Choosing biomass to create heat is an option for small farm operations interested in reducing the high cost of fossil fuel hot water heating systems. Using locally produced biomass can lead to significant cost savings and support the local economy. Due to recent advances in combustion controls and improved efficiencies of the heating network, small biomass heating systems below 300 kW (1 MBTUh) have low emission profiles that make them an attractive option to consider.

This Factsheet provides information on six technologies and management options available for using small manual or automatic biomass boilers with an output power of below 300 kW (1 MBTUh). These options improve the overall safety, combustion and seasonal efficiency of biomass heating systems.

Biomass combustion: Technology options
A high-efficiency biomass boiler has advantages, compared to traditional units, that can lead to significant savings. Table 1 compares several technologies, demonstrating that some high-efficiency equipment can make a difference in cost and performance. The major development in modern biomass boilers is automation. Newer combustion monitoring controls automatically adjust the air and fuel ratio to achieve higher combustion efficiency. Other automation equipment manages the timing and volume of biomass when heat is required.

These automated technologies are important for small biomass boilers because their maintenance and operation are becoming more similar to boilers using fossil fuels such as natural gas, propane or oil. Their higher capital costs are recovered by fuel savings, increased durability, lower maintenance and simpler (automatic) operation. These benefits reduce the payback time, depending on the technology options purchased and the fuel quality used.

For a description on the different sizes of fuels compatible for automatic fuel feeding, see the OMAFRA Factsheet, *Biomass Densification for Energy Production*, available online at [www.ontario.ca/omafra](http://www.ontario.ca/omafra).

Get professional advice on the proper sizing based on heat load to obtain a lower seasonal fuel cost. A high-efficiency biomass boiler that is oversized for the heat load will consume more fuel, fail prematurely and will not be able to offset the higher capital costs over the life of the equipment.

Several technological features are currently available for small high-efficiency biomass boilers, including:

- two-stage combustion zones
- oxygen sensor
- ash management
- clinker management
- hot water storage and other methods to limit idling
- automatic biomass feeding and starting

Information about each of these features is provided in this Factsheet.

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TWO-STAGE COMBUSTION ZONES

Stricter regulatory requirements in North American jurisdictions led manufacturers to develop small biomass boilers that demonstrate higher combustion efficiencies. This was done by using more advanced burn technology and controls, which were previously only available for much larger biomass heating systems, and by separating the combustion process into two distinct stages. These newer biomass boilers use a controlled combustion air supply in two separate zones, as seen in Figure 1.

The first stage is located where primary combustion air is mixed with burning biomass. Biomass gases and heat are released from this first zone and then moved to the second zone where they are mixed with secondary air. When the correct amount of secondary air is mixed with the biomass gases (or the smoke), the additional supply of oxygen creates a high temperature flame that burns the remaining smoke and hydrocarbons. The second stage of combustion provides more heat and releases fewer emissions than a traditional single stage combustion unit. Depending on the design of the combustion chamber, the two zones can be located closer to each other, as in automatic updraft two-stage units, or in separate chambers, as in manually stoked downdraft two-stage units, as shown in Figure 1.

OXYGEN SENSORS

Oxygen sensors, also called Lambda sensors, are an important feature of a two-stage biomass combustion system because they automatically regulate the air intake. The sensor detects the amount of oxygen left in the flue gas and adjusts the combustion air supply accordingly. This allows the boiler controls to alter the air-to-fuel ratio, similar to a car’s compression-ignition engine. Application of this sensor technology results in reduced carbon monoxide and hydrocarbon emissions, as well as increased fuel savings.

For larger biomass heating systems with an output power of above 1 MW (3 MBTUh), an industrial-type sensor is recommended for its improved durability and reliability. However, for smaller biomass boilers, an integrated oxygen sensor is preferred, to allow automatic control of the air-to-fuel mixture. The integrated oxygen sensor will allow automatic adjustment of combustion air and adapt to varying fuel properties such as biomass size, moisture and volatile carbon content to achieve the optimal oxygen flue gas content. Figure 2 shows an aftermarket flue gas oxygen sensor designed for the automotive market retrofitted on a two-stage biomass combustion system. The dial shows the free air oxygen content at 20.9%. Unless activated automatically by the boiler’s controls, the operator can run the biomass boiler manually around the optimal oxygen flue gas content (5%–11% O₂), depending on the fuel used. This sensor also offers a personal computer output for data logging and analog output capability.
Not all manufacturers of biomass boilers design their systems equally. Biomass boilers that do not have automatic air and fuel controls but use two-stage combustion technologies may set the amount of secondary air at the factory.

To maintain high-efficiency combustion, factory-made combustion air settings must be re-adjusted when the type, particle size or the moisture content of the biomass varies. One way to do this is to retrofit the biomass boiler with a compatible flue gas oxygen sensor (Figure 3). The dial's digital reading allows the operator to re-adjust the secondary air supply manually.

Also shown is a flue gas Type K thermocouple installed in the boiler's chimney. This thermocouple allows the operator to make further air adjustments and control the rate of burn to maintain high combustion efficiency. A flue gas temperature above 175°C (350°F) indicates that a lot of heat is wasted through the chimney and not transferred to the boiler's heat exchanger. Cleaning dirty flue gas tubes can increase the heat transfer between the hot flue gases and the boiler's water jacket.

A flue gas temperature below 135°C (275°F) can promote condensation of smoke in the chimney and form creosote. The Guide to Residential Wood Heating, Canada Mortgage and Housing Corporation, available at www.thewoodburner.com/residential-wood-heating, identifies creosote as a highly flammable substance that is the leading cause of chimney fires.

Lower flue gas temperature can also increase the corrosion of the boiler's water jacket and lead to premature failure even when using corrosion-resistant materials.

For best operation and reduced maintenance, invest in a biomass boiler equipped with an oxygen sensor and flue gas thermocouple that is already integrated in the unit.

**ASH MANAGEMENT**

Management of the ash from a biomass boiler includes storage, cleaning and disposal. Cleaning involves emptying a storage container, which retains a small amount of ash, rather than manually opening the boiler door and cleaning the system out. On automated units, the ash storage containers are generally large enough that they do not have to be emptied daily (Figure 4).

Depending on the amount of biomass burned, the ash produced is minimal; dry wood chips produce approximately 1%–2% ash, agricultural residues 3%–10% ash, and premium grade wood pellets produce below 1%. Using specialized equipment to clean the heat exchangers is also an option for high-ash or high-moisture biomass. Usually, compressed air pushes the volatile part of the ash out the flue gas heat exchanger where it falls near the ash augers. This is important for maintaining the high heat transfer efficiency. Dirty flue gas heat exchangers decrease the ability to transfer heat to the water jacket.
CLINKER MANAGEMENT

When burning agricultural residues or high-ash and high-moisture biomass, the residue left behind with the ash can cause sediment to build up and jam or damage the grates and ash augers. The grates are used to distribute the burning biomass evenly and move the ash away from the primary combustion zone (Figure 5).

If exposed to high temperatures, ash from high-moisture forestry or agricultural residues join together and form clumps called clinkers at the end of the grates. Clinkers are managed in different ways depending upon the manufacturer and the biomass. Most common is the use of cooled grates to prevent the ash from overheating and sticking to them.

Another option, used in larger biomass systems, is to recirculate the flue gases into the primary combustion zone. This method reduces the oxygen supply and drops the temperature on the grates, preventing the formation of clinkers. Higher-combustion bed temperatures increase the formation of clinkers depending on the ash properties of the biomass. For pelletized biomass, special burn pots are designed to dump or scrape the ash to prevent the formation of clinkers.

HOT WATER STORAGE

North American–designed, manually loaded biomass boilers frequently have difficulties with operating at much lower combustion and biomass consumption efficiencies due to the large firebox design that is used to accommodate daily temperature fluctuations. Typically, heat is stored in unburned biomass in the firebox or in a large water jacket around the boiler. High-combustion efficiency outdoor boilers that are not equipped with sufficient insulated water storage can reach seasonal efficiencies as low as 25%.

European biomass heating systems are typically designed with a smaller boiler compared to the peak heat load. European boilers store excess heat in insulated hot water tanks sized to match the peak heating load. Because of the reliability and safety of these boilers, many jurisdictions have approved their installation in heated dwellings or buildings rather than outside, where they’d be exposed to cold temperatures. This practice minimizes heat loss of the boiler and hot water tanks.

Research by the New York State Energy Research and Development Authority showed that residential biomass boilers designed with a large firebox but without sufficient water storage operate inefficiently over the season. The cause is the uncontrolled combustion of biomass when there is no demand for heat. When the water in the boiler hits a pre-set maximum temperature, the air supply is partially closed, and the biomass boiler goes into idle mode until the next heating cycle. In this idle state, the large amount of excess wood in the primary combustion chamber enters into pyrolysis, releasing harmful emissions. Pyrolysis is a combustion process that occurs when a hot fire is suddenly oxygen-starved.

Smoke, condensation, creosote and corrosion can occur in manually loaded biomass boilers and flue stacks because of pyrolysis during the idle mode. The New York research shows that European biomass heating technologies and design save a sizable quantity of biomass by running the boiler in peak output and storing the excess heat in insulated water storage tanks. Acting like thermal batteries, these insulated water tanks are sized to store the expected heat demand until the next firing cycle.
European biomass heating technologies and design prevent the biomass boiler from entering the idle mode and prevent the release of smoke between firing cycles.

To learn more about the study, *Environmental, Energy Market and Health Characterization of Wood-Fired Hydronic Heater Technologies*, by the New York State Energy Research and Development Authority, go to the website at www.nyserda.ny.gov.

Heating system designers and contractors can size the hot water storage tanks to hold the excess heat by letting the biomass boiler charge them (Figure 6). This practice runs the biomass boiler at full output and at peak combustion efficiency. The cost of the hot water storage tanks is recovered by the labour and biomass savings, and the longer boiler and flue stack life.

The amount of biomass loaded into the primary combustion chamber provides sufficient heat to allow for storage of hot water for domestic use during seasons when heat is otherwise not required (e.g., summer months). A properly designed hot water storage system can store heat for a couple of days using one firing cycle of a high-efficiency biomass boiler during the summer. This operation does not require daily loading of biomass and doesn’t release smoke or create creosote between on/off cycles. This method is called batch burning, since the load of biomass stoked in the boiler burns completely.

A well-insulated water tank will keep water hot for a few days until the water storage temperature drops. The size of the hot water storage can vary from 50–70 L/kW (4.0–5.5 U.S. gal/1,000 BTUh) of boiler input power depending on winter weather for small manual biomass boilers. Since it requires approximately 1 kilojoule (1 BTU) of heat to raise the temperature of 454 g (1 lb) of water by 0.55°C (1°F), a 2,250-L (600-U.S. gal) hot water storage tank operating with a design temperature difference of 22°C (40°F) will store 60 kWh (200,000 BTU).

That volume of water storage can hold enough heat to meet the January average domestic heat load of a 205 m² (2,200 ft²) home with good insulation located near Ottawa, Ontario, for 7 hr. Loading the biomass boiler twice a day will meet the peak daily demand if using a properly sized water storage tank.

Limiting idling helps reduce heat loss, smoke emissions and improves overall seasonal efficiency. A single-stage biomass boiler, operated in an on/off mode can produce condensation within the combustion chamber, resulting in the build-up of creosote and organic acids. This situation worsens if the biomass used is too wet and the biomass boiler is located outside, with poor insulation. This can lead to a premature failure of the appliance, due to corrosion, and lower combustion and seasonal efficiency. Ask a trained heating contractor to analyze the heat load, the size of the biomass boiler and the hot water storage requirements. Other heating devices such as mixing valves and outdoor reset sensors are recommended options to modify the heating network.
AUTOMATIC BIOMASS FEEDING AND STARTING

Automatic biomass heating systems make the operation and management of the system simpler. In Europe, the technology has matched the reliability and safety of oil and gas boilers for residential and commercial operations.

The automated auger feeds the biomass into the combustion chamber when biomass supply is needed, rather than requiring the operator to periodically stoke the boiler manually. For smaller biomass heating systems, pellet augers and bins are more popular and affordable. For larger systems using chipped materials, more biomass removal and handling options are available to bring the biomass to the boiler using augers or conveyors. Those options include vertical or horizontal storage and extraction systems.

The vertical system, called a rotative extractor, is shown in Figure 7. Rotative extractors are used when the operator prefers to dump the chips into a vertical silo, as opposed to storing the chips in a bunker silo where the fuel is pushed horizontally into the storage. Horizontal storage of chips uses a walking floor extractor to drag the chips from the back of the storage to the auger or conveyor supplying the biomass boiler.

Figure 7. A rotative extractor handling wood waste in a vertical biomass storage. The blades rotate around the centre and act as a spring, pushing chipped wood waste into the auger supplying biomass to the boiler. Source: A.P. Bioenergietechnik GmbH, Hirschau, Germany.

Figure 8. An automatic feeding and starting installation for an agricultural biomass heating system. Source: A.P. Bioenergietechnik GmbH, Hirschau, Germany.

Certain manufacturers of smaller biomass boilers have developed monitoring systems that regulate the quantity of biomass required to meet the heat load along with other safety shut-down processes.

Figure 8 shows the automatic ignition for the biomass heating system. This system uses an electric hot air gun to restart a fire instead of reactivating the biomass boiler from the sleep or idle mode. This step reduces the air pollution emissions and consumes less biomass.

Water drench valves, a burn-back protection valve and low-pressure monitors are common controls used to limit the risk of fire in the auger and biomass storage. Several biomass safety devices for modern biomass boilers and other hot water heating equipment are explained in detail in Modern Hydronic Heating for Residential and Light Commercial Buildings, available at www.cengage.com/us.
SUMMARY
Recent advances in biomass combustion controls and modern hot water heating systems make small biomass heating systems an attractive option to produce heat and domestic hot water for the farmstead and agricultural operation, compared to the operating costs of fossil fuel heating systems. Traditional biomass heating systems that are manually stoked have a tendency to release smoke and are inefficient due to the inability of older biomass heating systems to match the variability of heat demand and completely stop the combustion process in the firebox.

This Factsheet reviewed six technological improvements and best practices to improve the safety, combustion and seasonal efficiency of modern biomass boilers.

Select a heating contractor who specializes in modern biomass heating systems to:

• evaluate the best options (e.g., automatic controls, integrated oxygen sensor)
• properly size the hot water storage tank to match the heat load
• select the most economical and practical form of biomass (e.g., pellets, chips, logs) to heat the farmstead and agricultural operation

REFERENCES


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