Heating in the Northeastern USA with a Biomass Pellet Stove: Lessons Learned in a Rural Residential Setting

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Abstract The chapter provides an overview of the carbon-neutral biomass-based alternatives for residential heating in rural areas. As with all alternatives, there are trade-offs. For example, biomass pellet stoves and gasifiers provide heat at a lower cost compared to fuel oil, but using a pellet stove or gasifier requires the installation of new equipment and often daily filling and cleaning that is not required by oil or natural gas furnaces/boilers. An overview of existing technologies for the conversion of biomass to heat and methods for preparing the biomass are discussed. The impacts to air quality differ greatly with each technology. More research is necessary to determine how to best prepare the biomass, which equipment is most efficient for burning biomass, and which combination of biomass and equipment is best at reducing negative impacts to air quality.

Keywords Biomass · Heating · Pellet stove · Bioenergy · Corn stove

1 Authors' Note to the Reader

Prior to moving into an old farmhouse in 2002, the authors did not think much about keeping warm in winter until we had to flip on the furnace switch that first cold day of autumn when baking something was no longer sufficient to warm the house. We learned that many rural households begin preparing for winter by harvesting and stacking wood in May, giving the wood time to age and dry out by the winter heating season. This change in perspective (of when to start thinking about winter

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heating) was the first of many lessons learned in moving to the farm. Today, we find ourselves thinking about heating year-round. The first two heating seasons in the old (circa 1801) drafty oil furnace-heated farmhouse convinced us to look for less expensive heating options. Our first motivation in seeking an alternative heating system was economic, but in exploring the options and thinking long-term, we quickly became convinced that we needed an alternative that was also sustainable for our land/environment, our lifestyle, and our physical abilities. We explored many heating technologies, and these are the focus of this chapter. We also became familiarized with local and federal environmental laws relating to residential heating technologies and air pollution. The regulations have changed in the last decade with the increase in the use of biomass-based heating technologies. As with any decision, there are always trade-offs, and the best choice for each situation will depend upon the unique conditions at each site. We settled on a multi-fuel pellet stove and recorded fuel-usage data for one year prior and two years post-installation of the pellet stove. In our setting, the pellet stove paid for itself in the very first year of use (based on savings of displaced #2 heating oil). We are able to heat our home each winter in central New York on less than two acres of field corn. We recommend considering residential pellet stove installation for cost savings in homes heating with #2 fuel oil. In addition to providing heat, we also recommend placement in a location conducive to good ambiance for the family 'gathering around the fire.' We find our children compete for the 'best spot' on cold mornings. We have experimented with a variety of biomass feedstocks and prefer a homemade mixture of corn, cherry pits, grass, and wood pellets. Based on fuel use prior to installation of the pellet stove and prior to house renovations that improved insulation, we estimate the biomass heat we are using displaces approximately 10 tons of fossil fuel each winter. Due to newer, more efficient heating technology (compared to our oil furnace), we use about six tons of a combination of corn, cherry pits, grass, or wood pellets. At this writing, we are exploring biomass-based heat sources for extending the growing season in our farm's high-tunnel vegetable operation.

2 Introduction

According to a recent analysis by the USA Energy Information Administration (EIA), Americans are spending less of their total energy budget on heating our homes today than 20 years ago (Energy Information Administration 2013). It is believed this is due to the increased energy efficiency of homes and newer heating systems. Currently, there are approximately 116 million households in the USA. An estimated 97% of these households provide some form of heat to the residence for at least part of the year (Energy Information Administration 2014a). Nearly half (49%) of the households in the USA are heated with natural gas. Electricity follows natural gas as a primary residential heating source, with 34% of US homes heated by electricity. Homes located in areas that do not have access to natural gas pipelines often use truck-delivered heating oil (6%) or propane (5%) as the primary residential heat source. Wood is the primary heating fuel source in an estimated 1–2% of US homes, representing a 39% increase in this fuel type since 2004 (MacIntyre 2013). Nearly 2.5 million households (2%) used wood as their primary residential space heating fuel in 2012, which represents a 39% increase in wood use since 2004 (MacIntyre 2013; Energy Information Administration 2014b). The primary heat source varies by region of the country. Natural gas is the principal heating source for the majority of homes in the northeast, midwest, and western USA, while electricity is the primary heating source for the majority of homes in the southeast and central southern USA. Heating oil is primarily used in the northeastern USA, which accounts for 87% of the USA home heating oil market (Energy Information Administration 2014a, b).

This chapter discusses the technologies available currently and technologies under development for displacing fossil fuel sources of residential heat with less carbon-intensive biomass sources of heat.

3 Methods of Making Heat from Biomass Materials

Biomass (primarily plant-based sources of carbon) can be converted to heat for residential heating in three ways: combustion, gasification, and pyrolysis (Liu 2011). From a chemical conversion standpoint, the primary difference in the three methods is the availability of oxygen in the conversion reaction and the resulting end products. All three methods begin with a source of carbon-containing material such as biomass. In general, combustion is a chemical reaction of hydrocarbons in the presence of oxygen that produces carbon dioxide (CO_2), water (H_2O), energy (heat and light), and ash. Gasification also is a chemical reaction of hydrocarbons, but they are heated in the presence of low levels of oxygen producing a mixture of simple gaseous compounds such as carbon monoxide (CO), CO_2, hydrogen gas (H_2), and other flammable hydrocarbon gases such as methane. Other compounds produced from gasification are char and ash. The hydrocarbon gas (syngas) is then burned in a secondary combustion chamber where heat and light are again end products. Pyrolysis is a conversion method that involves heating a hydrocarbon source in the absence of oxygen to produce a black liquor liquid. The liquid can be refined and combusted in a turbine as well, for the production of heat and electricity (http://energy.gov/eere/energybasics/articles/biopower-basics).

In the archeological record

The original type of biomass heat combustion—the wood fire—has been providing heat to humans for over one hundred thousand years. This controlled, direct combustion of biomass for heating is a technology that appears in the archeological record during Paleolithic times, at least 125,000 years ago, when Homo sapiens left evidence of controlling fire (James 1989).

Current technologies increase efficiency and reduce pollution

Today's biomass combustion technologies allow for more complete combustion, as well as better capture and retention of heat from combustion than an open campfire; however, the fundamental thermochemical process is the same. Burning biomass for heat displaces the fossil fuels that we typically burn to provide heat, namely petroleum, natural gas, and propane. The idea of using biomass such as wood for heat is not a new concept. However, there are new technologies on the horizon that improve the efficiency and the environmental safety of using biomass for heat. Each has advantages and disadvantages for the user (Ciolkosz 2012; Foran 2014).

Fireplace technologies

The use of a residential fireplace helps capture more heat than an open outdoor fire, but fireplace combustion remains among the least efficient methods of producing heat from biomass. This low efficiency is due to two factors. First, much of the heat produced escapes along with smoke through the chimney. The upward draft that removes the burning wood's particulate matter from the house relies on convection and the upward movement of heated air. Second, fireplace combustion normally utilizes ambient air within the room, and the resulting fire burns at a lower temperature than in higher-efficiency combustion where the flow of oxygen to the flame is controlled, allowing more of the biomass to be completely combusted. In the process of direct combustion, dried biomass (often wood) is ignited by a spark or flame. The wood biomass contains hydrocarbons and carbohydrates which react with oxygen to produce heat, water, carbon dioxide, and light. If there is not sufficient oxygen present, the combustion process will leave behind residues and particulate matter. Over the centuries, attempts have been made to improve fireplace design for better retention of heat within the room. For example, the Rumford fireplace designed by Count Rumford of Massachusetts in the late 1700s provided a taller, narrower fireplace box that heated more fireplace bricks as the heat rose and radiated the additional heat back into the room (Brown 1969). An alteration in the shape of the exit path of the smoke into the chimney also reduced the amount of smoke in the room. Today, Rumford fireplace kits can be purchased for installation; however, the wood logs must be placed lengthwise to fit within the tall narrow fireplace box. The efficiency of fireplaces also can be increased by designs providing a longer exit-pathway through the chimney, collection of heat in chimney radiators with fans to blow chimney heat back into the room, and addition of oxygen inlet ports that bring outdoor air into the firebox with small fans for more complete combustion of the biomass. Biomass fireplaces require constant monitoring and feeding as the wood within the firebox is depleted and cannot be rapidly 'turned-off' if the fire tender needs to leave the house. Most fireplace systems remain excellent for ambiance and charm and for temporarily heating a single room, but low efficiency and high-maintenance reduce its usefulness in serving as a primary heat source in residential settings.

Outdoor wood boiler technologies

Outdoor wood boilers are another way to use biomass to deliver heat of combustion to a residential setting. As with fireplaces, the fuel source for an outdoor wood boiler is wood logs, though boiler burn chambers are in general larger than fireplace boxes, so the wood logs also can be a larger size. The boiler is located outdoors, so the biomass combustion takes place outside the home with this technology.

Large logs are placed into the outdoor wood boiler firebox, usually twice each day. The firebox of the boiler is surrounded by a metal enclosure. The firebox access door often includes a temperature-controlled fan to provide oxygen to the fire as needed. The metal enclosure is in turn surrounded by a water-reservoir jacket surrounding the metal box. The burning wood heats the water jacket that is in a closed loop, continuously being heated by the wood burner and cooled as water passes through each distribution point (radiators in the house). At the point of adding heat to the closed loop of water, a 'water jacket' surrounding the outdoor wood burner's burn chamber is heated to a target temperature of about 150 °F. When the water reaches the target temperature, a sensor turns on a pump that transfers the heated water through pipes into the building being warmed. Cooler water moves into the 'water jacket' around the burner, and the process repeats. Heat is transferred to the building either through hot water radiators or a heat exchanger to provide domestic hot water for the building's occupants. In general, outdoor wood burners are not very efficient for burning biomass, and due to the incomplete combustion of the biomass fuel, these boilers tend to produce a large amount of smoke and particulate matter during operation (Foran 2014).

A study from New York State found that outdoor wood boiler brands vary in efficiency and completeness of combustion and can also produce noxious pollutants that are harmful to human health. (Spitzer 2005) In recent years (since 2007), installation of new outdoor boilers requires the new units to meet US Environmental Protection Agency (EPA) regulations for heating efficiency and air pollution reduction. However, because outdoor wood burners are very convenient and provide a low-cost heating option, especially in rural settings where waste wood from nearby forest plots could be used, this stove has been a popular heat source for many farms in the northeastern USA. The wood logs need little pre-processing before use in an outdoor wood burner, and the boilers require very little maintenance. Nevertheless, the smoke produced is an irritant, and some of the pollutants in the smoke can cause negative cardio-respiratory effects (Foran 2014; Spitzer 2005). For these reasons, this type of heating system is generally considered undesirable and is now even illegal in many towns and cities where the population density is higher than in rural settings (Foran 2014; EPA's Air Rules for New Residential Wood Heaters 2015).

Indoor wood-burning stoves

Indoor wood-burning stoves provide heat by burning wood logs inside a chamber that is vented to the outdoors. The surrounding metal (and sometimes ceramic) stove parts heat up and radiate heat to the surrounding room air. Indoor wood-burning stoves must be re-filled several times each day, and during the filling, some smoke may escape into the room, while the stove door is opened. In general, the efficiency of heat capture from indoor wood-burning stoves is better than fireplaces but lower than biomass pellet or grain-burning stoves.

Benjamin Franklin invented a wood-burning stove that used a baffle behind the firebox. The baffle increased the length of the path smoke and waste heat traveled before exiting the house, and thus, more heat could be transferred to the room. The 'Franklin Stove' is one of several design attempts to improve the efficiency of burning wood for heat (Franklin 1786).

Efficiency of wood-burning stoves can be increased by increasing the length of the exhaust pipe between the stove and the exterior wall or ceiling, allowing some of the heat that enters the stove chimney to be recaptured by the room before being expelled outdoors. Wood fuel must be cut to lengths that will fit within the indoor stove chamber (usually 16–18 inches long). Indoor wood stoves, like fireplaces, provide localized room heating but at slightly higher heat-transfer efficiency than a fireplace.

Indoor Biomass pellet stoves/grain stoves

High-efficiency grain-burning and pellet-burning stoves address several of the concerns raised in utilizing other combustion technologies for heat production (Crema et al. 2011). The indoor version of pellet/grain stoves is similar in size to an indoor wood-burning stove but is filled through a hopper rather than by opening the burn chamber door. The hopper is an external bin that serves as a reservoir so that grain or pellets can be automatically fed into the burn chamber as needed, eliminating the problem of smoke escaping through the stove door into the room. This feature makes pellet stoves cleaner to operate indoors than the log-burning stoves. The pellet/grain stoves include a fan that provides oxygen and keeps combustion efficiency high and smoke and particulate matter low in comparison with the log-burning stove technologies (Cherney 2010). The burn chamber is surrounded by a metal housing designed with multiple layers and folds to capture as much heat as possible. High-efficiency pellet stoves capture so much heat of combustion that the chimney pipe is often cool to the touch with most heat being removed before the waste gases reach the chimney. Indoor biomass pellet/grain stoves require filling the hopper approximately twice a day (using approximately 40–80 lb of biomass at each filling) and cleaning every one to two days for the best operation. Heat from the burning biomass warms the stove jacket (usually a metal or ceramic block) and is distributed by a small fan that moves warmed air into the surrounding room.

Outdoor (or basement/garage-stored) biomass pellet or wood chip boilers

The biomass heat industry is expanding today through more efficient, more clean-burning stoves available for use in homes, and through an emerging biomass pelletizing industry. Outdoor pellet-burning boilers work in much the same way as outdoor wood boilers, by heating water that is transferred into the residence. However, less smoke/particulate matter is produced than with an outdoor wood boiler unit because the main burn chamber is not opened to the outdoors to feed additional fuel and because the consistent pellet size or wood chip size allows setting the correct oxygen flow for more complete combustion (EPA's Air Rules for New Residential Wood Heaters 2015). Outdoor pellet/wood chip boilers either have larger hoppers or can be automatically fed from a larger storage bin through an auger/pellet-feeding mechanism that reaches from the boiler into a large outdoor storage container of pellets. In these systems, pellets can be delivered in bulk (by the ton) into the storage units. The outdoor pellet boiler heats water, and the hot water is circulated within the residence to provide heat through interior radiators or domestic hot water through a heat exchanger. In some settings, this type of boiler may be housed within a small building or basement with easy access for feedstock supply and ash removal.

Biomass gasifiers

Gasifiers are another type of biomass heat technology/equipment that converts wood chips, logs, pellets, and even bio-based oils to heat through ‘gasification’ under conditions that provide control over the air–fuel mixture in the gasification chamber (Pahl 2004). In the gasification process, biomass is heated in the presence of low amounts of oxygen so that combustion does not occur and instead flammable gases are produced. The gases contain flammable hydrocarbons that can be collected and burned. Thus, gasifiers contain a secondary burn chamber for combustion of the gases. The gasification process is as follows: Wood chips, logs, or other biomass (including bio-based oil) is fed into the gasifier. The biomass is slowly converted to gas (syngas), and the gas is then burned in a secondary chamber to produce heat. The heat is collected through a series of exhaust pipes that wind through a water bath. The water is heated and then pumped into the residence where heat can be distributed either through a heat exchanger that can heat the building’s hot water or to a series of room radiators that heat the air. While the external plumbing aspects are very similar to an outdoor wood-burning boiler system, the gasifier provides a much cleaner burn, through more complete combustion. This significantly reduces particulates and other pollutants and ash compared to the outdoor wood boiler.

Biodiesel replacement of fossil-fuel heating oil

Heating oil furnaces are used for heating homes and businesses in many areas of the country. The traditional fuel utilized is referred to as ‘#2 heating oil’ or ‘HHO’ (home heating oil) (Pahl 2004). This heating oil is very similar in composition to diesel fuel. In industry, a red dye is added to #2 heating oil to prevent its sale as a motor fuel (which is taxed differently than heating oil). The home heating oil is usually delivered to the home or business by truck as opposed to pipelines utilized by natural gas home heating furnaces.

Biodiesel can be burned in oil furnaces with a specialized furnace motor that prevents biodiesel from clogging the lines. Biodiesel will gel or solidify at low temperatures, so the storage tank also needs to be kept warm for winter use. This can be accomplished through indoor storage of the biodiesel storage tank and any lines going from the tank to the furnace. Biodiesel can be made from waste cooking oils or plant seed oils; however, waste cooking oils tend to be high in particulate matter, and additional filtration may be needed to prevent clogging the furnace fuel lines. Another approach to prevent fuel-line clogging is to use a percentage of biodiesel mixed with #2 heating oil; for example, B20 is a mix of 20% biodiesel with 80% heating oil (petroleum-based).

4 Methods of Preparing Biomass to Serve as a Heating Fuel

Biomass for outdoor wood boilers and indoor wood stoves

Wood logs are collected and processed by sawing, chopping, or splitting into sizes that will conveniently fit inside the burn chamber. From the time of cutting, the split logs should be air dried and aged (seasoned) prior to use. Seasoned wood can be purchased (pre-dried), or greenwood can be purchased or collected in spring and then seasoned prior to use in the fall, depending on conditions. Drying the wood reduces pollutant emissions during combustion. In areas that permit wood burning for heat, the use of only seasoned wood (no greenwood) is recommended by stove manufacturers and also usually is required through local burning ordinances. Certain species of wood and climates that have high humidity much of the year may require longer time periods (up to two years) to season the wood.

Biomass for pellet stoves and pellet boilers

The production of biomass pellets begins with the harvest or collection of the biomass feedstock. The biomass can be baled, chipped, or bagged for transport. Currently, most biomass used for pellet production is transported by truck from fields, forest, or mill waste sites to a pelletizing plant http://www.biomasscenter.org/images/stories/grasspelle-trpt_0111.pdf. At the plant, the process begins with grinding of the biomass feedstock into a coarse powder. The grinding or size-reduction process may require several steps through a series of chippers, choppers, hammer mills, and grinders to obtain the right-sized biomass particles for pelletization. The coarsely ground biomass powder is compressed and heated as it is passed through an extruder, which shapes the pellets. Typically, the heating process in the extruder melts some of the natural plant lignin, providing a natural glue that holds each pellet together as it cools. The cooled pellets are bagged and stacked on a pallet for shipment or storage. Kept cool and dry, the pellets remain stable for a long time in storage but will quickly return to the powder stage if wetted or crushed in handling http://www.biomasscenter.org/images/stories/grasspelle-trpt_0111.pdf.

Corn or other grains can be used in specialized pellet stoves designed to handle multiple fuel types (pellets, grains, or cherry pits). Most stove manufacturers recommend corn or other grains should be dried to approximately 8% moisture content for the best combustion, compared to seasoned wood logs, which are recommended to be dried to 20% moisture content or less at the center of the log.

The Rutzke Biofuel Mix: Anecdote from experience: Through trial and error experimentation, we found that a combination of fuels works best in pellet/grain stoves. The ideal combination for heat production and completeness of combustion is mixes that contain a small amount of oil (such as corn) and a material that serves as kindling to overcome variations in moisture content often found in grains (such as wood pellets, grass pellets, or cherry pits). When the fuel mix was 100% corn grain, variations in ambient humidity could reduce the completeness of combustion, resulting in less heat produced and large ‘clinkers’ (stone-like residue formed from un-combusted corn residue) left behind on the stove burn pot or auger. Clinker formation also increased the frequency of cleaning required for pellet stove operation. On the other hand, when the fuel mix was 100% wood pellets or grass pellets or cherry pits, these very dry fuel sources burned easily and rapidly but required more frequent filling of the stove hopper. Burning grass pellets alone also left large amounts of dry, fluffy ash. However, using a combination of corn and one of the drier feedstocks (wood pellet, grass pellet, or cherry pits) provided a number of advantages. Using a mixture that was approximately (by volume) one-third corn and two-thirds of either wood pellet or grass pellet or cherry pits (or any combination of the three) provided a steady burn rate, with high heat output and low-to-no clinker formation. This combination of fuels reduced the number of times we needed to refill the stove, reduced the number of times we needed to clean the stoves, and provided more heat at a more uniform rate of output. We hypothesize that the drier fuels (wood, grass, and cherry pits) may be serving as hot burning fire kindling to overcome any moisture carried in the corn grain. When burned at the higher temperatures provided by the drier fuels, the corn grain provides a small amount of corn oil which may explain the overall increase in heat output and uniformity. We observed a benefit in mixing biomass fuel types for pellet stove heating purposes. Controlled studies are needed to examine these hypotheses and to optimize pellet and grain fuel mixtures for residential heating.

Biomass for gasifiers

Depending on the type of residential gasifier, some may require a uniform wood chip size, log size, or pellet size to function properly. Newer biomass gasifiers are being marketed as ‘fuel agnostic’ and can also burn combinations of dried biomass and bio-based oils. Gasifier exhaust tubes serve as heat exchangers in many systems and require frequent cleaning due to creosote buildup. In general, all of these technologies will perform more efficiently with dry biomass because less energy is consumed removing water.

5 Heat Value of Fuel Sources and Trade-Offs

The amount of heat that can be produced by a given quantity of fuel is called its ‘heating value.’ The heating value can be measured in a few different ways. A bomb calorimeter is one commonly used method. It can be difficult to compare heating values in the literature because they might be expressed in different units, such as the energy/unit mass of the fuel, energy/unit volume of the fuel, or energy/mole of the fuel. Heating values found in literature also vary based on the amount of moisture in the biomass feedstock, the type of biomass tested, and the efficiency of the particular burner utilized to convert the biomass to heat. Different biomass sources—and even different species of wood—have different heating values. The differences are based on the chemical composition of the biomass material. Some plant species contain more oils or more lignin than other species, and there can be differences between varieties within a species. The moisture content of the fuel also impacts a fuel's heating value. Another important factor influencing heating values found in literature is the percent efficiency of the biomass burner utilized.

The following list provides some standard heating values for both bio-based and fossil fuels for comparison (http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf; Bartok 2004).

Fuel source	Standard heating value
Seasoned firewood	15.4 million Btu/cord
Premium wood pellets	13.6 million Btu/ton
Corn cobs	16 million Btu/ton
Propane	92,500 Btu/gal
Oven-dried switchgrass	14.4 million Btu/ton
Fuel oil #2 (heating)	115,000 Btu/gal
Natural gas	100,000 Btu/100 ft3 (1 therm = 100 ft3)

Heating values found in literature can vary based on % moisture, type of biomass, and percent efficiency of the boiler/burner used

BTU British Thermal Unit is the amount of energy required to increase the temperature of one pound of water by one degree Fahrenheit

Data sources Data (http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf) and http://www.hrt.msu.edu/energy/pdf/heatingvalueofcommonfuels.pdf, developed by John Bartok, Jr., University of Connecticut, 2004

Trade-offs

As with all alternatives, there are trade-offs. Biomass pellet stoves and gasifiers provide heat at a lower cost compared to fuel oil, but using a pellet stove or gasifier requires the installation of new equipment and often daily filling and cleaning that is not required by oil or natural gas furnaces/boilers. Outdoor wood boilers are less expensive, but labor-intensive, making this technology more difficult to maintain for an aging rural population. Furthermore, the impacts to air quality differ greatly. Natural gas burns cleaner than #2 fuel oil (residential heating oil), and #2 fuel oil burns cleaner than heavier fuel oils or many biomass heat sources. More research is necessary to determine how to best prepare the biomass, which equipment is most efficient for burning biomass, and which combination of biomass and equipment is best at reducing negative impacts to air quality (Winebrake et al. 2012; http://www.biomasscenter.org/images/stories/grasspelle-trpt_0111.pdf). Another consideration in selecting a residential heating technology is fire safety. All heating methods carry some degree of risk to life and property. The nature of the fire risk changes with each particular heating method.

6 Environmental Laws Relating to Residential Heating Technologies

The US Environmental Protection Agency (EPA) oversees regulation of biomass heating technologies that impact air quality. The Clean Air Act, section 111, is amended, and new regulations created that evolve with new biomass heating technologies manufactured after 1988 (EPA's Air Rules for New Residential Wood Heaters 2015). On January 3, 2014, EPA proposed revisions to the residential wood heater new source performance standards (NSPS), and in 2015, new NSPS standards were published and are available in full through the EPA website (EPA's Air Rules for New Residential Wood Heaters 2015). These standards govern the manufacture of new wood stoves, and certain fireplace inserts and impose certain minimum standards for the reduction of air pollution. Wood-burning units made today must meet these standards and must provide the buyer with a tag confirming that the stove has been tested and certified to meet the air emission requirement standards. In order to allow time for manufacturers to ease into the new standards, the EPA is launching the compliance process in two steps: Step 1—requires the first level of air emissions (particulate matter maximum of 4.5 g/h of operation) beginning December 2015, and Step 2 requires that manufacturers meet the Step 2 air emissions (particulate matter maximum emissions of 2.0 g/h of operation) standards by 2020 (EPA's Air Rules for New Residential Wood Heaters 2015).

7 Capital Cost Comparisons

An important factor in the selection of a biomass heating system is the capital costs required to purchase a unit. The following provides price ranges from industry in autumn of 2015 for comparison. In general, the newer technologies (residential gasification units) are the most expensive.

Residential technology	Approximate capital cost range (US dollars) (2015)
Rumford fireplace	\$4000–\$10,000
Outdoor wood boilers	\$3000–\$10,000
Indoor wood-burning stoves	\$500–\$3000
Indoor biomass pellet stoves	\$1000–\$4000
Outdoor pellet or woodchip boilers	\$6000–\$18,000
Biomass gasifiers	\$6000–\$20,000
Biomass CHP systems	Not yet available for residential settings in USA

Cost is influenced by the size of the stove required to heat the space. In determining the size of the heating unit, a good rule of thumb for the average residential setting is to select a unit that will provide approximately 35 BTU per square foot of space to be heated (Albright 2006).

8 On the Technology Horizon

Newer high-efficiency burners have been developed and are used in Europe. Some of these technologies and equipment are also being developed by several companies for both industrial and residential markets in the USA. These new technologies are including options for systems that provide a combination of heat and power in the form of electricity (combined heat and power or CHP). A company in Europe has created a residential-scale CHP unit using a pellet-burning stove and a Stirling engine. Companies are responding to consumers' requests for more efficient, lower-pollution heating technologies that can utilize carbon-neutral biomass.

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Glossary of Terms

B20 A mixture of 20% biodiesel and 80% conventional diesel.

Biodiesel A biodegradable transportation fuel for use in diesel engines or heating fuel for use in specially-converted furnaces. Biodiesel, a fatty acid methyl ester, is produced through the transesterfication of organically-derived oils.

Bioenergy Refers to biomass based production of heat, transportation fuel, or electricity to displace fossil petroleum sources.

Biofuels Biomass converted to liquid fuels such as ethanol and biodiesel.

Biomass Any biologically-derived organic matter. Biomass available for energy on a sustainable basis includes herbaceous and woody energy crops, agricultural food and feed crops, agricultural crop residues, wood residues.

Biomass Pellet A biomass pellet is a cylindrical, extruded form of ground and heated biomass (usually made from wood or perennial grasses). Biomass pellets are approximately 10 times more dense than un-pelletized biomass. The pelletization of biomass improves efficiency of transportation, storage and improves fluidity of biomass feedstock in automatic feeding systems for heating units.

Carbon Dioxide (CO_2) A colorless, odorless gas produced by respiration and combustion of carbon-containing fuels. Plants use it as a food in the photosynthesis process.

Carbon Monoxide (CO) A colorless, odorless, poisonous gas produced by incomplete combustion.

Combined Heat and Power (CHP)/Co-Generation The technology of producing electric energy and another form of useful energy (usually thermal) for industrial, commercial, or domestic heating or cooling purposes through the sequential use of the energy source.

Combustion A chemical reaction of hydrocarbons in the presence of oxygen that produces carbon dioxide (CO_2), water (H_2O), energy (heat and light), and ash.

Feedstock Raw materials that may be treated or converted to create fuels. Biomass feedstocks may include forestry products, crop residues, municipal waste streams, manure and food processing waste.

Gasification of biomass A chemical reaction of hydrocarbons, but they are heated in the presence of low levels of oxygen producing a mixture of simple gaseous compounds such as carbon monoxide (CO), CO_2, hydrogen gas (H_2), and other flammable hydrocarbon gases such as methane. Other compounds produced from gasification are char and ash.

Gasifier A device that converts solid feedstocks to gas and then burns the gas in a secondary burn-chamber. Heat can be captured and redistributed by a variety passive and active methods. Generally refers to a heating technology using thermochemical processes.

Heating oil/home heating oil/#2 heating oil Fossil-fuel based #2 distillate from crude oil processing. Heating oil is chemically identical to diesel fuel but is dyed pink to differentiate between taxable transportation fuels and heating fuel.

Heating Value 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.

New Source Performance Standards (NSPS) Standards developed by the U.S. Environmental Protection Agency that govern the manufacture of new wood/biomass stoves and impose certain minimum standards for reduction of air pollution from biomass stoves.

Outdoor wood boiler A biomass (wood-based) heating technology that captures heat of combustion of logs in a water-jacket and redistributes the heat through a radiator system.

Indoor wood-burning stoves A biomass (wood-based) heating technology that captures heat of combustion of logs in metal or ceramic casing of the stove and passively redistributes heat to the surrounding airspace. Some stoves may contain a small fan that speeds distribution of heat to the surrounding space.

Particulate Matter Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. It is usually separated into PM10 and PM2.5, which are particles of diameter equal to or less than 10 and 2.5 micrometers (μm), respectively.

Pellet See biomass pellet.

Pellet stove A heating device used in residential settings that utilizes biomass pellets or grains as the heating fuel source. Biomass pellets are combusted and heat is captured and distributed to the room space.

Pyrolysis The breaking apart of complex molecules by heating in the absence of oxygen, producing solid, liquid, and gaseous fuels. a conversion method that involves heating a hydrocarbon source in the absence of oxygen to produce a black liquor liquid. The liquid can be refined and combusted in a turbine as well, for the production of heat and electricity.

Rutzke (rut-skee) Biofuel Mix A biomass heating fuel mixture for use in pellet/grain stoves that contains a mixture of corn grain, wood or grass pellets and cherry pits.

Seasoned wood Wood that is aged and dried over time (6 months to 2 years, depending on wood type and environmental conditions) through exposure to wind, rain, sun and natural drying conditions to remove moisture from newly harvested (green) wood. Seasoned wood produces less creosote and burns more cleanly than green wood.

Syngas Syngas, short for synthesis gas, is a mixture of carbon monoxide (CO) hydrogen (H_2) and methane. It is the product of high temperature gasification of organic material such as biomass. Following clean-up to remove any impurities such as tars, syngas can be converted to liquid biofuels such as synthetic diesel (via Fischer–Tropsch synthesis).

Thermochemical Gasification A process operated at elevated temperature that converts a solid feedstock into a gaseous fuel, while maximizing the chemical energy content of the product gas.

Questions for Critical Thinking

(1) What is the most cost efficient method of heating residential space in the Northeastern United States today?
(2) Which heating technology and fuel combination is responsible for the most air pollution in the United States today? Which is the cleanest burning?
(3) With use of wood-based heat on the rise in the United States since 2004, what number of households could be sustainably heated by wood-heat?
(4) How many acres of woods could we sustainably utilize annually to supply heat? What factors influence tree-replenishment rates?
(5) If a 1500 square foot home could meet all winter heating needs using 2 acres of field corn, how many acres of corn would be required to provide the nation's winter heating needs? Is this sustainable?

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