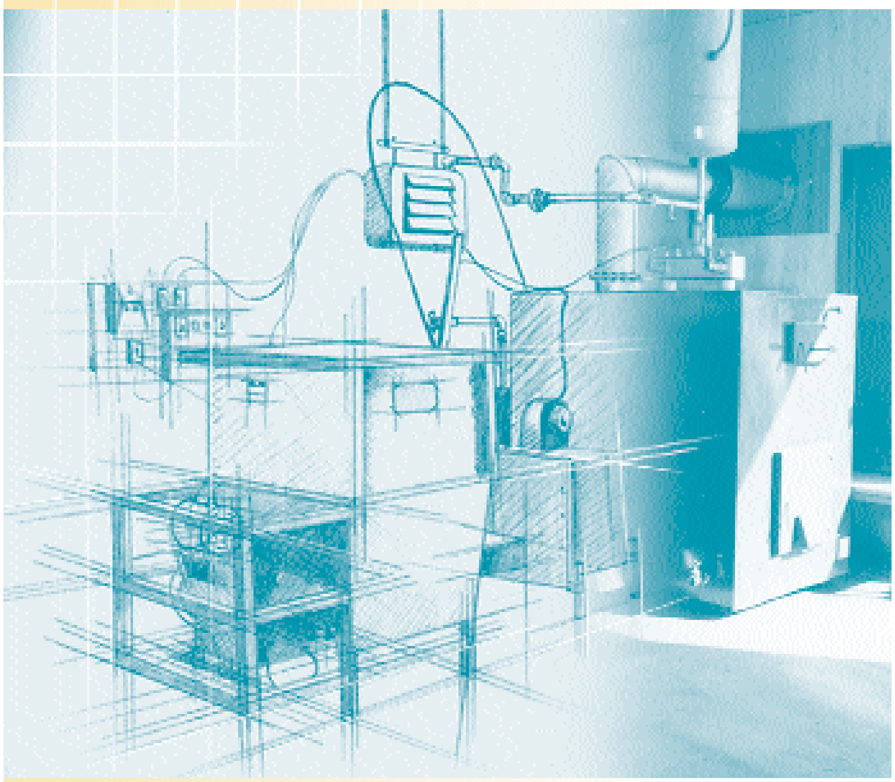
Buyer's Guide

To Small Commercial Biomass Combustion Systems



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PREFACE

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This publication was prepared by The CANMET Energy Diversification Research Laboratory and by SGA Energy Limited, for the Renewable and Electrical Energy Division, Energy Resources Branch, Natural Resources Canada.

Layout and Design by InnovaCom Marketing & Communication, Hull, Québec

ISBN 0-662-28899-8

Catalogue number: M92-186/2000E

Aussi disponible en français sous le titre :
Les petites installations de chauffage à la biomasse : Guide de l'acheteur

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ABOUT THIS GUIDE

Biomass Combustion Systems, also known as BCSs, are not a new technology. There are hundreds of these systems at work in Canada and many more throughout the USA and Europe. These systems are fed with biomass, a form of energy derived from plant or animal material such as wood, straw, grass, and manure. Wood is a common biomass fuel used in areas with sufficient wood supply. However, except for those directly involved in the wood heat industry, the general public and heating professionals are often not aware of the benefits of this cost-effective and reliable source of energy. Now, a recent emphasis on renewable energy resources as a replacement for conventional fuels is creating a renewed demand for biomass.

This Guide is intended to provide a practical approach to planning, procuring and operating a Biomass Combustion System (BCS). It will outline considerations the buyer should take into account before seeking the professional services of experts in the field. The Guide is <u>not</u> intended as a "how to" manual for the design, procurement, and installation or servicing of a BCS. In all cases, qualified advice should be sought to supplement the information provided here.

Who should use this Guide?

The Guide is intended for buyers interested in the most cost effective means of obtaining heat energy from forced air or hot water systems. Municipal and community leaders, business operators, architects, building designers and managers and energy service companies may all find this Guide of use.

What types of BCSs are addressed by this Guide?

This Guide addresses BCSs in the 75 kW (250,000 BTU/h) to 1,000 kW (3,415,000 BTU/h) range. A system of this size would not be suitable for most single residences, which generally use no more than 50 kW. On the other hand, it may well serve a multiresidential apartment complex or provide district heat to several homes. BCSs are intended primarily for institutional, commercial and industrial applications. For those interested in residential BCSs, we invite you to obtain a copy of Natural Resources Canada's (NRCan) *A Guide to Residential Wood Heating* (see section at the back of this publication called **Additional Information**).

This Guide deals with BCSs that transfer heat to water and distribute energy for space conditioning or process purposes. Small domestic systems (stoves, fireplaces, and furnaces) are not discussed, nor are the industrial boilers used in large sawmills, pulp mills and electrical utilities. Similarly, although other combustors in this size range exist to provide hot air directly for process heat (such as might be found in kiln drying), these are not addressed by the Guide. BCSs can also heat oil or produce steam for specialized high pressure requirements such as electrical generation; however, this application is not addressed in this guide.

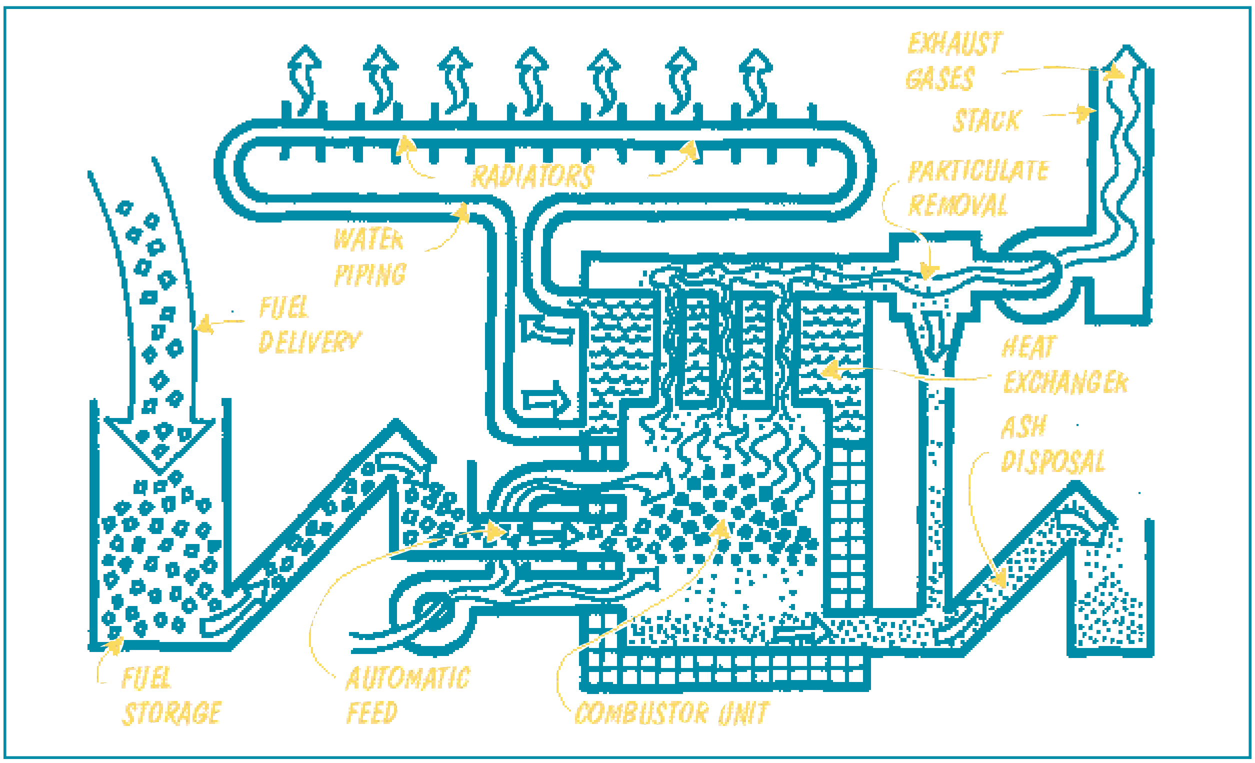
A complement to this Guide is the RETScreen™ Renewable Energy Project Analysis Software. RETScreen™ is a standardized analysis software that will help identify and evaluate the most viable opportunities for cost-effective implementation of renewable energy technologies (RETs), including biomass heating projects. (See **Chapter 6** for more information.)

There is a glossary of terms in **Chapter 7** of this Guide.

CHAPTER 1:
An Introduction to Biomass Combustion Systems

What is a BCS?

A BCS is a technology for extracting heat energy from biomass in a relatively convenient way. Biomass material, which is most often wood in solid chunk or particulate form, is combusted on a grate. Fuel can be fed either manually or, if it is a particulate, automatically, by using a screw auger or moving grate. The heat of combustion is transferred to water in a boiler that can either be separate from the combustion unit or attached as a water jacket. Water as hot as 90°C is pumped in a loop to serve the demand for heat either through radiant or forced air heat exchangers. Relatively close control of combustion and heat output can be maintained by synchronizing and automating the rate of biomass feed, the amount of combustion air intake and the temperature difference in inlet and outlet water temperature.



Biomass Combustion System - General Layout

Who uses one?

Because of their size and how they generate heat, nearly all systems are installed in the industrial/commercial/institutional sector. Typical applications are listed in the box below.

Examination of the systems installed during the energy crisis of the late 1970s and the early 1980s tells us where BCSs make sense. The greatest incentive is the cost of fuel: high conventional energy costs, low biofuel costs, or a combination of both. BCSs can be an effective substitute in a range of cases where:

- Electricity is the highest-cost energy form used for space and water heating.
- High transportation costs in remote areas can substantially increase the purchase price for light fuel oil.
- On-site (or locally) generated biomass residues are available at zero cost or at a savings, if there is a disposal fee for the residues.

BCSs work best for large loads operating with a substantial year round baseload, such as a process energy demand. These systems are more effective when operating at steady-state, near-rated capacity and with a high number of operating hours. This provides maximum fuel savings to cover the higher capital and operating costs of a BCS. Obviously, larger capacity applications enhance profitability due to economies of scale.

Although not the only users of BCSs, those in rural and/or industrial settings often favour this option since emission constraints may be lower, truck access may be better for biofuel delivery, auxiliary equipment such as loaders may be available and relatively low-cost labour may already be on-site.

Typical BCS Applications

Institutional

Health Care
- Hospitals, medical centres
- Seniors homes

Educational
- Schools
- Universities, colleges
- Religious buildings

Community/Sports
- Arenas
- Community centres (sports, fitness, crafts)

Commercial and Residential
- Apartment buildings
- Hotels, motels, B&B
- Stores, minimalls
- Warehouses
- Building supply centres

Agricultural
- Hog, dairy, poultry farms
- Fish farms, hatcheries
- Greenhouses

Industrial

Primary Forest Products
- Veneer, plywood
- Sawmills
- Lumber kilns
- Composite products (MDF, flakeboard, OSB)

Secondary Forest Products
- Furniture
- Pallets
- Trusses
- Cabinets
- Railroad ties
- Millwork
- Sports equipment
- Log homes
- Boxes, packaging
- Clocks
- Windows, doors
- Speciality items
- Mobile homes

Heavy equipment garages
Welding, metal fabrication, repair shops

Comparing a BCS to a Conventional Heating Plant

Selecting a conventional gas/oil heating system is relatively uncomplicated. Bids from different suppliers are comparable because fuel quality is standardized, systems are simple and combustion system designs are uniform. Price is often the only deciding factor when each conventional option gives the same quality of heat service and the same operating convenience.

Biomass combustion systems, on the other hand, are much more complex than conventional oil/gas systems and offer wide variations in design, leading, for example, to different feedstock or operating requirements. Comparing a BCS to a conventional plant requires diligence to effectively evaluate not only savings due to biofuel but also the contrasting bids normally obtained from different biomass system suppliers.

A biomass combustion system is different in many ways to a gas/oil system. These include:

Physical Size: Biofuel systems are much larger than conventional heating systems. They often require access for direct truck delivery of fuel, space for fuel storage, and a larger boiler room to house the mechanical fuel delivery and ash removal systems.

Fuel Considerations: Unlike gas and oil, biomass materials are generally <u>not</u> standardized, universally consistent fuels backed by large national suppliers. As a result, fuel quality, consistency and supply reliability become a concern, if not a responsibility, of the biofuel user. Energy content varies significantly depending on the type of biomass used for fuel (see table Determinants of Delivered Energy from Biofuels **Annex 1**).

Operation: BCSs typically require more frequent maintenance and greater operator attention than conventional systems. As a result, the degree of operator dedication to the system is critical to its success.

Mechanical Complexity: BCSs are more mechanically complex than conventional heating systems, especially when it comes to fuel storage, fuel handling and combustion. The complexity is necessary because of the different combustion characteristics of biofuel as compared to fossil fuels. The increased complexity means higher capital costs than for conventional systems and a cost estimate that is more difficult to establish.

Combustion Hazards: BCSs often require special attention to fire insurance premiums, air quality standards, ash disposal options and general safety issues.

The Benefits of a BCS

A BCS can provide substantial benefits to committed users.

First and foremost, there is the potential for *LOWER COSTS.*

BCS fuel costs are often much lower than those of conventional fossil fuels, with the exception of natural gas. **Table 1.1: Comparative Costs of Heating Fuels** shows the cost of a sample of fuels used to provide a unit of heat energy based on typical costs in 1998. Note that these costs compare only the value of heat in the fuel and do not include costs of the heating system.

Table 1.1:
Comparative Costs of Heating Fuels (1998)

Fuel	Price	Cost of Heat $ / GJ [1]
Electricity	8.02 ¢ / kW.h	22.51
Propane	39.9 ¢ / L	15.60
Light Fuel Oil	29.9 ¢ / L	8.47
Natural Gas	10.5 ¢ / m^3	3.05
Biofuel (mill residue)	$10 / tonne	1.68
Biofuel (whole tree chips)	$40 / tonne	6.73

(1) Assumes appropriate combustion efficiencies

Beyond economics there are other benefits:

Renewable Biomass: Biomass fuels are derived from a renewable resource. Fossil fuel supplies are ultimately finite. However, with proper management the biomass resource base can be sustained indefinitely.

Environmental Benefits: Biomass combustion is considered CO_2 neutral and so is not considered a major producer of greenhouse gas linked to climate change.
BCSs are not major contributors to acid rain. Most biofuels have a negligible sulphur content.

Available Biofuels at Stable Prices: Biofuels are widely available. In most areas of Canada, there is a supply of available biomass materials, either forest- or agriculture-based. Often the biofuels available are process wastes that require costly disposal and that have potential negative environmental consequences from landfilling or uncontrolled incineration.
Biofuel prices are relatively stable and locally controlled. Prices have remained steady over the years in spite of wide fluctuations in fossil fuel prices, and are expected to increase more slowly than those of petroleum-based fuels.

Local Economic Benefits: Biofuel dollars remain in the local economy. Biomass fuels are generated locally. Their collection, preparation and delivery involves greater labour input than fossil fuel distribution. The economic impact of this activity plus the actual fuel purchase means dollars remain in the local area, creating filter-down economic activity as well as improving the local tax base and building tax revenues.

Heating Comfort: Biomass systems often provide high comfort levels. Because biofuels can be inexpensive, system operators are able to justify increased building temperatures leading to greater comfort and productivity. With high-priced fossil fuels, there is greater pressure to lower temperatures for fuel cost savings.

Commercially Proven and Flexible: Biomass combustion technologies are commercially proven throughout Canada, having already achieved significant market penetration in residential and large industrial applications.
Biomass combustion systems are highly flexible. Solid-fuel systems can be easily converted to burn almost any conceivable fuel (solid, liquid or gaseous), thus providing the user with great flexibility in the future.

CHAPTER 2:
Steps in Selecting a Biomass Combustion System

The preceding chapter touched on a range of issues to be considered before selecting a BCS. This chapter discusses three of the key considerations:

- What are the potential biomass fuels?
- Is my energy requirement suitable for the BCS technology I want to install?
- Have I assembled sufficient information to have a supplier prepare a bid?

Step 1: Assess Sources of Biomass Fuel

Vast quantities of a wide variety of biomass fuels, or biofuels, exist in Canada. Forestry and agricultural activities generally produce these fuels. The technology for harvesting/collecting, preparation/storage, and transportation/delivery of these biofuels is technically proven and commercially available. Biofuels have some unique characteristics that require considerable specialized knowledge and care for their procurement and use.

"Variable" is the chief characteristic of biofuels. Fossil fuels (natural gas, petroleum, and coal) are marketed by large energy firms that provide a consistent, standardized fuel that has usually undergone considerable upgrading. On the other hand, the majority of biomass fuels are provided "as produced", with little refinement and no nationally recognized standards. Biofuels are typically locally generated, often by small independent contractors or brokers, and long-term supply may not be guaranteed. Care is required to ensure that several options exist to secure a reliable supply. Quality may vary between sources, from one year to the next, or even between deliveries, so you must carefully outline fuel specifications and other options in case contract obligations are not met.

Because of this variability, it is important to assess a potential biofuel supply for moisture content, ash content, heating value, type and source and delivery. All these will have an impact on price and the design of the BCS.

Moisture Content Considerations

Most biofuels contain water. Biofuel moisture content is normally expressed on a wet basis, i.e. the weight of water as a percentage of the total wet fuel weight. It will be important to determine biofuel moisture content when contracting for supply. Moisture can have a negative impact for these reasons:

- **Increased Costs:** The mass of water contributes to the cost of handling and transportation, but does not contribute any energy.
- **Loss of Efficiency:** The heating of the water and its conversion to steam requires heat which is taken from the heat generated by the biomass combustion. Heating systems using high moisture content fuels will have a slower response time to increased heat demand. The table "Comparing Determinants of Delivered Energy from Biofuels" in **Annex 1** shows the relationship between fuel moisture content and appliance efficiency. There is a decline of almost 50 percent efficiency between green whole tree chips and sawdust due to higher moisture and ash content in green wood.
- **Higher Emissions:** In basic, small capacity BCSs, moisture interferes with effective oxidation of the fuel, leading to high emissions of carbon monoxide and unburned hydrocarbons. Wet fuels can be burned without additional emissions in high temperature applications.

- **Increased Environmental Hazards:** Wet fuels are subject to biological activity that can cause oxygen depletion in closed storage areas, release of spores and heating that can lead to spontaneous combustion. On the other hand, very dry fuels create a dust hazard during handling and can pose a fire hazard.

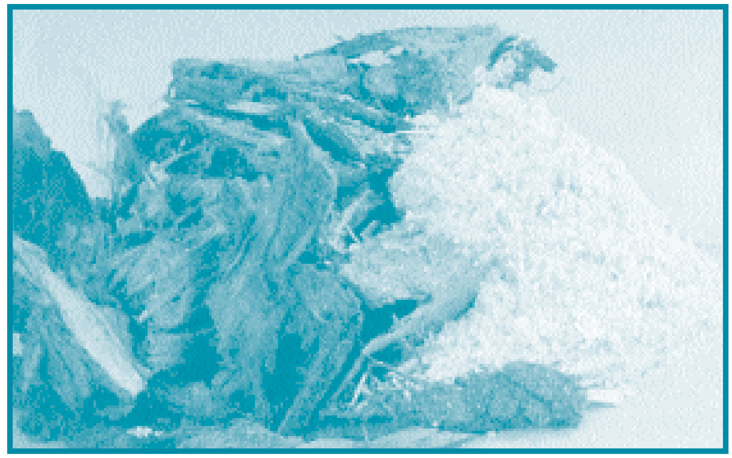
Ash Content Considerations

The non-combustible inorganic (mineral) content of biomass is generally referred to as ash. It can be either inherent, that is, deposited within the biomass during plant growth, or contaminant, that is, mixed with the biomass from external sources. Inherent ash is generally low in clean wood (0.5%), higher in bark (3.5%) and significant in annual crops such as straw (6.2%), but usually consistent within a fuel type. Contaminants such as dirt, sand, metal and plaster depend on the fuel source, how it was handled and the degree of cleaning during fuel preparation. It can vary widely within a fuel type or even within a fuel load. Ash content is usually expressed on a dry basis, i.e. the weight of ash as a percentage of the total moisture-free fuel weight.

Ash can cause problems. Ash does not contribute energy and represents a small energy loss if dumped hot. Major problems can occur when excessive contaminant ash softens/melts to form lumps of slag that can block grates and cause erosion and jamming of ash augers. Combustion of fuels with high alkali levels can cause problems in the boiler tubes when vaporized alkali deposits as slag on the heat exchange surfaces. The levels of ash found in clean wood do not normally create operating difficulties.

Heating Value Considerations

The quantity of heat released during biofuel combustion depends on the relative proportions of carbon, hydrogen and oxygen and the content of ash and moisture. Biomass generally has similar ranges of carbon, oxygen and hydrogen, but there is some variation depending on the origin of the fuel. In North America, energy content is generally presented as higher heating value. The table "Comparing Determinants of Delivered Energy from Biofuels" in **Annex 1** provides examples of heating values for a variety of fuels.



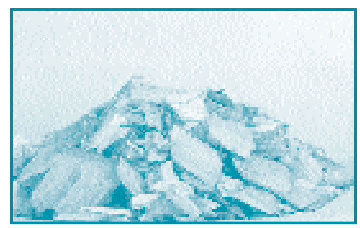
Biomass Fuels : Bark, Sawdust

Biofuel Type Considerations

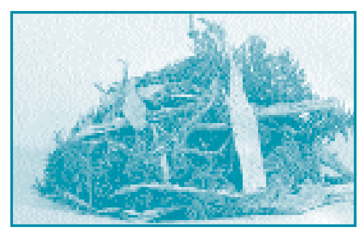
BCSs may use several types of common biofuels. Each of these types can vary widely in its moisture and ash content, and heating value. Types are categorized in **Annex 1** "Biofuel Types" based on source and mode of preparation.

Source and Cost Considerations

The cost of biofuels can vary, depending on circumstances. Source, location and quality are important, as are potential other uses for the fuel and the normal conditions of supply versus demand. Source is the most important factor in cost. The box "Biofuel Source Categories and Importance to Fuel Cost" in **Annex 1** sets out important cost factors in five wood categories: wastes, residuals, by-products, produced fuels and prepared fuels.

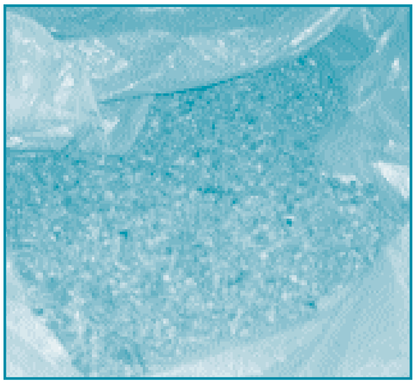


Biomass Fuels : Chips



Biomass Fuels : Forest Residue

Biomass waste, such as residue from a sawmill, is usually the lowest-cost option. In the absence of waste sources, trees harvested from a woodlot near the biomass heating facility might prove a cost-effective option. Harvesting on public lands should only commence once Aboriginal, municipal, territorial, provincial and/or federal approvals have been granted, and assurance is given that sustainable forest development is being implemented as outlined, for example, in the *National Forest Strategy, 1998-2003: A Canadian Commitment*. Practices that ensure a continued supply of wood, while maintaining the ecological integrity and productive capacity of the forest, should be implemented, regardless of volume requirements for bioenergy installations. It is important to ensure that the values and aspirations of local communities are regarded in all stages of the process, i.e. community consultation, planning, design, implementation and operation.



Biomass Fuels : Fuel Pellets

Costs for all biofuels will depend on the price paid for an alternative use of the biomass. Long-term contracts for fuel are therefore important. For example, bark that was once free would suddenly find a value if it were found suitable for landscaping. Should low cost biofuel residues become scarce and be replaced by a higher cost fuel, such as whole tree chips (WTC), costs can suddenly increase and may approach those of fossil fuels. When a large market exists for high value non-energy uses, such as pulp, the cost of quality biofuels easily exceeds their energy value.

Delivery and Storage Considerations

Unless generated on-site, the biofuel will normally be delivered by truck for a BCS of this size range. This can be by:

- dump truck;
- self-unloading truck or trailer;
- a truck or trailer unloaded by front-end loader; and
- pellet delivery in bags or bulk.

Each option will have an impact on the layout of the system. The Box “Biofuel Delivery Options” in **Annex 1** expands on these options.

Plans for your receiving/storage facility will depend on how you expect the biofuel to be delivered. For small systems, enough fuel for a full season may be purchased and stored on-site. Larger systems require regular daily or weekly delivery depending on the combustor size and storage capacity. Obviously, the receiving facility must have sufficient capacity to accept a full truckload of fuel.

Storage options depend on the type of fuel. Chunkwood (used in outdoor furnaces) can be stored in a shed or stacked in the open, but should be protected from rain. Square straw bales should be kept indoors, but round bales can be stored outdoors with relatively low losses.

Particulate fuels are either piled on the floor in above-ground buildings or placed in dedicated storage facilities such as above-ground rectangular or A-frame bins, silos or below-ground concrete bunkers.

Similar factors should be considered when agricultural wastes are used as a biofuel.

In-ground Concrete Storage Bin

Step 2: Size the System

BCS capacity and the size of the supplemental or backup system are crucial considerations that depend on the objective of plant operation. Experienced professionals should be consulted to determine system sizing. The general objective is to achieve the lowest cost energy supply through optimal performance at high overall efficiency and the lowest operating costs. Suppliers or designers of BCSs can provide assistance in accurately sizing a system. Generally, however, there are two approaches to system sizing: Peak Load design and Base Load design. The design approach directly affects the capacity and the capital cost of your system.

Approaches to System Design

	1. PEAK LOAD DESIGN	2. BASE LOAD DESIGN
DESCRIPTION	Determine the peak (or maximum) load, then oversize the system by a contingency factor to ensure those unexpected overloads can be met.	Maximize cost effectiveness by "undersizing" the BCS to handle only the major (or base) portion of the load. Allow a lower capital cost, smaller fossil fuel system to handle peaks.
ADVANTAGES	• Minimal fossil fuel (backup) is used; • Maximum biomass is used; • Provides the possibility for increased energy use at marginal cost (if biofuel cost is low); and • Provides a built-in capacity surplus for future load expansion.	• Increased portion of time that the BCS is running at or near its full (optimum) capacity, which will provide highest seasonal efficiency; • Significantly reduced capital costs; and • Better system control for efficient performance and lower emissions.
DISADVANTAGES	• A larger system greatly increases capital cost (and operating costs); • With variable loads (as in heating applications), the BCS must be operated at partial load for much of the time. This reduces operating efficiency, causing an increase in biofuel consumption; and • At high turn-down ratios, BCSs are more prone to high emissions (smoke) and often unstable combustion.	• A conventional system is required for peak loads; and • Fossil fuel use will be higher.

In general, peak load sizing is more common in large installations with high continuous energy demands. Using the BCS for a base load with fossil fuel handling peaks is more often the situation in smaller installations serving exclusively space heating or variable loads.

A unique situation occurs where there are wide differences in energy demand over a year, such as a summer process demand versus a winter process/ heat load. In this case, two BCSs might be used. A small unit would be operated in the summer with a switch to a larger unit sized for the main winter load, with both units operated during periods of peak demand. Each unit could be fired in the more efficient upper portion of its operating range over a longer period. In addition, partial heating capability is preserved when one system is shut down for maintenance.

Estimating the required capacity of the BCS takes into account several factors such as:

- the space heating and domestic hot water loads at the coldest or peak demand points in the year;
- the constant heating requirement of a process such as a laundry or a kiln-dryer;
- system losses; and
- a requirement for a low-cost conventional fuel peaking system.

The potential buyer is urged to seek expert advice from design specialists or manufacturers before proceeding beyond this step.

Step 3: Choose a Supplier

Before choosing a BCS supplier, you will need to write specifications for the system. Specifications establish what you wish the supplier to provide. Specifications are the technical description or “blueprint” of what the new BCS should be; what it is, where it is located, its inputs and outputs, the functions it is required to achieve and how it is to be operated. Good specifications are important for BCSs because the number of potential BCS suppliers, the availability of information on biofuel use, the base of local systems for examination and the existence of qualified bioenergy experts are limited compared to conventional systems. The information from these considerations is prepared as a written system specification or bid document. It specifies what the system must accomplish and within what constraints, but does not usually detail the exact design of the system. The supplier (bidder) is free to propose whatever system configuration he feels will best address the system specifications.

Specifications are specific guidelines for the supplier to make: first, a price quote and, second, to manufacture the BCS unit. Specifications can list complete details of individual components or can be non-specific, giving only fuel type, approximate capacity, general performance and operating constraints. They can be prepared by the owner/operator, by the facility staff or by a hired biofuel system engineer/consultant/contractor. See the Box on specifications for more details on contents.

Items for BCS Specifications

Key elements usually included in the specifications cover:

Fuel:
What type of biomass will be utilized and what are its specific characteristics (moisture content, particle size, components etc.)? What type of delivery truck will be used, what is its capacity and how will it be unloaded?

Storage:
How long must the system operate between guaranteed fuel deliveries? Are there constraints to storage bin location and type?

Location:
Will the BCS be in an existing boiler room, in a building addition or in a new separate combustion system building? Are there constraints on stack height or location?

Load:
What is the peak load, annual energy requirement and form of load curve? Are there specific requirements for load response, turndown ratio or proportion of peak load to be covered? Is backup/peaking available or required?

Operation:
What degree of automation is required? What operating staff are available? Are there constraints associated with downtime, service availability, etc?

Other:
Are there specific constraints with respect to emissions, efficiency, noise levels, etc?

Once specifications have been prepared, potential suppliers are identified from several sources:

- by contacting the operators of BCSs in the region;
- by contacting federal and provincial energy resource or industry departments; and
- from advertisements in trade journals and promotions at expositions and trade fairs.

When selecting a supplier or a consultant, it is important to consider the following important factors:

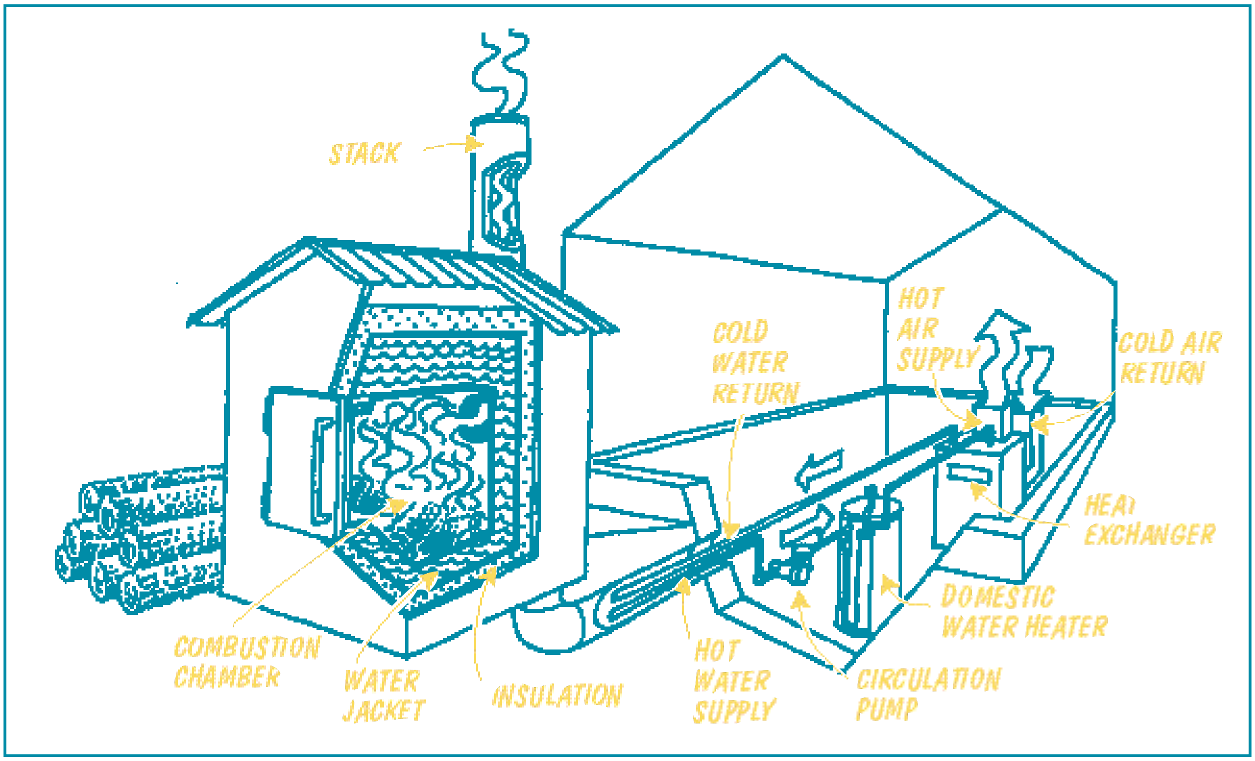
- The length of time the supplier has been in business. A firm that has been successfully installing systems over many years will probably have a better system, more fully established support services and better performance guarantees than a firm that has been hastily established to take advantage of a sudden market opportunity.
- The number of systems that remain in operation. A supplier with many installations in a variety of applications demonstrates that the supplier has encountered and become familiar with the widest possible range of fuels, loads and operating constraints.
- The level of local involvement. A supplier with local representation (and local installations) will be aware of the quality of local fuels, the availability of competent service agencies and all aspects pertaining to regional environmental standards and regulatory requirements.
- The degree of vertical integration. A firm that designs, manufactures, installs and services their own line of BCSs will usually have better overall control than a project manager who simply acquires components from a number of suppliers, then assembles a system, possibly without ever having previously done a similar unit.

CHAPTER 3:
Operation and Design Features

This chapter addresses the unique features of Biomass Combustion Systems both in operation and design. Many of the terms used in this chapter are defined in **Chapter 7**.

Types of Systems

BCS configurations are defined by variations in fuel and air delivery, combustion chamber and grate design, type of heat exchanger and exhaust gas, and ash handling approaches. Canadian installations generally fall within three broad categories: **small manual feed** (50 to 280 kW) chunkwood systems, typically which are outdoor furnaces with hot water heat distribution; **small automatic feed** (50 to 500 kW), particulate fuelled systems, typically two-stage combustors and fire-tube hot water boilers; and **moderate-sized automatic feed** (400 kW and up), fully automated particulate fuelled systems, typically moving or fixed grate combustors with integral or adjacent fire-tube boilers for hot water, steam or thermal oil.



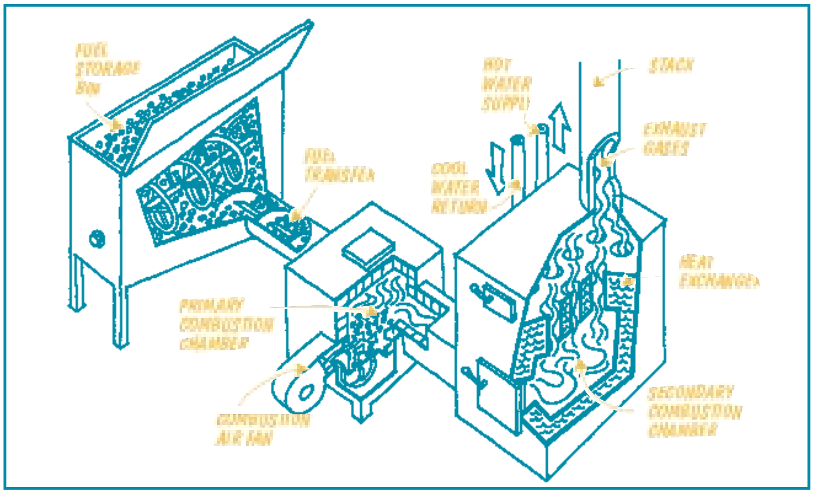
Typical Small Manual Feed BCS

In addition to these general types, there are a wide variety of speciality Biomass Combustion Systems configured to meet specific fuel characteristics. Suspension burners, designed for either cyclonic or true suspension, are used for dry, very fine fuels such as sawdust, hammermilled shavings or sanderdust.

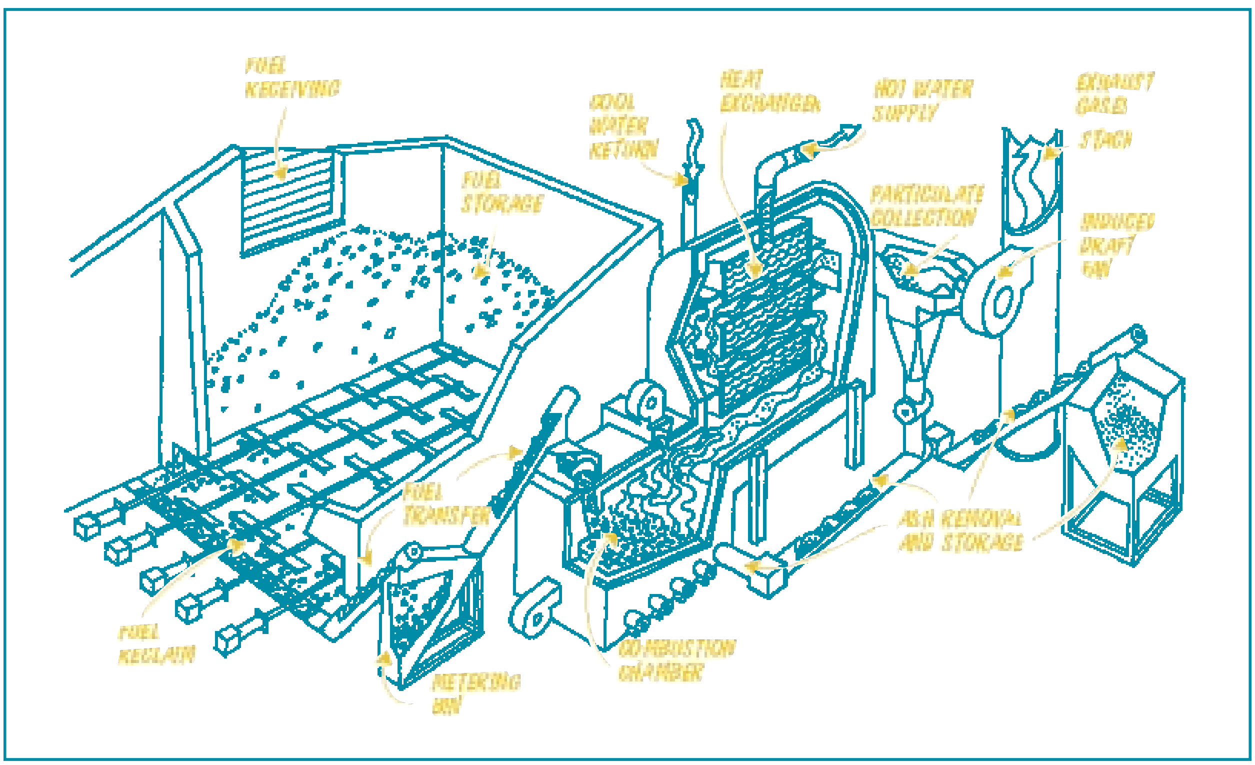
Somewhat coarser materials can be pneumatically injected into a refractory-lined, fixed-grate combustion tube in a Scotch Marine boiler.

Fluid-bed combustors (bubbling-bed or circulating-bed) are used for low quality biomass fuels with high moisture and/or ash contents.

Conventional oil/gas boilers have been retrofitted to use biomass through installation of a close-coupled gasifier that converts the solid biofuels to combustible gases which are ducted to and burned in the existing boiler.



Typical Small Automatic Feed BCS



Typical Moderate-Sized Automatic Feed BCS

System Components

Solid fuel biomass combustion systems are more complex than fossil fuel systems and generally require additional components beyond the simple combustor/heat exchanger. This means BCS components must be carefully integrated to ensure successful, trouble-free operation. Although not used in all systems, components generally include:

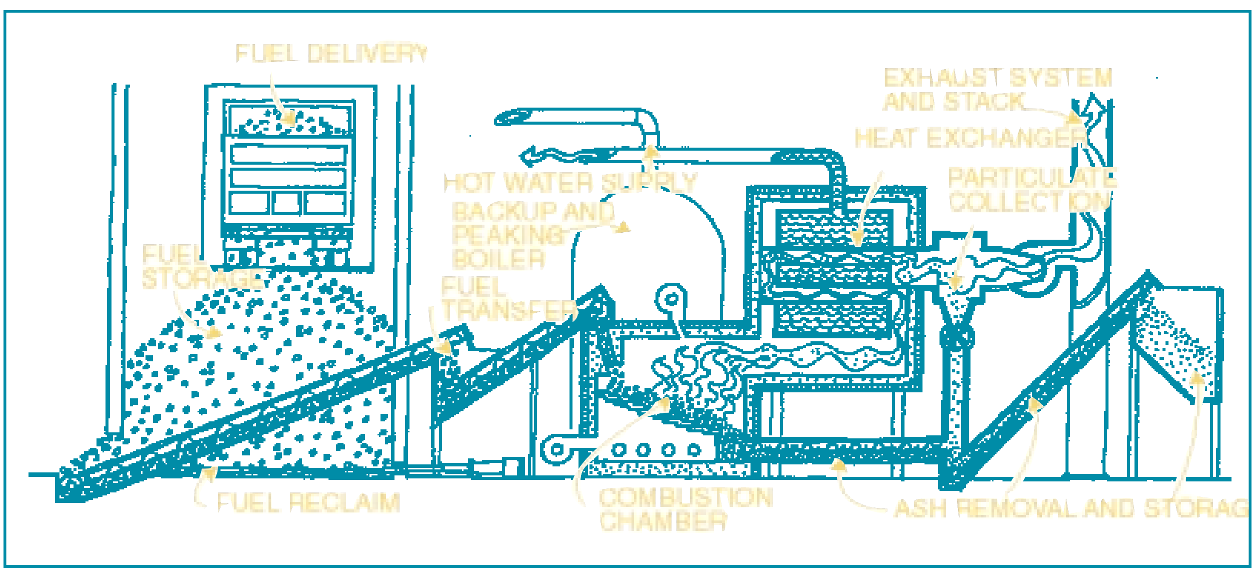
- **fuel receiving**;
- **fuel storage;**
- **fuel reclaim;**
- **fuel transfer;**
- **combustion chamber;**
- **heat exchanger;**
- **ash removal** and storage;
- **exhaust system** with particulate collection **and a stack;**
- **instrumentation, controls and safety** systems;
- **backup** with a conventional fuel system; and
- **peaking boilers** with conventional fuel systems.

This section discusses the importance of each component to the overall system.

Fuel Receiving

If a system requires fuel to be delivered to the site, truck access is the first consideration (unlike fuel oil delivery, where the truck can park on the street and run a hose across the lawn to a storage tank). Avoid steep slopes, narrow roadways and tight turns. Overhead clearance must be adequate and the road surface strong enough to stand up to heavy loads, particularly at the spot where the truck rear wheels rest when dumping a load. Remember that trucks unload from the rear and must either have room to turn around in the unloading area, or must be able to back in from the main road. Receiving of chunkwood for use in outdoor furnaces is less constrained since unloading and transfer are usually manual.

Mobile Loader Delivering Fuel to In-ground Bin



Biomass Combustion System Components

Fuel Storage

Particulate biofuels can be stored outdoors or indoors.

Indoor storage protects the fuel from precipitation (and often from freezing) and can eliminate the need for an intermediate storage bin. But indoor storage has a high capital cost and can present other problems, for example, difficulty in achieving full bin capacity, oxygen depletion from biological activity if ventilation is insufficient, and physical damage from pile pressure on bin walls. Indoor storage of particulate fuel can be either above ground (buildings or bins/silos) or below ground (concrete bins). Bins come in a wide variety of shapes such as rectangular or A-frame.

The small, automated-staged systems fuelled by particulate biomass often use a simple storage shed. Received fuel is dumped on a paved area, then moved into the storage area by a front-end loader. Moderate-sized systems use a dedicated bin or silo with direct fuel unloading into below-ground areas or a conveyor from a receiving pit to the top of above-ground storage facilities.

Outdoor storage is low-cost, and it is easy to mix a variety of different fuels to create a uniform blend for better combustor operation. Often used in very large utility systems, outdoor storage of particulate fuel is rare in smaller installations such as those considered in this Guide. There are disadvantages, however: increase in moisture content from precipitation, increased potential for decay in wet areas, greater fuel contamination from dirt pickup, creation of large chunks from precipitation and freezing, plus environmental problems associated with leachate runoff and wind-blown particles. Outdoor storage also involves a second handling operation for fuel reclaim and transfer to intermediate storage.

Chunkwood for manual feed systems should be in a protected storage area preferably close to the location of the outdoor furnace. If obtained green, the fuel should be allowed to air-dry for at least a full season before use.

Fuel Reclaim

How you will move particulate biofuels from storage to combuster is an important design consideration. This is called fuel reclaim. And mobile loaders normally achieve this in above-ground storage buildings or live-bottom unloaders and augers in bins/silos.

Interruptions or delays in reclaiming fuel are directly related to fuel properties, i.e. poor flow, compaction, frozen chunks, oversize material and contaminants. Uneven filling of a bin can cause erratic operation of hydraulic scrapers and bridging over unloaders. Sticks, wire and gloves, for example, can jam augers.

Manual fuel reclaim for outdoor furnaces is straightforward but labour intensive.

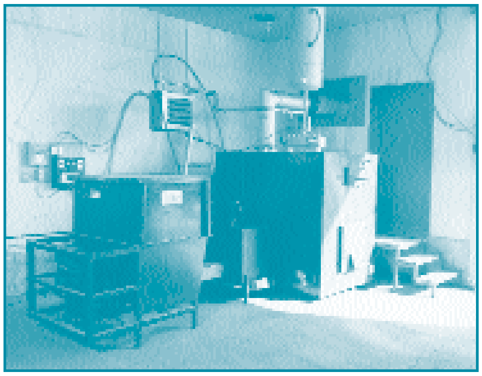
Fuel Transfer

From the fuel storage (or day bin) exit, particulate fuel must be moved by mechanical conveyors to the fuel injection system of the combustor.

The most common conveyor for small automatic feed systems is the screw auger either in an open or closed trough. A bridge breaker in the metering bin usually assists screw feed. Augers are relatively compact, simple and rugged but must be straight and are limited to moderate inclines. The main problem is jamming of the auger from irregularities (sticks, frozen lumps, or stringy material) in the fuel. The overload protection (electrical or shear pin) must be carefully selected to prevent damage to the screw flights and trough covers from fuel blockages. Easy access should be provided for manual clearing.

The final step (prior to the combustor fuel injector) is often a small metering bin. Fuel is dumped in loads in the storage bin, so the metering bin acts as a regulator to carefully control the fuel injection rate into the combustion chamber. The metering bin should be fully live-bottom (preferable with negatively sloped sides) to prevent bridging and has high- and low-level indicators which control fuel transfer from storage. Level indicators, can be mechanical (fixed or rotating) or electrical (photoelectric or proximity).

The final transfer of fuel from the metering bin into the combustion chamber can be done in a number of ways: a stoker auger (under, over or side feed), a mechanical ram, a gravity drop chute or a pneumatic (often cyclonic) injector. The back flow of combustion gases through the fuel entry is controlled by lock hoppers, rotary valves or merely the flow resistance from the fuel in a screw auger. Fuel transfer is controlled separately by signals from the metering bin indicators.



Small Commercial Biomass Heating System

Combustion Chamber or Combustor

The combustor includes a method to deliver both fuel and air, and has an enclosed area where combustion occurs. It also must have a grate, a method to remove bottom ash and an exit for hot gas. In small-scale outdoor furnaces, the combustion chamber is a simple steel (or stainless steel) rectangular firebox with full water jacket and a large cast iron door for fuel input and ash removal. Combustion air supply is either natural or forced and can be preheated. Air supply is controlled by a thermostat in response to energy demand. Exhaust gases pass through a short flue to an insulated steel stack mounted on the unit. The combustion system is assembled as a modular unit enclosed in an insulated steel shed and mounted on skids.

If fuels with higher moisture content are to be used, there must be a method to retain heat in the chamber. The amount of energy required to first dry, then burn, the incoming fuel is significant, and a high temperature must be maintained in the combustor. This is often achieved by lining the chamber with refractory (such as fire brick), which radiates and reflects heat back into the fuel layer. The refractory also protects the walls and base of the furnace from the high temperatures in the combustion zone.

Most combustors have grates that support the fire bed and allow for air to move under the fuel. Grates are usually constructed of cast iron or refractory and can be sloped, flat or stepped and either stationary or moving. All grates have holes that allow the underfire air to be blown up through the fire bed. Larger systems use moving grates to maintain an even bed of fuel and to move the burning fuel progressively over different zones of underfire air. The movement also shakes ash to the end of the grate to keep it from blocking air movement.

A supply of air to support combustion is essential. In addition to underfire air, air is injected above the fuel bed to provide added oxygen and turbulence to ensure complete combustion. Effective control to balance over- and under-fire air is critical if the fuel is to be completely burned, including char, which may remain on the grate, and volatiles released into the air by the burning fuel.

The hot exhaust gases exit the combustion chamber and pass to the heat exchanger either directly in integral systems or through a refractory duct and secondary combustion chambers in staged systems. In small outdoor systems gases are removed directly to the stack.

Heat Exchangers

Heat exchangers recover heat directly from the combustion area or from the hot gases that are ducted to the heat exchanger. In outdoor furnaces, the primary heat exchanger is a simple, insulated water jacket that surrounds the firebox.

Larger systems use boilers, with hot water, steam or thermal oil used as the heat transfer medium. In the boiler, the heat exchanger is either water-tube or fire-tube. In a fire-tube boiler, the combustion gases pass inside the boiler tubes, which are located within a water-filled shell. Water-tube boilers have a series of tubes through which water passes with the combustion gases on the outside of the tubes.

An electric pump moves the heated water through insulated underground pipes to the load.

Ash System

There are two types of ash: bottom ash which remains in the combustion chamber on the grate, and fly ash which is sufficiently light that it is suspended in air, picked up by the combustion gas flow and carried out of the primary combustion area.

Bottom ash in outdoor, manual-feed furnaces, as well as in some small automatic-feed BCSs, is removed manually from the small, flat refractory floor. This is done through the firebox door when combustion has died and the ash cooled.

Daily Manual Ash Removal from a Small BCS

In a system with grates, ash collects below or at the side of the grate. The ash is then removed either by hand or automatically by augers.

Ash Removal Conveyor and Storage Drum: Automated BCS

Because it is moved by combustion gas flow, fly ash can deposit in several locations. It can form in secondary combustion chambers, in specifically designed dropout areas or on the heat exchange surfaces in the boiler. This ash must be regularly removed to maintain good heat transfer performance. In small systems, these deposits are removed by manual brushing. If the system is designed that way, fly ash can collect in a specifically designed particulate collection system. It can also drop out in the stack or be carried into the atmosphere as particulate air emissions.

The frequency of ash removal depends on the system, the ash content of the fuel and the completeness of the combustion process. Ash removal can vary from once or twice a year to every week.

Problems encountered with ash removal and handling include:

- Clinker or slag formation. When local hot spots occur in the combustor, temperatures may increase to the point where the usually dry fluffy ash actually melts into a molten slag which solidifies into a very hard glassy clinker when cool. These deposits can adhere to grates and jam ash removal augers.
- Biofuel ash is light and can present a dust problem if systems are not fully enclosed.
- If the ash has a high carbon content and does not cool sufficiently before exposure to air, fires (and possibly explosions) can occur.

In general, ash from biofuel burning is not considered a hazardous waste and can be placed in local landfills. However, most ash is an excellent soil additive and can be provided to local gardeners and farmers or can be spread on farms or in forested areas. Difficulties in ash disposal may be encountered if combustion efficiency is low and the ash has a high content of unburned carbon.

Exhaust System and Stack

Exhaust system designs work in one of three ways: natural, induced or forced-draft.

Natural drafts are used only in relatively small systems. In a natural draft system, warm air moving out of the stack creates negative pressure in the stack which draws exhaust gases up the stack.

In small outdoor furnaces, a short duct leads the exhaust gases into the base of a chimney mounted on the unit.

Forced-draft systems rely on the combustor's (incoming) air delivery fans. Fans create a positive pressure in the combustor, forcing the gases through the heat exchanger and out the stack. The disadvantage of this approach is that any leaks in the system result in escape of combustion gases into the boiler room.

An induced-draft system uses a large blower located in front of the stack which sucks the exhaust gases out of the boiler and forces them up the stack. The draft of this fan is regulated in relation to the combustion air to maintain a very slight negative pressure in the combustor so that no combustion gas leaks occur.

The capacity of the stack must carefully be matched to the combustion system. Stacks are constructed of either masonry or steel and can be insulated to allow low heat exchanger exit temperatures but still avoid condensation in the stack. You have to consider the height of the building and surrounding buildings, local topography and wind conditions in order to determine the height of the stack.

Biofuel system stacks must have an access door in the base to permit fly ash removal and an unobstructed drainage outlet to prevent ice buildups.

A Stack at the Prince Edward Home (Seniors Facility) Charlottetown, PEI District Heating, 1985

Instrumentation, Controls, Safety

Instrumentation is important for efficient operation, response to energy demand and safety.

Instrumentation in outdoor, manual-feed furnaces is kept to a minimum. A thermostat controls the input of combustion air in response to energy demand.

Automatic-feed BCSs have a more complex control system strategy. Modern biofuel combustion systems are fully automated, using computers or micro-processors to match heat delivery with demand. Start-up and shutdown sequences are programmed, and alarms will sound in upset conditions.

A key task of the control system is determining the rate at which fuel and air are fed to the combustion chamber to ensure efficient combustion. The simplest systems have on/off fuel and air feeds. This can lead to inefficient and smoky operations during low load periods because on/off controls cannot respond to varying loads. Some systems have two on/off modes, high fire and low fire, that give better control.

The best control is achieved when fuel and air are automatically modulated simultaneously to maintain the correct ratio under high or low demand. Microprocessors input data from heating fluid temperature, draft, exhaust gas, oxygen content plus outdoor temperatures, time of day, etc. to regulate system operation.

There are safety demands. Biofuel systems require protection from burnback or fire travelling back from the combustion area along the incoming fuel stream. A temperature sensor in the fuel feed near the combustor can activate a water-quench that floods the fuel delivery area. Also required is a safety device that cuts off fuel supply when the combustor fire has failed. Normally standard smoke detectors, CO detectors and boiler room sprinkler systems are used. Alarms can be set off and automatic diallers used to alert operators in the event of an upset condition.

Systems must be designed to function safely in the event of power outages and should have auxiliary power to maintain computer operation for shutdown. Mechanical fuel handling systems can be dangerous and all moving components must be covered and shielded.

Backup Requirements

Most institutional and commercial biofuel plants have an oil/gas backup. In many retrofit installations, the existing fossil fuel system is kept as the backup. In new facilities, a separate backup system can be installed, or a backup burner can be included in the BCS design. These can be either permanently mounted or fitted on a swing-away door that is manually moved into firing position when required.

The presence of a fossil-fuel backup capability enables:

- use for very low-load periods when operation of the BCS is inefficient or would cause excessive emissions (smoke);
- coverage of scheduled BCS shutdowns for maintenance;
- operation when fuel supply is exhausted or when oversized fuel components jam the fuel delivery system;
- takeover during breakdown outages of the primary BCS;
- handling of peak loads that are beyond the capacity of the biofuel system; and
- capability to meet, on a short lead time, a significant load expansion.

Backup systems can be activated manually or automatically by the control system when the biofuel fire fails or the BCS does not meet energy demand. When no staff is on-site, such as overnight in an institutional setting, fully automatic duplicate systems are often used. Any upset in the BCS triggers automatic start-up of the backup unit and shutdown of the biofuel system.

Peaking

If there are relatively few hours per season where the system will run near capacity, it is usually more cost effective to install a fossil fuel peaking boiler to supplement the BCS. This way, a much smaller BCS can be purchased to handle the base load. The capital cost savings by installing a smaller BCS will more than offset the cost of the backup system and the fossil fuel it uses.

The control system is designed to fire the peaking boiler under two circumstances: (a) when the demand is greater than the BCS capacity; and, (b) when the load drops, to shut down the fossil fuel unit before the BCS capacity is reduced.

In situations where there is a large difference between the year-round base load and a shorter period of high load, a second BCS would be installed. One system operates at low load, and both operate to meet peak load. In many installations, a fossil fuel system serves the dual purpose of backup and peaking.

System Performance and Efficiency

The objective of most BCS installations is to reduce overall heating costs while meeting the heat load. Because biofuel systems often have significantly higher capital and operating costs than gas/oil systems, it is essential that fuel consumption be minimized. Greater operating efficiency will reduce fuel consumption. The prime reasons for the lower efficiency of most BCSs are excess air and high fuel moisture. In addition, clean, effective combustion is necessary to meet increasingly stringent emission regulations. An in-depth discussion of efficiency can be found in **Annex 2**.

The term 'efficiency' is much used and very often abused in the heating industry. Efficiency is a ratio, usually expressed as a percentage, of output thermal energy to fuel energy input. The number will indicate the losses that result from the system operation, and therefore the proportion of fuel energy that is purchased but not actually used.

Fossil fuel systems often have much higher efficiencies than biofuel systems. To compare which system best suits your circumstances, you need to have an understanding of, and accurate values for, efficiencies. Unlike fossil fuel systems, which use only one type of fuel, BCS efficiencies should always be quoted along with fuel type and moisture contents.

There are three different efficiency values that are regularly used (see **Annex 2** for a detailed discussion of each):

1. **Combustion efficiency:** is an indication of the completeness of fuel combustion.
2. **Appliance efficiency:** incorporates combustion efficiency plus the effectiveness of the heat exchange medium in transferring thermal energy to the load. It is usually specified under optimal capacity operating conditions.
3. **Seasonal efficiency:** considers all aspects of the total combustion and heat distribution system giving the appliance efficiency averaged over a full operating season under varying operating conditions. This may be only the winter, the whole year or some other period.

CHAPTER 4: Other Considerations

The bulk of this Guide has been devoted to assist a potential buyer of a BCS to make informed technical and economic decisions. This chapter covers a host of other issues, often non-technical, which are also key to a successful project. Subsequent sections outline such issues:

- environmental approvals;
- insurance;
- tax implications;
- system quotation;
- contract negotiations;
- installation;
- start-up, commissioning and performance tests;
- system warranty;
- operation and maintenance; and
- life expectancy.

Environmental Approvals

Determining all federal, provincial and municipal standards and regulations should be one of the first steps in a BCS project. Local air quality regulations, usually a provincial responsibility, are the main concern. Small manual feed outdoor systems may also be subject to municipal regulation because of the potential for high uncontrolled emissions. Apply for permits early in the project. Projects that are the first of their kind in a region usually have more difficulty than projects where a number of other biofuel systems are already operating.

Ash disposal usually is not a problem, except in very large systems. In many cases, the system supplier can guide (or may take responsibility for) environmental approvals. Regulated stack emissions vary with the geographic location but may include those shown in the box **Emission Regulations**.

Emission Regulations

Opacity – This is an indication of the “darkness” of the plume issuing from the stack. It is determined by measuring the reduction of intensity of light passing through the plume. High opacity results from high levels of particulate (soot) and aerosols (fine liquid droplets). The effect of water vapour condensation is not considered, i.e. opacity is measured prior to the condensation of water vapour that occurs when the exhaust contacts a cold atmosphere.

Particulate – The quantity of solid material being exhausted, usually ash and unburned carbon. There may be separate regulations for total particulate and for particulate of less than 10 microns in diameter. It is measured by extracting a sample from the stack and passing the measured volume of gas through a fine pore hot filter.

Carbon monoxide, sulphur oxides, nitrogen oxides and hydrocarbons – These air pollutants are more commonly a concern for larger combustion systems but may be regulated on smaller systems in non-attainment areas. They are typically measured by passing a stack gas sample through a gas chromatograph or by specialized on-line analyzers.

Carcinogens – Some jurisdictions have (or are proposing) regulations on the emission of identified carcinogenic compounds. These include heavy metals (for example: arsenic, lead, chromium, nickel, mercury), dioxins and furans and chlorinated phenolics.

In some areas, regulations are based on specific emission limits, such as weight per unit volume of gases or weight per unit of fuel energy input, while in many jurisdictions permitting is based on the impact of the emissions on ambient air quality in the specific area of the facility.

Insurance

Some BCS owners have been faced with an increase in insurance premiums because of perceived fire hazards. On the other hand, several informed insurance companies do not invoke a penalty as long as the installation has the required safety controls and is installed to industry standards. The impact a BCS will have on insurance costs should be checked early in the planning process. Suppliers can usually provide names of sympathetic insurance companies.

Tax Implications

There may be tax benefits to purchasing a BCS. The tax position of each potential user will be different. Buyers should seek advice on possible tax advantages in a BCS investment.

Federal tax law (Capital Cost Allowance Class 43.1) currently allows an accelerated write-down of BCS capital cost if the heat generated is used in an industrial process. The annual Capital Cost Allowance rate for Class 43.1 is 30% on a declining balance, which is about a 7-year write-off. If the heat is used for other than an industrial process (say space heating) the accelerated write-off would not apply.

Provincial tax varies with each jurisdiction. PEI, for example, forgoes tax on BCS equipment but not fossil fuel systems. System suppliers will often know the tax situation in specific provinces.

System Quotation

When the system specifications have been prepared, a request for quotation then goes out to potential suppliers. Two general approaches have been used to receive quotes; competitive or informal bidding.

In competitive bids, the system performance specifications become the basis for proposals from system suppliers. All bidders have the freedom to configure their proposals according to their particular designs, so long as they remain within the specifications. The bids will outline the system, describe its performance, list guarantees and will include a price quote good for a specified period of time. It is also possible some bidders will give different options and the price of each option.

When bids are received, they are checked to see if the performance specifications have been met. Often the final selection will involve a judgement decision where the value of non-quantifiable aspects is weighed against costs. For example, what additional capital cost is justified for the lower risk associated with a proven system? Does reduced operator attention compensate for the extra cost of automation?

Advantages of the competitive bid approach include:

- there is pressure on bidders to give the lowest possible cost;
- manufacturers are encouraged to be innovative in developing system requirements to gain a competitive advantage;
- a wider range of options is provided for consideration; and
- the greatest negotiating power is given to the purchaser.

With informal bidding, the owner (or an expert hired to represent the owner) examines characteristics of systems known to be available, inspects existing installations, interviews operators, then selects the general system type and the manufacturer considered most suitable for the application. A contract is then negotiated between the buyer and seller based on meeting the performance specifications at a favourable price.

Advantages of the informal bid process include:

- a very simple approach which usually requires less time for performance specifications preparation, bid review, negotiations, etc.; and
- typically gives priority to system performance. If the supplier selected has a number of successful systems operating in the local area, there is little chance that an unproved (but lower cost) system would be selected.

Contract Negotiations

There are several approaches that can be taken to move a project through to completion. Each of these options requires attention to contract details. Approaches include:

1. manufacturer turnkey;
2. supplier turnkey;
3. project manager turnkey; and
4. owner-installed project.

The box **BCS Project Implementation Options** provides details on each of these.

Whatever option is taken, it is important that all uncertainties are fully discussed and resolved, with details clearly outlined in the written contract. It is also important that remedies for default are clearly specified and approved.

Installation

BCSs require more space than gas/oil systems, especially if a separate fossil fuel boiler is maintained for backup. While retrofit BCSs are put in existing boiler rooms, this can lead to problems if fuel and ash handling systems have to be compromised because of space. Often, a separate BCS building is constructed near the existing boiler room (in which the fossil fuel system is retained for peaking and backup). This effectively separates any mechanical noise or dust from the main facility and gives greater flexibility to fuel storage and delivery.

Depending on the size of the system, considerable concrete work may be required. Foundations for the combustor (with its refractory, which can be heavy), and the stack must be adequately reinforced. An underground storage bin may be required. Conveyors and bin unloaders must be firmly mounted to resist the forces generated when fuel compaction or overloading occurs.

BCS Project Implementation Options

1 *Manufacturer Turnkey:*
The owner deals directly with the system manufacturer on a turnkey basis. The major responsibility for system suitability and performance lies with the manufacturer, but the owner makes the major decisions.

2 *Supplier Turnkey:*
The owner deals with a local supplier who purchases components from various manufacturers and integrates them into a total system that meets the project specifications. The major responsibility for the system lies with the supplier but the owner makes the decisions and gives the approvals.

3 *Project Manager Turnkey:*
The owner hires a biofuel engineer/consultant as project manager with responsibility for the entire system. The manager then contracts for a turnkey system from a supplier or, more typically, sub-contracts for various components to assemble the total system. The main responsibility lies with the project manager who makes many of the selection and contractual decisions, usually with general approval from the owner on major aspects. If the biofuel system is part of a new facility construction or of a major facility restructuring, the general contractor may be the project manager for the biomass energy system.

4 *Owner Installed:*
In small-scale, often industrial, situations the owner may undertake to design and install his own system based on the purchase of proven sub-systems or components from the manufacturer. In this case all responsibility lies with the owner.

Start-up, Commissioning and Performance Tests

Start-up and commissioning of a biofuel system should be the responsibility of the contractor (manufacturer or supplier).

The start-up phase involves a mechanical test of all components (leak testing of boiler and heat distribution) followed by the first actual firing and operation of the unit. The refractory may have to be cured by firing the combustion chamber at low intensity. There will also likely be an initial test period for adjustments, tuning and possibly minor modifications.

After start-up, the system is commissioned. It is run for a period of time in accordance with stipulated load, fuel and operating procedures to prove to the purchaser that the system meets the basic operating specifications.

Performance tests may also be carried out separately to establish that performance criteria such as emissions, efficiency, turn-down and response can be met. They may be carried out at the time of commissioning or after a specified period of normal operation. Full load tests should be included, which may require testing at a time other than start-up. For example, if a seasonal heating system is started in early autumn, performance tests may be delayed until full-load conditions in mid-winter. If performance tests are required, the operating conditions and operating procedures will be defined in the contract. In some cases, these tests are carried out by contracting an independent third party not associated with the manufacturer/supplier/installer/contractor.

The lowest quality fuel that meets the system's guarantee criteria should be used for commissioning and performance testing.

Start-up services usually include operator training. The time allocated for this is specified in the bids and usually completed before the contractor leaves the site. Systems should be accompanied with full documentation on maintenance procedures and schedules, repair manuals with part numbers for the major components plus manuals for the standard items (motors, blowers, pumps, etc.), wiring diagrams, safety system reset procedures, computer troubleshooting instructions, etc.

System Warranty

Warranties are a standard component of a supplier's formal bid and must be clearly stipulated in the purchase contract. Typically the supplier of the system gives a general warranty with respect to overall operation and performance, plus specific guarantees for unique segments of the system. Standard components (motors, gearboxes, pumps, etc.) usually carry the warranty from their individual manufacturer, although the system supplier should guarantee the suitability of the selected items.

Operation and Maintenance

The system manufacturer (or supplier) will provide detailed instructions for routine operation and maintenance; however, these procedures may require alteration to fit the specific requirements of the facility staff. Make sure the proposed changes are discussed with the manufacturer to ensure the system performance will not be adversely affected or any component warranties voided.

Biofuel systems generally require regular attention. Tasks such as ash removal and/or ash disposal, general cleanup (usually in the fuel storage and handling area), checking boiler water levels, checking the fuel delivery system for oversize material build-up, plus checking stack temperature and possibly flue gas composition to adjust fuel/air delivery rates are usually done daily. Computerized systems can signal the operator in upset conditions or for out-of-range readings. Systems in the size range covered in this Guide usually do not have full-time operators.

In addition, there are regular maintenance tasks that are performed on a periodic basis that may vary from weekly to monthly to even yearly. These can include:

- boiler tube cleaning;
- mechanical component lubrication;
- inspection and adjustment of chains, gearboxes, blowers, etc.;
- refractory inspection and repair;
- testing of safety devices;
- checking for leaks or air infiltration; and
- inspection of insulation and cladding.

How often the internal system is cleaned will depend on the operating characteristics of the specific system. Over a period of time, operators will become familiar with how often maintenance, such as fly ash removal, tube cleaning, stack clean-out, etc., will have to be done. However, until operators are familiar with this, close inspection is required.

The routine maintenance can be carried out by the system operator, by general on-site maintenance staff or by a dedicated maintenance crew, or contracted to an outside maintenance and service firm. Contracting out may have merit when the on-site staff does not have the time or skills required for BCS maintenance. In addition, this approach has the advantage of regular inspections by experts with specialized knowledge in the unique aspects of biofuel handling and combustion. However, it may reduce the level of interest and dedication of the owner's staff. A maintenance contract must clearly define individual responsibilities. Generally on-site staff handle the daily tasks while the maintenance contractors will address the routine preventative maintenance and repair requirements.

Life Expectancy

In theory, a BCS can last indefinitely, since the components can be replaced as they wear out or deteriorate. In the forest industry, wood combustion systems have been in operation for over 50 years. A system may be replaced if a newer technical design provides better efficiency, lower emissions or greater flexibility or on the basis of operating costs which show that annual repair/replacement expenditures exceed the projected capital recovery costs of a new system. In practice, 15 to 20 years is used as a reasonable BCS life expectancy for the purpose of life-cycle costing for systems of the size range in this Guide.

CHAPTER 5:
Assessing Costs

Cost is the bottom line when deciding if a BCS is a viable alternative. To proceed, the overall costs of the BCS must be less than the next available fuel option. Comparing costs is difficult, however. This chapter will help you compare a BCS on an equal basis with a sound alternative.

Cost the BCS and its Alternatives

Before you can start the cost comparison, you have to know the amount of heat required, the size of BCS and backup boilers, the amount of fuel and so on. From the design values, cost estimates can be established. These rough values can be refined over time.

A combustion system will have two types of costs: *Initial Costs* and *Annual Costs.*

Initial Costs are generally incurred only once at the beginning of the project and are required to take the heating plant up to full and regular production. Initial Costs include items such as:

- feasibility studies: a planned BCS may require a thorough site investigation and a biomass resource assessment;
- project development: a BCS may require permits and approvals, arranging project financing and managing the project;
- engineering and design: a BCS requires site, building and energy system design as well as tendering and contracting and construction supervision;
- purchase and installation of heating plant: a BCS requires a biomass burner and possibly a separate boiler, chimney stack, pumps and electrical equipment, spare parts and transport to the site;
- purchase and installation of appropriate balance of plant: depending on design considerations, a BCS may require peaking and backup conventional fuel boilers, piping and trenching for district heat distribution, construction of heating plant building and preparation of a fuel handling yard; and
- other costs such as training.

Annual Costs are the expenses incurred in the running and operation of the plant on a recurring basis. Annual costs include items such as:

- property taxes and insurance;
- labour for operation and maintenance – BCS labour would include filling the fuel hopper and cleaning out ash;
- parts for annual maintenance and repair;
- administrative costs;
- fuel or electricity costs – BCS fuel will include delivered, particulate biomass, oil for peaking and backup boilers and electricity for pumps, motors and fans.

Remember to make itemized estimates of initial and annual costs for both the BCS and at least one alternative system to compare the two options. A BCS project cost estimate is more complex and more difficult to evaluate than a conventional heating system. A BCS has more system components, a higher level of component integration and a greater variation in design approaches. If the BCS is not a turnkey installation, several subcontractors can be involved requiring skilful project co-ordination.

Generally, there are two sets of circumstances where a comparison between a BCS and an alternative system can take place:

1. *New Construction*. There is currently no heating plant in place for the requirement. All costs of a new BCS installation would be compared to all the costs of installing and operating (i.e. initial and annual costs) an alternative such as an oil boiler.

2. *Retrofit Construction*. There currently is a conventional heating system (say an oil burner/boiler) in place. All costs of a new BCS installation would therefore be compared only to fuel oil savings. The oil system initial costs have been made already and therefore are not considered. Only annual costs should be compared to those of the BCS. The analysis becomes further complicated if the initial cost of the BCS is reduced because the existing oil boiler could be used as a peaking/ backup unit and the existing heating distribution system is used. On the other hand, if the existing oil unit is due for replacement, then analysis would assume heating plant costs for both the BCS and the oil system.

Annex 3 shows an example of an analysis for a BCS and an oil alternative that is being installed to heat a new warehouse and an existing home. The assembled initial costs for the alternative oil system include a new boiler for the warehouse but no cost for a home furnace (since it already exists).

Once the situation is defined, an economic analysis should be undertaken. For the comparison to be fair, a time frame of 10 or 15 years should be set. This way, the lower annual costs of the BCS and the lower initial cost of the conventional system can be properly compared.

It will probably be necessary to carry out an analysis at various stages of the project life as cost and design information becomes more available and attains greater accuracy. In the early stages, a conceptual "back-of-the-envelope" design for the heating plant and distribution piping is carried out. A manufacturer gives a "rough price" for manufacture and installation. A local forester gives the cost of waste wood from a local mill. An oil boiler representative gives an estimate for installation of their system and an estimated cost of fuel based on what the heating load might be. The above information would be sufficient to do a preliminary feasibility assessment comparing a BCS with an oil alternative. This assessment is often called a "pre-feasibility" analysis. A **computer tool** called **RETScreen™** is available from Natural Resources Canada for quickly carrying out a pre-feasibility analysis of a BCS (see **Chapter 6** on RETScreen™). The next section presents basics of economic analysis.

Economic Analysis of the Options

This section does not intend to give instruction on how to carry out economic analysis. The conduct of a thorough analysis is best left to experts. Rather, it will convey basic concepts to allow the uninitiated to speak with some authority and understand the meaning of the results.

The first step in an economic analysis is to summarize the costs on a regular, generally annual, basis. Start with the initial cost, and lay out annual costs, year by year, over the entire expected life of the project. This is called the *life-cycle cost stream*. It is always wise to consider the full lifetime costs of a project, not just its initial costs. For example, the initial costs of a BCS are generally higher than an oil boiler system (as shown in the example in **Annex 3)**. Comparing only initial costs would suggest the purchase of the oil option. A full *life-cycle analysis* on the other hand would also consider annual costs over an extended period of operation. Because of relatively high fuel oil costs, one would likely see that the BCS was the least-cost option <u>over the full project life</u>.

In this example, it should be noted that distinct cost fluctuations are shown for the BCS and its alternative. In short, one can say that the goal of an economic analysis is to present these fluctuations in terms of common, easily understood factors.

Simple Payback

Simple Payback tells how many years it will take, if one implements the BCS project, to break even with the costs of the alternative system. The payback year is found by accumulating the initial and the annual costs each year up to the year when total BCS costs equal total alternative system costs.

The simple payback, although easy to understand and calculate, is sometimes misleading. For example, it generally reports only the first year when cumulative costs of the BCS and the alternative are equivalent. The performance of the two systems is not compared beyond this. Simple payback does not account for high extraordinary costs that might be required, say for maintenance or parts replacement. In other words it doesn't effectively compare the full *life-cycle* of the project. A second problem is that it does not account for the time value of money. Economists account for the time value of money by *discounting* future values that are expressed in today's values. See the box *Net Present Value* for one method of overcoming the problems inherent in simple payback.

Net Present Value

Net Present Value (NPV) gives a more accurate means of comparing alternatives over simple payback. It represents the net or difference of costs in the life-cycle streams of the BCS and its alternative. It does this, however, by first *discounting* future expenditures so that as a dollar is spent its value becomes less and less the further the expenditure occurs from the present. Money today has more worth than that of the future. Economists account for the time value of money by *discounting* future values that are expressed in today's values. For a project to be economically viable, its *net present value* has to be *positive. Net present value* is a more realistic term of comparison for heating alternatives than simple payback because on one hand it takes into account total *life-cycle* expenditures while on the other hand it appropriately *discounts* future expenditures so that they are valued less than those made before them. In an example given in **Annex 3** the *discount rate* used is 10%. It compares the NPV for the BCS and the oil alternative cost streams. It shows that total life-cycle costs, discounted, for the BCS are less than for the oil alternative. This indicates that the BCS project should be the preferred heating option. Note that without taking this life-cycle approach the oil alternative, based only on its initial cost, would have been preferred as an option.

The first common term is *simple payback* (see the Box **Simple Payback**) which expresses the number of years you would have to wait before the BCS investment would be paid back out of fuel savings. For an investor, the least amount of time before payback, the better.

The second term is *net present value*, or NPV (see box **Net Present Value)** a more complicated value, which expresses the **net** (or difference) of life-cycle costs of any two projects (say a BCS and its alternative). When the NPV of a BCS project is positive, then its total life-cycle costs are lower than the costs of its alternative.

In any project there will be uncertainty:

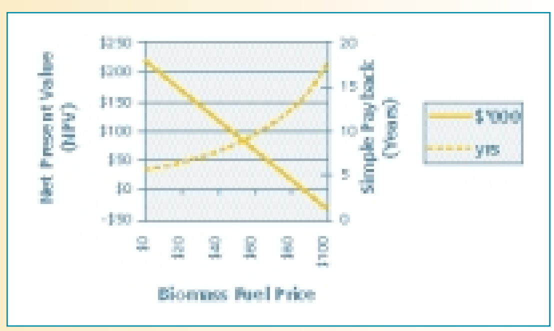
- Future biomass costs may be unknown or be expected to fluctuate;
- One may be uncertain about which discount rate to use (i.e. how much will a dollar be worth ten years from now?);
- A new road into the community may or may not reduce oil prices considerably; and
- Future fossil fuel and electricity prices may change.

To account for these uncertainties, economists use *sensitivity analysis.* Inserting high and low values for example, of expected biomass prices, will give two NPV values to compare. The sensitivity analysis will tell the attractiveness of the BCS project under the two biomass cost scenarios and possibly those in between; it tells what biomass price one can afford to pay to still make the project viable compared to the oil alternative. Sensitivity analysis is a powerful tool for helping assess the risk of uncertainty and for indicating its impact on the economic viability of the project. The box **Sensitivity Analysis** shows the results of a sensitivity analysis carried out for a school and attached buildings in a remote community. In this case, the proponent was uncertain about the cost of biomass fuel and so tested the attractiveness of the BCS option under a range of biomass costs.

Economic analysis works well when dealing only with costs. It does not take into account indirect benefits that have no direct financial value. A BCS can provide indirect financial benefits, for example, by removing unsightly waste biomass, by creating jobs locally, or by replacing fossil fuel emissions. Remember these potentially important benefits when examining the economic analysis.

Sensitivity Analysis

The graph below shows the result of a sensitivity analysis. The analyst wanted to understand what effect changing biomass costs would have on the life-cycle performance of a BCS project (compared to an oil alternative). Results show that even with the cost of biomass at zero the payback was at 6 years and NPV was $220,000. At costs of $60/tonne, payback occurred at 10 years, and NPV was reduced to only $75,000.



CHAPTER 6:
Next Step - RETScreen™

In parallel with or as a complement to this Guide, the use of the RETScreen™ Renewable Energy Project Analysis Software is strongly recommended. RETScreen™ is a standardized renewable energy project analysis software. It helps the user make appropriate inputs for designing and costing a BCS project in most situations where space and water heat are the primary loads. It returns a range of financial indicators for assessing the viability of your project, which include *simple payback* and the *net present value* of total savings. Output also shows a yearly cash flow of how savings would accumulate.

The user-friendly software assists the user in identifying where to make inputs and suggests acceptable value ranges. An accompanying manual provides a detailed description of the RETScreen™ software as well as a substantial background on renewable energy technologies.

RETScreen™ carries out preliminary analysis of renewable energy projects anywhere in the world, including:

- **Wind energy;**
- **Small hydro;**
- **Photovoltaics;**
- **Biomass heating;**
- **Solar air heating;**
- **Solar water heating;**
- **Passive solar heating; and**
- **Ground-source heat pumps.**

RETScreen's **Biomass Heating Model** can be used to evaluate projects, from larger scale developments for clusters of buildings to individual building applications, anywhere in the world. Three standard worksheets (Energy Model, Cost Analysis and Financial Summary) are provided in the biomass heating project Workbook file. A Heating Load sub-worksheet is provided to estimate the heating load for the potential biomass heating system.

The latest version of RETScreen's **Biomass Heating Model** incorporates an on-line weather database and an on-line product database (including BCS available in Canada with manufacturers' points of contact).

The entire program (written on Microsoft Excel), the user manual and supporting worldwide databases showing location-specific climate information and other pertinent data is available **free of charge** at **http://retscreen.gc.ca**.

CHAPTER 7:
Definition of Terms

Air-dry: Material (usually wood) that has lost moisture from exposure to ambient air. Typically results in a moisture content below 20% but can be as low as 15%.

Backup Boiler: A duplicate energy system, usually fired with fossil fuel, that supplies the heating load when the primary biofuel system is out of service.

Baseload: A minimum steady energy requirement.

Bio-fuel: Biomass (or materials derived from biomass processing) that are utilized for generation of energy via combustion. Most commonly solid lignocellulosics.

Biomass: Complex polymers composed primarily of carbon, hydrogen and oxygen that have been created by metabolic activity of living organisms.

BTU: British Thermal Unit, a standard unit of energy that is equivalent to the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Char: The mostly carbon solid residue that remains when biomass volatiles are driven off during pyrolysis.

Cogeneration: The practice of simultaneously producing both electric energy and thermal energy from a single combustion system.

Combustion Efficiency: The ratio of energy released during combustion to the potential chemical energy available in the fuel.

Combustion Gases: The exhaust gases produced by burning the fuel. Composed of chemical reaction products (CO_2, H_2O, NO_x, SO_x) plus water vapour and the non-reacting air components (N_2).

Commissioning: A period of operation to establish that a new system can meet the performance specifications laid out in the purchase contract.

Cyclonic: See Suspension Burner.

Day Bin: An intermediate fuel storage bin with sufficient capacity to automatically fuel the combustor for a selected period of time (often one day or one shift).

Discount Rate: An interest rate that reflects the financial return that a system's owners could achieve if their funds were invested elsewhere.

District Heat: An energy supply approach in which a centrally located combustion system provides hot water or steam which is piped to a number of separate buildings located in the general area.

Fluid-Bed Combustor: Fluid-bed combustors burn fuel particles with a wide range of sizes and moisture contents (up to 65%) in suspension within an air-dispersed bed of inert granular material, usually silica sand. Combustion air is injected through nozzles in the chamber base while fuel is either injected into the bed, or dropped onto the bed surface. The sand particles act as a heat reservoir and provide direct conduction rapid heat transfer to the fuel while the vigorous bubbling and mixing action of the fluid bed provide excellent fuel mixing and turbulence for effective combustion. Large particulates (and sand) disengage in a freeboard above the bed. Fluid-bed combustors are noted for high capacity but have low turndown ratios and high particulate emissions.

Gasification: The conversion of a feedstock to a combustible gas (with negligible char residues). The gas can then be used as a fuel.

Gasifier: A fully automated biomass combustor system that uses the products of gasification as a fuel. Gasifiers have mechanical fuel delivery from a storage bin to the refractory lined gasification chamber where partial combustion (usually of the char) generates sufficient heat to cause volatilisation of the incoming fuel. The hot fuel gases are ducted to a low energy gas burner which fires cleanly in the boiler combustion chamber, maintaining radiant heat transfer. Gasifiers can be close-coupled with natural gas and oil boilers as a retrofit. These conventional fuel boilers normally have no provision for fly ash collection, have a relatively small combustion chamber, and rely on significant radiant heat transfer. While some gasifiers can operate on wet fuels, the small-scale units that have been used to successfully retrofit existing boilers typically utilise dry, particulate wood residues. Gasifiers are often a better choice than conventional boilers for biomass conversion of conventional boilers because direct biomass firing can lead to a large de-rating and often to major problems with tube fouling. While a gasifier plus close-coupled boiler and a multiple chamber combustor are similar in general operation, there is a basic distinction based on the proportion of total air supplied in the first stage. In a gasifier, minimal air is supplied to avoid combustion of the volatiles. As a result, the fuel gases produced have a heating value sufficiently high that they can be cooled, ducted to a separate unit and then ignited and burned with a self-sustaining flame. In a pre-combustor more air is supplied and partial combustion of the volatiles occurs. This reduces the heating value of the gases produced such that they must be burned hot in a continuation of the combustion process started in the primary chamber.

Grates: The mechanical surfaces that support the burning fuel bed. May be metal or refractory, flat or sloped, stationary or moving and typically contain air passages through which underfire air is forced upward into the combustion zone.

Hammermill: A mechanical device using rotating hammers and stationary anvils to smash, crush and tear large biomass pieces into smaller fragments.

Heat Exchanger: Typically a grouping of parallel metal surfaces that maintain separation between two fluids while transferring heat from the hot fluid to the cooler fluid. In combustion systems, thermal energy is transferred from the hot exhaust gases to a heat transfer fluid that can be water, air, thermal oil or an antifreeze solution.

Higher Heating Value (HHV): The maximum potential energy released during complete oxidation of a unit of fuel. Includes the thermal energy recaptured by condensing and cooling all products of combustion. As HHV varies with moisture content, HHV should only be presented in conjunction with moisture content.

Hog Fuel: Biomass fuel that has been prepared by processing through a "hog" – a mechanical shredder or grinder. If produced by primary forest industries, it usually consists of a mixture of bark and wood often with sawdust, shavings or sludge mixed in and is generally wet and fibrous with a high ash content. Also produced from secondary materials such as pallets, construction or demolition wood yielding a dry, mostly wood fuel but often with significant contaminant inorganics.

Lignocellulosics: Biomass that is composed primarily of cellulose and lignin. Typically the structural component of plants, created by photosynthetic activity.

Live Bottom Trailer or Bin: Also walking floor van. A self-unloading trailer or van that utilizes hydraulically operated floor segments, which move the biofuel out the rear doors. Can be parked at a receiving conveyor and used as a metering storage bin. A bin may also have a live bottom for fuel reclaim.

Lower Heating Value (LHV): The net energy released during oxidation of a unit of fuel excluding the heat required for vaporisation of the water in the fuel and the water produced from combustion of the fuel hydrogen. $LHV = HHV - 21.998(H) - 2.444(W)$.

Mill Residues: The non-merchantable wood and bark components produced at the plant site during processing of logs into conventional forest products.

Moisture Content: The weight of water in a unit of biofuel, usually expressed as a percentage of the total sample weight.

Particulate: Very fine solid particles, typically ash plus unburned carbon that are entrained by the combustion gases and escape to atmosphere. Usually the main air pollutant from biomass combustion.

Pneumatic: Operated by or containing compressed air.

Pyrolysis: Chemical decomposition by the action of heat.

Refractory: A high temperature masonry (firebrick) used to line combustion chambers. It acts as a heat sink to reflect and re-radiate heat back to the fuel bed to support pyrolysis and combustion.

Rotary Valve: A set of rotating pockets that mechanically pass solids while preventing excessive return flow of gases. Used on fuel systems to prevent burnback or for metering and on multiclones to dump fly-ash without air entry. Also known as rotary airlock.

Roundwood: Logs, bolts or other sections cut from the boles or large branches of trees.

Scotch Marine Boiler: The traditional Scotch Marine package boiler used for oil or gas firing has been modified to permit semi-suspension firing of particulate biofuels. The units consist of a large horizontal water-filled tank encasing multiple fire-tubes for heat transfer, plus a single large combustion tube near the bottom. For biofuels, the combustion tube is fitted with a simple fixed grate and lined with refractory. Fuel particles are pneumatically conveyed to the top of the boiler into a cyclonic drop-tube which injects the fuel down into the combustion area. Fine particles burn in suspension, utilizing the conveying air for combustion while any larger pieces drop onto the grate where combustion is completed with forced under-grate air. The hot combustion gases pass from the end of the combustion tube into a plenum, turn 180˚ to pass through one bank of heat exchanger tubes, then turn again for a final pass down the length of a second horizontal tube bank. Coarse particulate is collected by an internal multiclone often with fly-ash re-injection. An induced draft fan moves the exhaust gases to the stack.

Seasonal Efficiency: The ratio of delivered useful energy relative to the input potential fuel energy determined over a full heating season (or year).

Stack: The vertical duct (steel or masonry) that carries exhaust gases from the boiler room for dispersion to the atmosphere. Also called chimney.

Staged-combustion: A system design that separates the combustion process over more than one discrete chamber. This approach increases residence time for more complete combustion and lower ash carry-over.

Stoichiometric: A process that yields the component elements of a compound in a proportion represented by its chemical formula. In relation to biomass combustors, it is the process of converting fuel to combustion gases.

Suspension Burner: Relatively clean, finely-sized, dry particles are thoroughly mixed with air and burned in suspension. There are two sub-types: pure suspension and cyclonic. Pure suspension units are true “burners” in that a stable open flame (similar to a gas or oil burner flame) is created by air jets that are usually mounted in the wall of the combustor or boiler. Cyclonic suspension units have a refractory cylindrical combustion chamber into which the fuel particles and air are introduced tangentially. The long cyclonic gas circulation keeps the fuel circulating in the chamber, resulting in complete combustion of the fuel, but all ash normally exits with the hot exhaust gases. Fuel is fed to both types of these burners by pneumatic feeders with the fuel air stream forming the primary air supply.

Sustainable Forest Development: The development of forests to meet current needs without prejudice to their future productivity, ecological diversity or capacity for regeneration.

Turn-down Ratio: The numeric ratio representing highest and lowest effective system capacity. Calculated by dividing the maximum system output by the minimum output at which steady, controlled, efficient, pollution-free combustion can be sustained. For example, a 4:1 turn-down indicates that minimum operating capacity is one-quarter of the maximum.

Turnkey: A purchase/installation/start-up contract in which one supplier has complete responsibility for all aspects of the system. The owner receives the key to a complete operating system that has undergone tests to demonstrate that performance specifications have been met.

Volatiles: Organic vapours and gases released from biomass during low temperature heating. Also, that portion of biofuels that is converted to vapours and gases during pyrolysis (all components other than residual char).

Wastes: Materials resulting from human activity for which no immediate use exists and which must normally be disposed of.

Whole-tree chips: Chips produced by the processing of whole trees, tree tops, branches or brush through a chipper. Composed of wood, bark and often foliage.

ANNEX 1:
Biofuel for a BCS

A1.1: Biofuel Delivery Options

Dump Truck:	A dump truck (trailer or container truck) self-unloads onto the ground, into a receiving pit or directly into a below ground storage bin. Advantages of this approach are very short unloading time and low-cost equipment (since trucks can be multi-use). Disadvantages are the requirement for adequate overhead clearance and safety issues associated with fuel avalanching or truck tipping when loads freeze in place.
Moving Floor:	A moving floor truck/trailer self-unloads onto the ground, into below-ground storage or into a receiving trough. Advantages include a controlled unloading rate that can be set to match the take-away system capacity and the opportunity to leave a trailer on-site as a storage/metering bin. Disadvantages are a longer unloading period and the high capital cost for a relatively dedicated-use system.
Front-end Loader:	A standard truck/trailer with full opening rear doors can be backed up to a loading dock and fuel scooped out by small bucket loader. Costs of this approach are relatively low if an on-site loader is already available, but unloading time is long and an operator is required.
Pellet Delivery:	The improved flow properties of prepared fuels such as pellets or corn permit greater flexibility in delivery system options. Self-unloading options include belly-dump trucks and units fitted with auger, belt or pneumatic conveyor systems mounted on the truck. Pellets are also delivered to small systems in bulk bags, unloaded by a truck-mounted boom or a front-end loader.

A1.2: Biofuel Types for a BCS

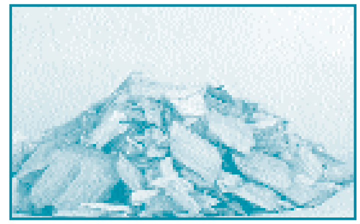
The list below does not consider agricultural wastes. Refer to it for wood waste examples.

Whole wood / split wood / round wood: This type precludes automatic handling and feeding systems. Some farm installations use splitwood which is cut from on-site woodlots. Similarly, small wood industries may manually feed process cut-offs to an industrial combustor which is equipped with a large firebox door, often as supplementary fuel, in addition to the automatic feeding of a base biofuel. Newer unitized outdoor boiler designs use this fuel.

Whole Tree Chips (WTC): WTC are produced by forcing solid wood against a set of rotating knives that successively cut off chips, typically to dimensions of 1/2 to 1 inch (1.27 to 2.54 cm) wide by 1 to 3 inches (2.54 to 7.62 cm) long by 1/4 inch (0.64 cm) thick. Chips are generally produced from forest residuals including slash, silvicultural removals and land-clearing materials. In this case WTC are blown directly into tractor trailer vans for delivery to customers or central storage. Alternately, WTC may be produced by a forest products industry on-site as a way of handling processing waste. Whole tree chips represent a mixture of solid wood, bark, twigs and foliage.

WTC are normally a fairly consistent, high-quality fuel if produced in the forest. If WTC are produced from processed wood, waste quality (i.e. high ash and low energy) may be inconsistent. They have a relatively high moisture content (MC) (40% to 55%) and may contain a high level of contaminant dirt if the slash has been dragged to a central processing area.

Major problems can be a high content of oversize pieces (splinters, twigs) that restrict flow and jam augers, or excessive moisture (and large frozen chunks) from ice/snow accumulation in the chips. Freezing and clumping can also occur in storage. Chip quality can be ensured by good operation and maintenance procedures with respect to collection, chipping, storage and delivery.

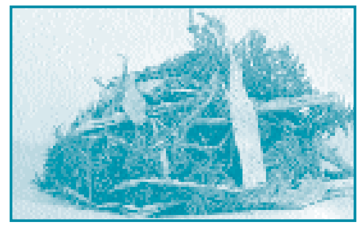


Biomass Fuels : Chips

Hog (hogged fuel): A "hog" (shredder, tub grinder, etc.) uses rotating hammers and stationary anvils to smash, crush and tear large wood into smaller fragments. Maximum output particle dimension is less than 3 inches (7.62 cm).

Raw materials that are hogged include: debarker residues, log and sort yard debris, cull and trim, land clearing debris (brush, stumps, etc.), municipal yard wastes (brush, leaves, branches), industrial packaging (pallets, boxes, crates), and construction/demolition wood wastes. Typically clean wood is chipped while low value dirty materials are hogged. Hog fuel from sawmills often includes sawdust, shavings and chip fines mixed with the hogged bark and trim, while hog fuel from a pulp mill woodroom may contain clarifier sludge.

In general, hog fuel is more difficult to handle than WTC since it is more fibrous, has a lower bulk density and contains a wide range of particle sizes. Moisture content is usually high and the ash content can be significant (from 2% to 3% to as high as 20%). Since the quality and component mix of hog fuel can vary considerably, it is important to clearly define specifications when contracting for a supply of hog fuel.

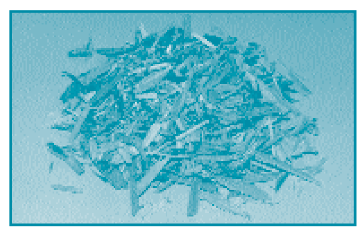


Biomass Fuels : Forest Residue

Biomass Fuels : Bark, Sawdust

Particulate: This broad category covers a variety of small diameter biomass particles that occur as by-products or residues from conventional processing operations. Wood based materials include: sanderdust, sawdust, shavings and chip fines. Agricultural based materials include: rice hulls, grain screenings, fruit pits, nut shells, coffee grounds, etc.

The particle size can therefore vary from dust to larger sizes such as peach pits and the MC from very low (2% to 3%) to very high (55% to 60%). Ash content also can be low (0.3% to 0.5%) to relatively high (7% to 20%). Thus, some particulates are high-quality premium biofuels that can be burned in suspension with flame characteristics and efficiency similar to that of fuel oil, while others are low-quality fuels that require special combustors to handle the high MC and/or ash levels. Very dry particulate fuels present a dust hazard with potential for fire or explosions.



Biomass Fuels : Hogged Fuel

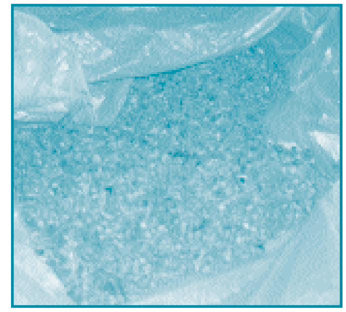
Prepared: The most common form is pellets which are typically 1/4 to 5/8 inch (0.64 to 1.59 cm) in diameter by 3/8 to 1-1/4 inch (0.95 to 3.18 cm) in length and are produced from wood, bark, straw, paper, leaves, and other biomass material. MC is typically below 8% with ash content a reflection of the feedstock ash level. Pellets flow readily and can be easily metered by small diameter augers. As a result of the low MC they can be electrically ignited for fully automated start-up.

Less common are the similar composition but larger sized cubes (1-1/2 x 1-1/2 x 3 to 5 inches, 3.81 x 3.81 x 7.62 to 12.70 cm) and briquettes (1-1/2 to 4 inches [3.81 to 10.16 cm] in diameter x 1/2 to 3 inches [1.27 to 7.62 cm] in length).

As a consequence of drying, grinding and high-pressure fusing, these dense prepared biofuels are costly.

Bales represent a further class of prepared biofuels. Typically agricultural field residues (straw, hay, corn stover, sunflower/soybean stalks, etc.) can be prepared by field drying, collection and compression into large square or round bales, or conventional small rectangular bales. Special combustors have been designed to operate on manually or automatically fed whole bales or to progressively shred bales before feeding into a combustion chamber.

Prepared fuels have the benefit of uniformity – of size, and of energy, moisture, ash content – Their major drawback is higher cost.



Biomass Fuels : Fuel Pellets

A1.3 Comparing Determinants of Delivered Energy from Biofuels

Biofuel Type	Moisture Content % Wet Basis	Ash Content % Dry Basis	Combustible Content kg of Dry, Ash Free Combustible per kg of As-Fired Fuel	Higher Heating Value (HHV) MJ per kg of Dry Ash-Free Combustible	Appliance Efficiency % Based on HHV of Combustible	Delivered Energy MJ per kg of As-Fired Fuel
Whole Tree Chips (green, softwood)	50	1.2	0.494	20.9	62	6.4
Chunk Wood (air-dry, hardwood)	20	0.8	0.749	19.6	73	11.4
Sawdust / Shavings (kiln-dry, hardwood)	8	0.5	0.915	19.5	76	13.6
Straw (air-dry)	15	6.2	0.797	19.4	74	11.4
Pellets	7	1.0	0.921	20.7	76	14.5

A1.4: Biofuel Source Categories and Importance to Fuel Cost

Wastes: (negative cost)	Wastes represent an opportunity for a source of low-cost biofuel. Many materials classified as wastes are delivered to regulated landfill sites where a tipping fee is imposed, for example, the wood component in municipal solid waste (MSW), demolition debris, construction residues and even log/sort yard debris. In built-up areas where the fee is high, it is often possible to cover the costs of separation/collection, handling/preparation and delivery by avoiding landfill costs. If the material is generated on-site, the savings in disposal costs actually represent a negative fuel cost.
Residuals: (no cost)	Residuals represent a no-cost, directly available biofuel source. An example would be bark residues from a small sawmill where there is no disposal requirement or cost but there are no alternative uses. The producer is often open to a biofuel user simply removing the material, free of charge. The cost to the user is minimal, involving only the transportation expenses. Another category of residuals is that of the available, no-charge material, but with some preparation required in addition to transportation. These would be agricultural residues (straw, stover) and forestry landing slash piles. The owner does not require payment but a cost results from the collection/preparation/handling and delivery.
By-products: (low cost)	By-products are biomass materials that are readily available, do not usually require extensive preparation, but do have low-value alternative uses such that the owner can demand a minimal payment for the material. The supplier may also include delivery in the purchase price. Examples are sawdust and shavings from small sawmills located remote from conventional wood processing facilities.
Produced Fuels: (moderate cost)	These are materials that have undergone specific processing operations that were applied only because the raw material was selected for use as a fuel. Within this category are two groups: harvested and purpose-grown materials. The main example of harvested fuels is whole tree chips produced from available forest stands. Often low-quality trees are harvested and chipped for dedicated use as fuel. While there may be secondary benefits, such as replanting with superior species, the primary objective is fuel production. Also included are natural perennial crops such as marsh grasses and cattails. Purpose-grown crops are planted, tended, harvested and processed specifically as biofuels. Examples include: hybrid poplar and willow plantations or sorghum, switchgrass, and elephant grass.
Prepared Fuels: (high cost)	Prepared fuels are the most expensive, often exceeding the cost of fossil fuels on an energy basis, but the lower capital and operating costs for the combustion system have sometimes allowed their use in niche markets where other factors, such as security or aesthetics, are considered. The prime example is densified fuels such as pellets or briquettes, but corn kernels and grains are often classified as prepared fuels.

ANNEX 2:
A Discussion of Efficiencies

A2.1: Combustion Efficiency

Combustion efficiency is a measure only of the completeness of fuel combustion that takes place in the combustor chamber. If combustion is not complete, not all of the energy potentially available is released and the non-combusted components are released as undesirable pollutants or remain as char. The requirements for complete combustion include a sufficiently high temperature, adequate time for oxidation reactions to be completed, and sufficient air turbulence to deliver adequate oxygen to the fuel. These requirements are met by effective design and operation of the combustion chamber. Normally, BCSs have high-combustion efficiencies with only small losses from incomplete combustion. Because combustion efficiency is the highest efficiency value, it is popular with sales persons and manufacturers who often incorrectly portray it to be overall appliance efficiency (see below).

A2.2: Appliance Efficiency

Appliance or steady state efficiency is relatively easy to measure since it compares the thermal energy output from the heat exchanger (the energy transferred to the heat exchange medium) to the higher heat value of the fuel input when the system is operating at a set constant rate. Factors affecting steady state efficiency include: the efficiency of combustion, excess air levels, fuel ash content, fuel moisture, stack temperature and radiation losses. Fuel ash and moisture content are operating variables that can have an impact on efficiency. When comparing BCS efficiency claims, be sure that fuel types and moisture contents are also comparable.

Excess Air: A specific amount of theoretical air is necessary to provide the oxygen required for complete combustion of a specific mass of biofuel.
Any air in excess of this creates a loss by absorbing energy as its temperature is raised to that of the flue gases exiting the system. In practice, mixing of air and fuel is never perfect and a certain level of excess air is maintained to ensure complete combustion. The lower that the excess air level can be maintained without reducing combustion efficiency, the higher will be the appliance efficiency.

Fuel Ash: The fuel ash is also heated in the combustor and removed at an elevated temperature thus creating a small thermal loss.

Fuel Moisture: A significant reduction in appliance efficiency results from the fuel moisture. The energy required to vaporize the moisture in the fuel (plus the water produced from oxidation of the fuel hydrogen) and raise its temperature to that of the stack gases is not recovered in the heat exchanger.

Stack Temperature: The thermal energy liberated from fuel combustion is transferred directly by radiation or by the flue gases to the heat exchanger surfaces. Heat that is not extracted in the heat exchanger is lost up the stack. The lower the exhaust temperature the lower is the heat loss. However, too low a stack temperature can lead to condensation of flue gas moisture in the stack causing corrosion, and/or ice blockage as well as insufficient draft in natural draft systems. Stack temperature is controlled by effective system design and optimized system controls. Over time, ash/soot builds up on the heat exchanger surfaces, reducing the effectiveness of heat transfer and producing higher stack temperatures (and lower efficiency). Surfaces must be cleaned, either manually or by automated soot blowers, to restore heat exchanger effectiveness. Monitoring of stack temperature is often used to regulate frequency of tube cleaning.

Radiation Losses: Radiation losses from the combustor, heat exchanger, stack and ash conveyors/storage can contribute to efficiency losses. If the BCS is located within an area that requires heating, radiated heat can be utilized and therefore is not a loss. These are not typically included in tests to determine steady state efficiency.

A2.3: Seasonal Efficiency

Seasonal efficiency is the ultimate determination of a system's effectiveness. It represents the ratio between the total useful energy actually delivered to the thermal load over a full operating season and the total potential energy within the fuel burned over the period. Seasonal efficiency is affected by many factors external to the actual combustion system (appliance) efficiency. These include such factors as location of the boiler, fuel quality and variability, effectiveness of the insulation on the heat distribution piping, frequency of system cycling between high and low loads, etc. Because of this, seasonal efficiency depends on a given site and application, and can vary considerably between installations using identical BCSs.

ANNEX 3: Cost Assessment

A3.1 A BCS Case History

ABC Industries is installing a new warehouse and office building (800 m^2) in the yard adjacent to the owner's home. For the climate of the region, the structure will have a design heat load of 105 W/m^2. The owner has had bids from an oil boiler representative and a supplier of BCS systems to install heating systems. The oil boiler (150 kW capacity) would be installed in one corner of the warehouse. The BCS (160 kW capacity) would have its own corrugated steel shed constructed with an adjacent covered fuel storage platform. Heat to the warehouse and office would be supplied by in-floor piping through which hot water would flow. The BCS would also provide a hot water loop to the owner's home, replacing the need for the existing oil furnace. Neither system would use a backup system (although the oil furnace would be kept in the owner's home even when BCS heating replaced it). The BCS would not use an oil peaking boiler.

The bid on the oil boiler system is $19,000. This includes all design, engineering and installation costs, the burner, a boiler, a chimney, oil storage tank, pumps and plumbing (up to the heat distribution network in the buildings) and controls.

The bid on the BCS is $72,000. This includes all design, engineering and installation, the combustion unit, a boiler, a chimney with ash clean out, pumps and plumbing (up to the heat distribution network of the buildings), fans and motors, fuel feed system, fuel storage day bin, fuel storage long-term (a covered concrete pad), a shed with steel cladding (10 m x 5 m) with foundation, a water-to-air heat exchanger for the house and system controls.

The distribution piping and heat exchange system for the warehouse/office is a cost common to the two heating options and so need not be included in a comparison.

The owner knows he currently pays about $530 a year (1000 L of fuel oil @ $0.53/L) for home heating. The oil boiler representative estimates ABC would require 30,700 L of fuel to heat the warehouse and office. Electricity for fans and pumps is estimated as $300/year. Apart from the cost of oil, operation and maintenance of the oil system would likely only be about 5% of capital cost yearly. The BCS supplier estimates ABC would use about 165 tonnes of mill waste each year to heat all the buildings and about $400 of electricity a year for fans and pumps. Apart from this, the cost of operation and maintenance, which includes loading fuel into the day bin once a day and regular ash clean out/disposal (the ash would go to local gardens nearby), is about 10% of capital cost yearly. The owner expects to provide much of the labour needed for free.

The owner lives about 10 km from a small sawmill that produces large quantities of waste wood. Currently they are using some for heating their operation's buildings, but the majority is chipped and disposed of at a local landfill at a cost of $15/tonne. The sawmill owner agrees to supply ABC with delivered chipped mill residue on a long-term basis for $8/tonne.

A3.2 Assembling Costs

As discussed in **Chapter 5**, the first step in comparing the two systems is to assemble costs. The owner has done this in the table below. The table assembles both the initial and the annual costs of the two options. The Guide provides a detailed checklist of costs at the conclusion of this Annex as a handy way for a first time buyer to assemble costs.

Cost Items	**BCS Costs**	**Oil Boiler Costs**
INITIAL COSTS		
a) Feasibility study (owner's cost)	$800	$200
b) Complete installed cost	$72,000	$19,000
c) Contingencies (add 10%)	$7,200	$1,900
Total	**$80,000**	**$21,100**
ANNUAL COSTS		
d) Operation and maintenance	$8,000	$1,055
e) Energy		
Biomass	$1,320	—
Oil	—	$16,800
Electricity	$400	$300
Total/year	**$9,720**	**$18,155**

a) The BCS feasibility study requires higher costs than the oil system since the owner must devote more research on fuel supply, etc. for the BCS.

e) Biomass: 165 tonnes x $8 /tonne

Oil: $530 + (30,700 x $0.53) – Note: Oil fuel cost for the house is included.

The table above shows that the initial cost of an oil system is about 75% less than a BCS. One can see however that the annual running costs are about 90% more for the oil system over the BCS. How do these low annual costs effect the *life-cycle* cost comparison of the two options taking into account the *present value* of future expenditures? Will the *net present value* (being the present value *life-cycle costs* of the oil boiler less the life-cycle cost of the BCS option) be negative or positive? If it is positive the *life-cycle costs* of the BCS are less than the oil system.

A3.3 An Economic Comparison

To answer these questions, the owner hired a local engineering consultant to carry out a life-cycle analysis. The owner found that with a $5,000 down payment, he was able to obtain a 10-year loan for either the BCS or the oil system at a 6% interest.

The consultant recommended a discount rate of 8% over a project life of 20 years. He found that NPV = $29,000. In other words, taking a life-cycle approach showed that a BCS could provide considerable savings over a longer term and rapidly pay back the investment. This would not have been the conclusion if the owner had only compared the initial costs of his options.

The foregoing analysis has not taken into account any existing government programs in place or the tax implications of purchasing a BCS. These could favourably affect (or at the least be neutral to) the economic advantage of BCS over a fuel oil system.

To prepare a financial evaluation of BCS project see RETScreen™ (chapter 6).

CASE HISTORIES

1 Opeongo Forestry Services

Opeongo Forestry Services, located in Renfrew, Ontario, is a producer of high-quality kiln-dried speciality lumber. They use an electric dehumidifier kiln system for which the supplementary heating was previously supplied by a manually fed slab burner. To reduce operator attention and increase the use of excess wood residues, an automated auger fed biomass-fired hot water boiler and heat distribution piping was installed in late 1997. This system now supplies process energy to the two kilns plus space heating for the sawmill and lumber storage shed.

Heat Load

Process heat is required to maintain a 35°C temperature in two 40,000-board foot lumber drying kilns. Peak load is about 73 kW. Space heat is also provided for the lumber storage shed and the sawmill, a seasonal load with peak requirement of about 59 kW.

Fuel Supply

The sawmill operation produces about 1500 tonnes per year of waste wood with a disposal cost estimated at $17/tonne. Between 200 and 300 tonnes of chipped slabs (pine plus several hardwood species) are used as biofuel each year. Fuel moisture content (MC) varies with the season, but is estimated to average about 50%.

System Description

The combustion system was designed and manufactured by Grove Wood Heat of PEI Design. Capacity is 146 kW based on a fuel MC of 20% to 30%; average operation has been estimated at 103 kW on 50% MC chips.

Wood chips are fed from a day storage bin by a screw auger to the fixed-grate primary combustion chamber. Under-fire air is supplied for char combustion, which creates the high temperatures necessary to gasify the incoming biofuel. The burning gases traverse a refractory lined duct to a secondary combustion chamber where a thermostat-activated damper regulates secondary air to control combustion temperatures. Solid wood chunks can be manually fed to the secondary chamber if required.

Heat is recovered by the water heat transfer medium from the top of the primary combustion chamber and from a fire-tube boiler located above the secondary combustion chamber. Insulated piping carries the hot water to heat exchangers in the kilns and storage shed, while a glycol loop distributes heat within the concrete floor of the sawmill shed.

Economics

Capital costs for the biomass system were approximately $41,200; $21,000 for the BCS equipment, $5,000 for the building, $5,500 for auxiliary equipment and $9,700 for procurement, transportation and installation. The capital cost for a comparable fuel-oil fired boiler was estimated at $19,100.

Based on an annual energy requirement of 812 MW.h, the saving from avoided fuel-oil purchase is about $28,000 per year (based on oil at 30 cents per litre). The savings in residue disposal is about $2,000 (based on a $10/tonne saving since the wood residues must still be chipped and handled).

Therefore, the payback on the incremental cost for the biomass system was less than one year.

Summary

This system has been very successful as a result of low capital costs, a significant year round process heat requirement, and a negative cost on-site supply of biofuel.

2 Five Elms Greenhouse

Five Elms, in Memramcook, New Brunswick, has been operating a 1000 m^2 greenhouse for about 10 years, currently growing tomatoes on a year round basis. Heating for the double plastic, hydroponics operation had been supplied through combustion of about 65,000 litres per year of propane. In 1994, a 146 kW wood-fuelled combustion system was supplied by Grove Wood Heating, PEI to enable use of lower-cost, locally available biomass fuels.

Heat Load

Over 90% of the energy requirement to maintain the 18°C greenhouse temperature is supplied by the biomass combustion system with propane used to cover peaking in the coldest period of the year.

Fuel Supply

The system operates on local softwood mill residues, either sawdust or hammermilled trim, generally with a moisture content of 20% to 30% but occasionally up to 45%. Fuel is picked up when required using a dump truck with a capacity of 18 m^3 (about 3 tonnes of wood on a moisture free basis). The material is dumped on the concrete floor of the storage building, piled and reclaimed by a front-end loader. One truckload of fuel lasts about 4 days in winter, 7 days in spring/fall and up to 2 weeks in summer. The day bin on the combustor is filled regularly, up to 3 times per day during peak load operation.

System Description

A screw auger automatically feeds the fuel from the day bin to the fixed grate, refractory lined primary combustor chamber which uses forced underfire air. Operation cycles between full-fire and hold-fire modes in response to an aquastat (a type of thermostat for water) signal. Burning gases pass through a refractory lined duct to the secondary combustion chamber which has been fitted with a door for manual addition of larger biomass fuels such as chunkwood, corrugate, etc.

A hot water boiler unit integrally mounted over the secondary combustion zone extracts heat from the exhaust gases that exit through an insulated stack mounted on the unit. The heated water is pumped to the greenhouse for radiant heating via a pipe network.

Ash is removed manually, once or twice per day depending on the season, typically requiring about half an hour.

Economics

Total costs for the biomass system, including a new combustor building and the hot water heat distribution system were about $85,000. With annual maintenance costs estimated at $500 and biofuel costs estimated at about $6,000, the net yearly savings from displaced propane would be $16,500 providing a simple payback of just over 5 years.

Summary

This system's success is based on relatively low capital costs, very low biomass energy costs and the displacement of a high-cost premium fuel.

3 Ouje Bougoumou Remote Community

In 1992 the Ouje Bougoumou Cree Nation decided to install a biomass-fuelled district heating system in their new self-sufficient community located in Northern Quebec. This system, designed and supplied by KMW Energy of Ontario is located in a central boiler house and provides space heating and domestic hot water to all buildings within the community.

Heat Load

Space heat and hot water are provided to 151 buildings with an estimated peak heating load of 2.4 MW. In 1997, the system generated 8,600 MW.h of heat; 6,200 MW.h using biomass and 2,400 MW.h using oil. The hot water heat transfer system operates at variable temperature (depending on the outside temperature) to a maximum design of 90°C.

Fuel Supply

The system is supplied with wood residues, which are transported by a community-owned truck from a local sawmill. It consists of sawdust that would otherwise be landfilled. Average moisture content is about 40% to 50%.

System Description

Fuel is unloaded in a below ground fuel storage bin. A hydraulic system feeds an auger system into a metering bin prior to the combustion chamber. A reciprocating step-grate and automatic ash removal plus controlled under- and over-fired air ensure complete, efficient combustion while a multiclone removes particulate from the flue gases to maintain high ambient air quality. Heat is recovered from a fire-tube boiler located above the combustion chamber with energy output automatically controlled in response to building heat requirements. A backup oil burner and a standby generator were also installed in the boiler house.

Economics

Sawdust is purchased for $6 per tonne for an annual cost of $18,000. Residents, on average, pay $192 every two months for their heat and hot water, less than half what they would pay for electric heat. Statistics for 1997 indicate that biomass provided 72% of the energy used to fuel the district energy system, but accounted for only 10.5% of the fuel cost.

Summary

This small community system has proven highly successful based on the use of very low-cost local biomass wastes as fuel and the relatively high costs of fuel-oil in this remote community. In addition, it has provided benefits from local employment, waste utilization and the environmental benefit of greenhouse gas reduction. A further significant benefit was the contribution to the overall sense of self-sufficiency provided to the community.

4 Digby Elementary School

In 1988, a biomass combustion system was installed to provide space heating for the new elementary school in Digby, Nova Scotia. The 400 kW system was designed and supplied by KMW Energy of Ontario.

Heat Load

The biofuel unit delivers thermal energy through a hot water distribution system that can be set between 77°C and 88°C. The wood-fired unit is operated during the coldest period of winter with a full capacity back-up oil boiler used during the shoulder periods when heat demand is low.

Fuel Supply

Whole tree chips (hardwood and softwood) are purchased from a local chipper operator. The fuel, with a moisture content of about 45%, is delivered by dump trucks which unload directly into the 14-tonne capacity in-ground concrete storage bin.

System Description

Fuel is reclaimed from storage by hydraulic scrapers that dump into a screw-auger collection trough. An inclined transfer auger delivers the chips to a live-bottom metering bin. The fuel reclaim system operates in response to signals from high- and low-level indicators in the metering bin. An under-feed stoker auger forces the fuel up into the combustion chamber through the centre of a stationary grate through which primary combustion air is supplied. The system operates in low- or high-fire modes with timed fuel feed cycles.

Heat is recovered from the combustion gases in a horizontal fire-tube boiler. A multiclone collects fly ash, which drops through a rotary valve into an ash drum. An induced draft fan moves the exhaust to a central stack.

About once per week the ash is manually raked to a drop chute from which it is moved by screw auger to the ash drum. When possible, ash is used as fertilizer on the lawns. Boiler tubes are cleaned once per year, requiring about half a day.

Economics

The net capital cost for this complete system is about $195,000 (in 1999 dollars). Green chips costs have increased to $30 per tonne delivered, while fuel oil is now only $0.25 to $0.30 per litre. Other operating costs have been minor since the system is fully automated.

Summary

In this institutional setting a higher capital cost fully automated BCS was chosen over the semi-automatic one. This provides operating convenience and lower operating cost but increases the initial costs considerably. Notably, this system has been operating successfully for over 10 years although current low fossil-fuel prices and limited operator time has encouraged use of the more expensive fuel (oil) when the heating load is low.

ADDITIONAL INFORMATION

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