossary

Appliance efficiency: The ratio of output energy to input energy when the combustion system is running under design conditions. Also called steady state efficiency.

Ashing auger: An auger, operated manually or by a motor, used to remove ash from the base of a furnace or boiler setting. Also called ashing screw.

Backpressure turbine: A type of steam turbine that produces low-pressure steam exhaust, which can be used as the source of heat for space heating or other uses.

Backup system: An alternate fuel combustion system used to provide heat when the primary system is out of service or unable to meet the full heat load.

Bag house: A type of electrostatic particulate removal device used with very large biomass heating plants.

Bio-gas: A gas produced from biomass. Can be used as a combustion fuel.

Biomass: Any organic matter that can be burned for energy. Here used as synonymous with wood in its various forms.

Blast tube: A short connecting passage between a combustor and a boiler or other heat exchanger. Hot combustion gases from the primary chamber pass through the tube, sometimes with the addition of secondary or tertiary combustion air.

Boiler: A heat exchanger used to extract heat from hot combustion gases and transfer the heat to water. The boiler output can be either hot water or, if the water is allowed to boil, steam.

Bole chips: Wood chips produced from the main stems or trunks of trees, excluding branches and tops.

Bottom ash: Ash that collects under the grates of a combustion furnace.

Btu: British thermal unit, a standard unit of energy equal to the heat required to raise the temperature of one pound of water one degree Fahrenheit.

Btu meter: A device for measuring energy flow over time. Used to measure boiler heat output or energy consumption. For a hot water boiler, a Btu meter includes a water flow meter and temperature sensors that give the increase in temperature between the return water and output water.

Bucket elevator: A solid fuel handling device that lifts the fuel vertically.

Burnback: Movement of flame from the combustion chamber back along the incoming fuel stream.

Calorific value: The energy content of a fuel, expressed in units such as Btu per pound.

Carbon burn-out: The end of the combustion process in which all uncombined gaseous and solid carbon is oxidized to carbon dioxide.

Char: Carbon-rich combustible solids that result from pyrolysis of wood in the early stages of combustion. Char can be converted to combustible gases under certain conditions, or burned directly on the grates.

Char reinjector: A device that collects unburned char at certain locations in large boilers and injects it back into the primary combustion zone, both to keep it from going up the stack and to capture its energy through recombustion.

Chipper: A large device that reduces logs, whole trees, slab wood, or lumber to chips of more or less uniform-size. Stationary chippers are used in sawmills, while trailer-mounted whole-tree chippers are used in the woods.

CHP: Combined heat and power.

Close-coupled gasifier: A biomass combustion burner 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.

Cogeneration: Combined heat and power (CHP). A term used in industrial settings, now being displaced by the more descriptive term CHP.

Combined-cycle gas turbine: A type of high-efficiency turbine for burning gas to produce electricity. Can be used to burn the output bio-gas produced by a biomass gasifier.

Combined heat and power (CHP): The simultaneous production of heat and electrical power from a single fuel.

Combustion efficiency: The efficiency of converting available chemical energy in the fuel to heat, typically in excess of 99% in biomass burners. Efficiencies of conversion to usable heat are much lower.

Combustor: A freestanding primary combustion furnace, usually located adjacent to the boiler or heat exchanger. Exhaust gases from the combustor pass into and through the boiler before exiting to the stack.

Commissioning: The process of verifying that a new heating plant meets the performance specifications called for in the installation contract.

Complete combustion: Combustion in which all carbon and hydrogen in the fuel have been thoroughly reacted with oxygen, producing carbon dioxide and water vapor.

Cyclone separator: A flue gas particulate removal device, which creates a vortex that separates solid particles from the hot gas stream.

Day bin: An intermediary solid fuel storage bin that holds enough fuel to last approximately one day. Could be designed with the capacity to feed the combustion system for a weekend.

Demand charges: A class of charges typically found in commercial and industrial electric rates. Reflect the cost placed on the utility of the maximum number and size of all the electricity-consuming devices in use at any one time during a billing period.

Design/build: A design and contracting process under which the contractor bears ultimate responsibility for the design and function of the equipment or system installed.

Design specifications: For mechanical systems, specifications (and drawings) produced by the owner's mechanical or design engineer. Become part of the contract for the installation. The designer bears ultimate responsibility for the design and function of the system.

DHW: Domestic hot water.

Direct-burn system: A biomass combustion system in which the primary combustion chamber is located under and directly connected to the combustion chamber of the boiler itself.

Discount rate: In economic analysis, the interest rate that reflects the rate of return the owners could get if their money was invested elsewhere.

District heating: The use of a single boiler plant to provide hot water or steam for heating a number of buildings in a locality.

Energy service company (ESCO): A company that provides a broad range of energy services to a building owner, typically including the financing and installation of energy improvements under a contract that allows some of the dollar savings to accrue to the company.

Excess air: The amount of combustion air supplied to the fire that exceeds the theoretical air requirement to give complete combustion. Expressed as a percentage.

Fly ash: Airborne ash carried through the combustion chamber by the hot exhaust gases, and typically deposited in the passages of the boiler heat exchanger.

Flying Dutchman: A device commonly installed in round fuel silos to knock fuel down into the base of the silo, for transport by the fuel handling equipment to the combustion appliance.

Furnace: The primary combustion chamber of a biomass burner. The term also refers to warm-air heating appliances.

Gasification: The pyrolysis reaction in which heated biomass is converted to combustible gases in the primary combustion zone. Also refers to the conversion of char to combustible gases in the absence of oxygen and to the overall process of converting biomass, in an oxygen-starved environment, to combustible medium-Btu-content gases that are not immediately burned, but are cooled and cleaned to be used in a variety of ways.

Gasifier: A combustion device that produces bio-gas from solid biomass. Also shorthand for close-coupled gasifier.

Gasify: To convert solid biomass into combustible gas.

Grates (or combustion grates): Slotted or pinhole grates that support the burning fuel and allow air to pass up through the fuel bed from below.

Green biomass fuel: Biomass fuel that has not been significantly dried, with approximately the same moisture content as at harvest.

Heat exchanger: A device that transfers heat from one fluid stream to another. The most common heat exchanger in biomass combustion systems is the boiler, which transfers heat from the hot combustion gases to boiler water.

Heat load: The demand for heat of a building at any one time, typically expressed in Btus/hour or million Btus/hour. Peak heat load refers to the maximum annual demand for heat, and is used in sizing heating plants.

Heat transfer medium: A fluid (either water, steam, or air) that carries heat from the combustion system to the point of use.

Heating consumption: The annual total amount of heat a building requires. Can be expressed in energy units (million Btus) or fuel units (tons of biomass, gallons of oil, kilowatt hours of electricity).

Hog: Shorthand for hog mill, a device used to grind up various forms of biomass into chip-sized pieces.

Hogged fuel: Biomass fuel produced by grinding up various forms of wood and bark, possibly mixed with sawdust. Often refers to a variable low-quality fuel. If produced from clean, high-quality dry scrap, can be a very high-quality fuel.

Hydronic: Refers to a water-based heat distribution system that uses either hot water or steam.

Induced draft fan: A fan mounted at the discharge of the boiler, before the stack, to keep furnace pressure at the correct level and assure proper movement of flue gases up the chimney. Also called the ID fan.

Injection auger: The final fuel auger that moves the solid fuel into the combustion zone. In particular, an auger that forces fuel through an aperture onto the grates.

Life-cycle cost analysis: A method of economic analysis that includes all costs associated with a course of action for the lifetime of the equipment being installed. Includes price and cost inflation over time, and accounts for the time-value of money.

Live-bottom trailer: A self-unloading tractor trailer with a hydraulically operated moving floor, which is used to push the biomass fuel load out the back of the trailer. Typically filled directly by the chipper in the mill or in the woods.

Metering bin: A small bin in the fuel feed stream, just upstream of the combustion device. Allows a precise feed rate, or metering, of the fuel to the fire.

Mill chips: Wood chips produced in a sawmill. Typically produced from slabwood and other unmerchantable wood from debarked green saw logs.

MMBH: A unit that characterizes the size or peak output of a boiler, equal to one million Btus per hour.

MMBtu: A unit of energy equal to one million Btus (each M represents 1,000). In boiler or system sizing, also represents 1 MMBtu per hour.

Modulating fuel feed: A fuel feed system that adjusts the feed rate up or down in response to changes in the heat load.

Moving floor trailer: See live-bottom trailer.

Multi-chamber system: A variation on the two-chamber combustion system in which there is a connecting refractory-lined chamber between the combustor and boiler to give a longer flame path to enhance completeness of combustion.

Multi-clone (or multi-cyclone): A particulate removal device that includes a number of cyclone separators.

Municipal wood waste (MWW): Wood from sources like urban demolition and construction debris, urban tree waste, land and right-of-way clearing, and chipped pallets.

Nominal inflation rates: Price inflation rates including the rate of general inflation in the economy.

NOx: Oxides of nitrogen. Air pollutants that can be released from various types of combustion processes, including biomass combustion.

On/Off fuel feed: A fuel feed system that delivers fuel to the grates on an intermittent basis in response to boiler water temperature and load variations. Efficient combustion is typically achieved during on cycles and during high-load conditions. In low-load conditions, and while off-cycle, combustion is less efficient.

Over-fire air: Combustion air supplied above the grates and fuel bed. Also called secondary combustion air.

Particulates: Very small solid airborne particles. A source of air pollution that can result from biomass combustion.

Performance specifications: For mechanical systems, specifications used in design/build and turnkey contracting. Set forth the owner's minimum requirements for how a system will be configured and function.

Pile burner: A type of biomass combustion burner in which a pile of fuel burns on the grates. Primary combustion air comes from above the grates, not below.

Process steam: Steam used as a high-temperature medium for a variety of industrial purposes.

Pyrolysis: The oxidation process by which solid wood is converted to intermediate combustible gases and combustible solids through a variety of thermo-chemical reactions.

Real inflation rates: Price inflation rates that do not include the general inflation rate in the economy.

Refractory: A material resistant to high temperatures that is used to line combustion chambers in order to reflect heat back to the fire and to keep furnace temperatures steady.

Retention time: The transit time of hot gases from the point in the combustion process where the last combustion air is added to the beginning of the heat exchanger. The period during which carbon burn-out takes place.

Rotary airlock: A device used to pass solids such as incoming fuel or fly ash from a multi-cyclone without passing air. Can be used to prevent burn-back or the introduction of boiler room air into the exhaust gases through a multi-cyclone.

Seasonal efficiency: The efficiency of a heating system averaged over an entire heating season.

Sensitivity analysis: A part of economic analysis used to determine how sensitive the results of the analysis are to changes in the input variables.

Setting: A base on which a boiler or combustor sits, used to elevate a boiler. Houses the grates and primary combustion zone in a direct-burn system. Can form the connecting chamber in a multi-chamber system.

Shared savings: A form of energy project financing in which the party supplying the financing and/or installation gets a share of the dollar savings resulting from the reduction in energy consumption.

Simple payback: A method of economic analysis in which cost-effectiveness is based on installed cost and first-year savings. Also refers to the number of years it takes an improvement to pay back the investment, computed by dividing the installed cost by the first-year energy savings.

Sizing: The process of specifying the size (measured in MMBtu/hour or MMBH) of a heating plant.

SOx: Oxides of sulfur. Air pollutants implicated in acid rain, caused by combustion of fossil fuels but not biomass.

Stack: The chimney of a combustion system.

Stack emissions: The components of the hot combustion gases (including particulates) exiting from the stack.

Stack temperature: The temperature of the combustion exhaust gases passing into the chimney. One indicator of appliance efficiency.

Steady state efficiency: See appliance efficiency.

Stem: The main trunk of a tree, exclusive of branches and top.

Stoker: An auger or other device for feeding solid fuel into the combustion zone.

Summer boiler: A small boiler sized to meet the summer or off-season heating load.

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).

TA study: Technical assistance study under the federal Institutional Conservation Program (ICP).

Tertiary air: Combustion air in addition to under-fire and over-fire air, injected downstream in the flame path to increase turbulence and aid in carbon burnout.

Tertiary heat exchanger: A heat exchanger that removes latent heat from the exhaust gases by cooling them below the condensation point.

Tramp air: Unintentional, uncontrolled air entering the combustion chamber.

Tramp metal: Metal found in biomass fuel (nails, chainsaw chain, tools, etc.).

Turn-down ratio: An index of the range over which efficient combustion can be achieved by a biomass burner. Calculated by dividing the maximum system output by the minimum output at which efficient, smoke-free combustion can be sustained (for example, with a maximum of 2.4 MMBtu and a minimum of .4 MMBtu, the turn-down ratio is 6:1).

Turnkey: For mechanical systems, a contracting process under which the contractor has full responsibility for design and for the complete installed package of work. The owner accepts the completed system once the contractor has demonstrated that the system meets the performance specifications.

Two-chamber system: 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.

Ultimate analysis: Laboratory analysis that tells the percentage components of the elemental constituents of a fuel, including water and ash.

Under-fire air: Combustion air added under the grates. Serves the function of drying the fuel, cooling the grates, and supplying oxygen to the pyrolysis reactions.

Van: A delivery trailer (the trailer of the term tractor trailer).

Volatiles: Fuel constituents capable of being converted to gases at fairly low temperatures.

Walking floor trailer: See live-bottom trailer.

Wet scrubber: A flue gas particulate removal device that uses a water spray to capture and remove small, gas-entrained solid particles. Used only in very large biomass burners.

Whole-tree chips: Wood chips produced in the woods by feeding whole trees or tree stems into a mobile chipper, with discharge directly into a delivery truck.

Wood chips: Small rectangular pieces of wood (approximately 1" x 2" x 1/2") produced by either a mill chipper or a whole-tree chipper.

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