

# Wood Heating Appliances for Homes and Businesses

## Choosing the Right Equipment

January, 2014



Using wood as a heating fuel is ancient technology that is seeing increased popularity with the advent of modern wood heating appliances. Many people opt for wood, wood pellets and grains as low-cost alternative energy sources, especially during periods when energy prices rise. The transition to wood appears higher for folks with access to woodlots. Using wood may be low-cost but it isn't free! It requires equipment such as chainsaws, splitters, trucks or trailers, and something very precious – time (see: Economics of Wood-burning Appliances, pg 10). Equipment cost, energy efficiency, and air quality health impacts are important factors in deciding whether or not, and how, to heat with wood.



James Faust

This fact sheet describes what you should consider when contemplating using wood as a primary or secondary heating fuel for your home or business.



### Energy conservation first

Before making the switch to an alternative fuel, it may be wise to consider adopting or installing energy efficiency measures and practices in your home or business. These might include updating to a high-efficiency furnace or boiler (90 percent efficiency or greater), increasing attic and wall insulation, replacing single pane windows, and weatherizing to reduce air infiltration. These things will often give a better return on investment than heating with wood.

### Who's heating with wood?

Approximately 200,000 (9 percent) of Wisconsin homes burn about 1.2 million cords of wood every year as either a primary or secondary fuel source (U.S. Energy Information Administration, <http://www.eia.gov>). While many combustion appliances are EPA-approved reduced-emission wood stoves, a substantial number are unregulated high-emission units, either because they pre-date regulation or are unregulated (e.g., outdoor wood boilers).

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## Wood as Fuel

The combustion of wood is a complex process. Wood undergoes dramatic changes as it burns. First, heat is used to drive off moisture. This is why seasoning (drying) your firewood is extremely important: seasoned wood does not waste energy burning off excess moisture.

Next, the wood undergoes pyrolysis (see glossary for underlined terms) when it reaches 500-600°F, breaking down into organic gases that can burn. About 85 percent of the mass and 60 percent of the heating value is contained in gases produced by pyrolysis. After most of the gases have burned off, the remaining portion is charcoal, which burns at about 1100°F. Any unburned residue will be in the form of smoke or creosote (condensed pyrolysis gases).

Complete combustion requires plenty of oxygen and the three Ts: temperature, turbulence and time:

- high enough temperatures (1100 to 1500°F) to ignite the pyrolysis mixture;
- enough turbulence (an air/fuel ratio of 10 to 12 pounds of air per pound of fuel to mix the pyrolysis gases with sufficient oxygen to maintain combustion; and
- sufficient time (2 to 4 seconds in the high temperature zone and no flame contact with cold surfaces that might quench the flame) under the two previous conditions to complete the reaction.



Jeffrey J. Strobel



### Thinking about buying a wood-burning appliance?

- High thermal efficiency appliances use less fuel per unit of heat delivered. Educate yourself about the thermal efficiency and capacity of the appliance, and look for EPA certification of efficiency. Ask to see a copy of the owner's manual before you buy.
- Size matters! An oversized unit will smolder and create more air pollution than one that is sized correctly or slightly undersized. Sometimes the most cost-effective unit is one that will provide adequate heat 80 percent of the time and allow your conventional heating system to help on the few coldest nights of the year.
- Purchase EPA-certified stoves and fireplace inserts, and EPA-qualified fireplaces and hydronic heaters. These units have been designed to reduce smoke emissions and are more energy efficient.
- Check state and local codes before purchasing any wood-burning appliance. Some towns and villages ban outdoor wood-fired boilers because of excessive emissions and neighbor complaints.

# Types of Wood Fuels

## CORDWOOD

Cordwood is the traditional wood fuel, cut to length, split and air-dried. The energy content of the wood will vary depending on its moisture content and the tree species. Generally, hardwood trees will have higher energy content per cord than softwood, mainly due to the wood's density. For hydronic heaters (outdoor wood boilers) the wood often is not split into small pieces or not split at all, as it would be for an indoor stove or fireplace. Leaving wood whole or in large sections reduces the ability of the wood to dry, especially if the bark is left on.

Burning wet wood is a waste: if it's wet, don't use it (USEPA-b). The higher the moisture content of the wood, the less heat will be generated because some of the heat will be used to vaporize the moisture in the wood before it will burn. Wet wood also creates more harmful emissions (e.g., formaldehyde, benzene, and/or particulates) because of incomplete combustion.

To promote drying, all wood should be split into halves or quarters so the wedges are no larger than



### Is my wood dry enough?

Water in wood is a good conductor and can be measured using electrical resistance. Meters to measure wood moisture can be purchased for about \$30.

Testing the moisture content of wood is simple. Pick out a representative piece, split it in half to expose fresh wood, then press the meter pins into the wood on the freshly split surface. Take several readings per piece of wood and test several pieces of wood per pile to get an average value.

Other signs that the wood is seasoned include cracks in the ends of the wood and bark that is falling off. For videos and a brochure on how best to season your firewood and use a wood moisture meter, please visit EPA's Burn Wise website at <http://www.epa.gov/burnwise>



Wood moisture meter

**TABLE 1 – Burning characteristics of select wood species**

Wood Species	Weight (Lbs/Cord)		Energy Per Dry Cord (Million Btus)	Relative Smoke Emissions
	Green	Air Dried		
<b>Green Ash</b>	4184	2880	20.0	Low
<b>Birch</b>	4312	2992	20.8	Medium
<b>Boxelder</b>	3589	2632	18.3	Medium
<b>Cottonwood</b>	4640	2272	15.8	Medium
<b>American Elm</b>	4456	2872	20.0	Medium
<b>Black Locust</b>	4616	4016	27.9	Low
<b>Sugar/Rock Maple</b>	4685	3680	25.5	Low
<b>Silver Maple</b>	3904	2752	19.0	Low
<b>Bur Oak</b>	4960	3768	26.2	Low
<b>White Oak</b>	5573	4200	29.1	Low
<b>White Fir</b>	3585	2104	14.6	Medium

Source: M. Kuhns and T. Schmidt, Heating with Wood, University of Nebraska-Extension

6 inches. Cordwood should have a moisture content of 20 percent or less. To reach this level, softwood should be seasoned for at least 6 to 12 months

## Scrap Wood

Any scrap wood products should be free of paint, chemicals (including pressure-treated lumber), petroleum products, rubber and plastic. Plywood, OSB (oriented strain board), particleboard, or any

(warm months) before use and hardwood for at least 18 to 24 months. A wood moisture content meter (see sidebar) can be purchased for about \$30.

wood with glue on or in it should not be burned. Glues contain toxic chemicals that are released into the air when burned.

## Pellet Fuel

In recent years wood pellets have become popular, for indoor and outdoor stoves. Wood pellet stoves, boilers or furnaces have low emissions and thermal efficiencies from 80 to over 90 percent. Wood pellets are uniform in size and shape ( $\frac{1}{4}$  to  $\frac{5}{16}$  inches in diameter and 1 to 1½ inches long) and in moisture content, which promotes efficient combustion.

Pellets are available in three grades, premium, standard and utility. Premium grades have less than 1 percent ash content, standard grades are less than 2 percent



Doug Reinemann

ash, and utility is less than 6 percent ash. Wood pellets are generally available in 40-pound bags from feed stores, home improvement centers, hardware stores or specialty hearth stores. In some areas, bulk delivery may also be available. Pellets can also be made from other biomass including grasses, waste paper, grains, or a combination of those with wood. The best time to purchase bulk pellets is often in late spring or early summer if you have a dry, well-ventilated location to store them until needed.

## Chipped Wood

For larger-scale heating, wood chips (green or dry) can be an inexpensive fuel, but they require special handling and combustion equipment. This chip-burning equipment can handle treetops, limbs, scrap or wood waste (wood that generally isn't useful for other purposes).

Wood chips can often be stored outside, which reduces the need for a bin or building. However, chip fuel piles require some type of bulk material handling equipment, typically a front-end loader. As with any biomass fuel, the drier the chips, the more usable energy will be available.

Wood chip combustion systems are a significant capital expense for commercial users and require routine, even daily, maintenance. Reputable and established vendors typically provide performance guarantees and warranties. Before investing, make sure there is a reliable local fuel supply, as wood chips are bulky and therefore expensive to ship very far. Wood chip boiler systems would be suitable for larger buildings, or building or greenhouse complexes. Output capacities start at 500,000 Btu/hr.

## Grains

Grains such as corn, rye and wheat can also be used as a fuel. Grains should be dried to about 12 percent moisture to burn properly. Corn from a feed mill is typically 14 to 15 percent moisture. It often doesn't

burn well and can lead to uneven burning, causing the flame to go out. Some grain mills will dry the corn to 12 percent specifically for corn stoves and lightly oil it to prevent dust during handling.

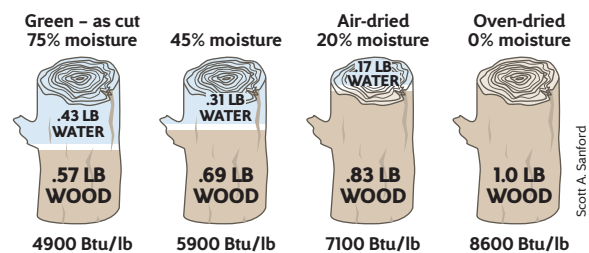
## Heat Potential of Different Fuels

The amount of energy that can be extracted from a fuel depends on its type, moisture content, and the kind of boiler or furnace used. Fuels such as natural gas, propane or heating oil don't contain water so the heat value is very predictable.

A therm (approx. 100 cubic feet) of natural gas will provide 100,000 Btu of energy. A gallon of liquid propane (LP) gas contains 92,000 Btu, whereas a gallon of No. 2 heating oil generates about 140,000 Btu of energy.

Wood, wood pellets or grains contain moisture that must be evaporated from the fuel before it will burn. It takes energy to evaporate the water from the fuel, which reduces the amount of energy available for heating. The heating value of hardwood that has been oven-dried (zero percent moisture) is around 8600 Btu per pound while softwood pine species contain 9000 Btu per pound. Softwood is less dense so it takes more wood to make a pound. All wood being burned will contain some amount of moisture, which will reduce the net amount of heat available.

**FIGURE 1 – Water & energy content of 1 lb. of firewood**



Green hardwood (oak, maple, elm, etc.) averages about 75 percent moisture at cutting but can range from 55 to 90 percent depending on the species. One pound of green hardwood will contain 0.57 pounds of dry wood and 0.43 pounds of water. The total heat available will be 4900 Btu (0.57 pounds x 8600 Btu/pound dry wood). If the wood is allowed to season (air-dry) for a long enough period, it usually will contain about 20 percent (or less) moisture or 0.83 pounds of dry wood and 0.17 pounds of water. The available energy will be 7100 Btu per pound (0.83 x 8600 Btu/pound dry wood).



### You can't heat efficiently with a fireplace

Open fireplaces are not suitable for heating because 90 percent or more of the heat produced goes up the chimney. If you have an open fireplace and you wish to heat with wood, you should install an EPA-qualified fireplace insert or replace it with an EPA-qualified wood stove. If you are installing a fireplace for ambiance, look for an EPA-certified fireplace insert.

Fireplaces with sealed doors, that use outdoor air for combustion, will be much more efficient and produce less smoke emissions than will traditional models. Putting glass doors on an older fireplace will not increase the efficiency. They cannot be sealed and the combustion air will still come from inside the home, which uses air that has already been heated.

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To demonstrate the importance of seasoning, suppose wood was cut late and did not have ample time to dry, or was not split, or not split small enough to adequately dry. It might have a moisture content of around 45 percent. The energy value of this wood would be 5934 Btu per pound (0.69 x 8600 Btu/pound dry wood). A building that requires 4 cords of seasoned wood (at 20 percent moisture) to heat in an average winter would require about

5 cords of wood with 45 percent moisture to provide the same amount of heat.

Drying wood too much can cause problems of a different kind. Wood with a moisture content of less than 10 percent burns very rapidly and may create temperatures too high for the wood-burning appliance. This would typically only happen if someone were burning kiln-dried wood, such as scraps from a furniture factory.

**It pays to use properly seasoned wood. It requires 45 percent more greenwood than dried wood (by weight) to produce an equivalent amount of heat.**

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## Types of Wood-burning Appliances

### EPA-certified Wood Stoves

EPA-certified wood stoves can be freestanding or may resemble a fireplace with airtight doors. Caution should be used around freestanding stoves, as surfaces can become very hot during use. These indoor systems are either catalytic wood stoves or non-catalytic wood stoves.

A catalytic stove has a ceramic-coated honeycomb device where the smoke and particles are burned as they pass through to reduce emissions. A non-catalytic stove has a baffle above the firebox that keeps the combustion gases hot,

so when pre-heated combustion air is emitted under the baffle the combustion gases ignite, which reduces emissions. To be certified, catalytic wood stoves are required to have a particulate emission rate of 4.1 grams per hour or less. The emission rate for certified non-catalytic wood stoves must be 7.5 grams per hour or less.

The thermal efficiency (conversion of fuel into useful heat) of EPA-certified wood stoves averages 72 percent for catalytic wood stoves and 63 percent for non-catalytic wood stoves.

### Pellet Stoves, Furnaces and Boilers

Pellet combustion appliances can burn pellets made of wood or other biomass (waste paper, grains or grasses) for fuel. The pellet delivery systems are classified as either top-feed or bottom-feed to the combustion chamber.

Top-feed systems contain an auger that meters pellets into the combustion chamber from the top of the system into a steeply pitched chute. The pellets slide down the chute into the combustion chamber by gravity. Bottom-feed systems contain

an auger that meters pellets into the bottom of the combustion chamber. The pellets burn as they move up through the combustion chamber. The ash overflows the top of the fire bowl and is deposited either in an ash pan or



Pellet stove

Scott A. Sanford

pushed out of the chamber to a container outside the appliance.

The major advantage of a pellet stove, furnace or boiler is the ability to meter the fuel into the combustion chamber based on current heating requirements. This helps prevent excess fuel in the combustion chamber, which could produce smoke if the heating demand is reduced.

These appliances also have other advantages. The combustion airflow rate can be adjusted on some pellet appliances for more efficient

combustion based on the fuel type. Pellets (on a Btu basis) may cost more than a cord of wood, but these appliances can run unattended for up to 24 hours or more. A pellet system eliminates the time and equipment required to harvest the wood (unless you decide to make your own pellets). The thermal efficiency of these systems is typically 80 percent, but can range from 70 to 85 percent. There are a few manufacturers that offer models with efficiencies greater than 90 percent.

## Outdoor Wood Boilers

Sometimes called hydronic heaters, outdoor wood boilers (OWBs) have gained in popularity as energy prices have increased. These boilers look like small utility sheds. They are basically simple fireboxes, typically surrounded by a jacket of water.

These appliances are fraught with problems. The water jacket may keep temperatures in the firebox from getting high enough to allow for good combustion. In addition, poorly controlled dampers starve the combustion process of oxygen, which releases unburned hydrocarbons (smoke) into the air. The more wood in the firebox when the damper

closes, the more smoke will be produced. The smoke contains at least 100 different compounds and small particulate matter (PM), which can cause respiratory (e.g., asthma attacks) and cardiovascular health problems and lingering odors (WDHS, 2010).

There have been an increasing number of complaints because of the high amount of visual smoke emission that is common to OWBs (Johnson, 2011; Russell, 2011; Fontaine, 2011; Freedman & Kellerhals, 2011).

In 2007 the U.S. Environmental Protection Agency (EPA) launched a



## Health risks from wood smoke

Burning wood produces emissions that are widely recognized as harmful to human health. Wood smoke emissions contain particulate matter, carbon monoxide, nitrogen oxides, volatile organic compounds, hazardous air pollutants and carcinogens. Smoke from residential wood-burning appliances can increase fine particle pollution (PM<sub>2.5</sub>) to levels that cause significant health concerns (e.g., asthma attacks, heart attacks, premature death). Many people have increased susceptibility to the effects of wood smoke emissions.

In January 2014 UESPA proposed strengthening the fine particle emission limits for wood heating appliances, saying: "Particulate pollution from wood heaters is a significant national air pollution problem and human health issue. These proposed regulations would significantly reduce particulate matter (PM) emissions and many other pollutants from these appliances, including carbon monoxide (CO), volatile organic compounds (VOC), and hazardous air pollutants (HAP)." If adopted, the rule will lower the emission threshold for most wood and pellet stoves to 1.3 grams/hour, and for outdoor wood boilers to 0.06 pounds per million btu, beginning in 2015.

Source: EPA-HQ-OAR-2009-0734 1/3/14



voluntary hydronic heater program with the goal of reducing smoke emissions from OWBs by 90 percent. The EPA first tested existing OWBs and found the average thermal efficiency to be 40 percent, with a range from 20 to 50 percent. For comparison, a standard gas or oil furnace/boiler is 80 percent efficient; high-efficiency units are above 93 percent. Many companies have developed OWBs to meet the USEPA's voluntary requirements. Some of the new designs use gasification to burn the wood more completely. These new boilers are more efficient, averaging about 70 percent thermal efficiency.

The EPA Burn Wise website has a list of the qualified hydronic heaters (<http://www.epa.gov/burnwise/owhlist.html>) that have been tested by an independent lab. These units have an emission level of no greater than 0.32 pounds of smoke and

particulate emissions per million Btu (MMBtu) of heat output. Manufacturers should provide a rating tag listing the maximum heat output rating (Btu/hr), 8-hour output rating (Btu/hr), and the particle pollution rate in grams per hour and pounds per million Btu. The heat output is the average over an 8-hour period based on one loading of fuel, while the maximum output rating is the highest output rate during the 8-hour period. Smoke emissions are compared to the EPA maximum benchmark of 0.32 pounds/million Btu. The 8-hour output rating is not included on pellet units because they are continuously fueled so the maximum and the 8-hour rating would be the same. The output ratings and emissions information are also listed on the Burn Wise website under the “list of qualified hydronic heaters” link. The 8-hour output rating (Btu/hr) should be used for sizing a cordwood unit.

## Hydronic Pellet Boilers

Several manufacturers have introduced hydronic heaters that burn wood pellets and can be installed either indoors or outdoors. Thermal efficiency is typically about 80 percent, with some units having efficiencies of greater than 90 percent. On average, emissions from pellet-fueled heaters are 66 percent less than the EPA target. Pellets for the boiler are typically stored in a bin next to the boiler and fed by an auger from the bin directly into the boiler. The ash is augered out of the boiler to a receptacle for disposal.

These systems have the advantage of automatically changing the feed rate to match the heating load. There are more moving parts on a pellet boiler



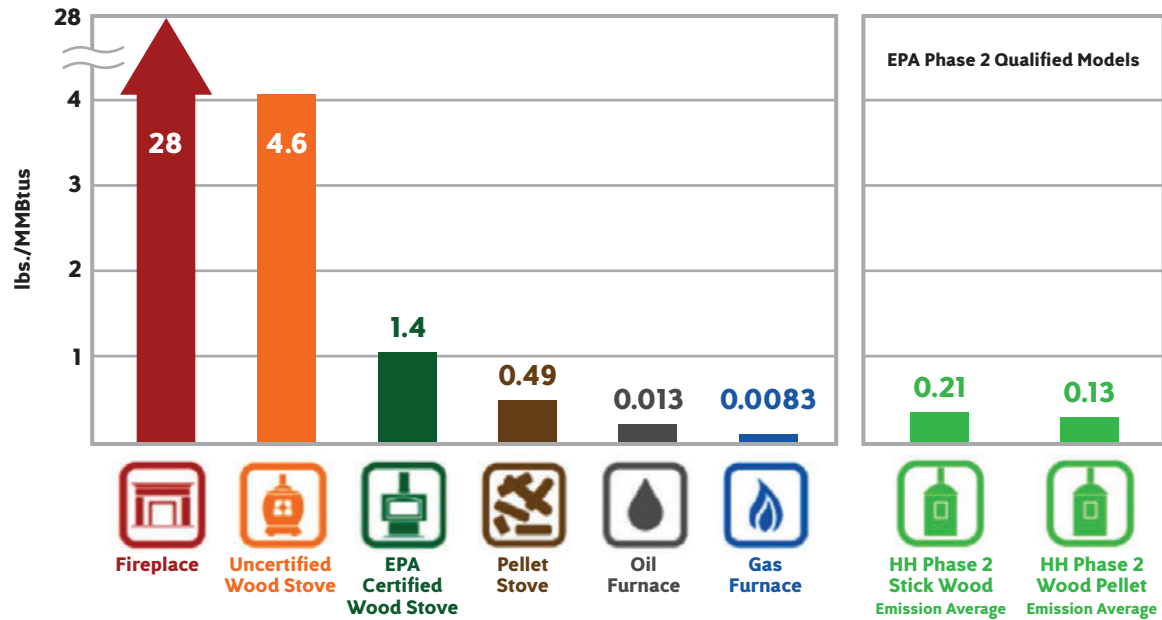
Hydronic pellet boiler with pellet storage bin.

than on a stick-wood-fed boiler so plan for more maintenance. Pellet-fueled systems require less refueling labor than a wood-fueled OWB.



**FIGURE 2 – Fine particle emissions of heating appliances (lbs./MMBtus of heat output)**

SOURCE: U.S. Environmental Protection Agency, 2011



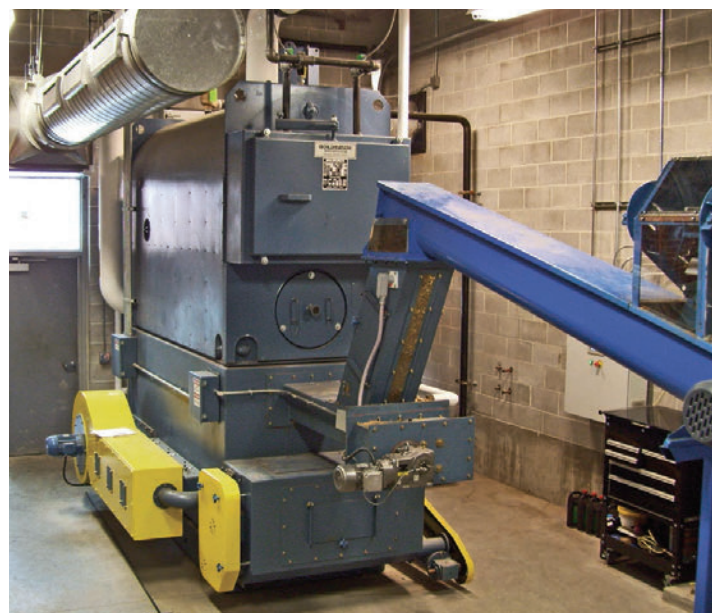
### Wood Chip Boilers

The use of wood chips as fuel may be a viable alternative for medium to large greenhouses, schools, homes or businesses. Wood chips can be obtained from multiple sources including sawmills, tree maintenance or harvesting operations, and furniture manufacturers. Chips with lower moisture content will provide more net energy but may be in greater demand for other uses such as paper pulp, animal bedding or fuel pellet production. Chip size and moisture levels are important for proper operation and combustion. In all cases, the chips would be delivered in truck-sized loads and require bulk storage.

Wood chips can be stored in a pile on the ground or in aboveground or below-ground bins. A hard surface under chip piles is recommended for ease of moving. The surface must have adequate drainage, and large chip piles should not be allowed to stand for extended periods of time without being turned. Under certain conditions, a

static chip pile may create an environment where spontaneous combustion is a threat.

Ground-level storage will have lower construction costs but will require daily labor to move chips to the boiler with a bucket loader.



Wood chip boiler.

Biofuel Boiler Technologies LLC

Although covered storage reduces moisture absorption from rain or snow, it also adds cost. Fuel storage volume should be one-third to one-half times larger than the delivery volume so the bin can be refilled without interruption to your heating system. Belowground storage bins do have some advantages. They are less visible and don't require special handling equipment to unload self-unloading trucks (dump trucks or trailers with walking floors). Storage below the frost line keeps the chips from freezing. A fully automated system to move the chips from storage to the boiler can cost twice what a semi-automated system costs, but will reduce daily labor requirements.

Boiler capacity can range from about 1 MMBtu per hour to about 150 MMBtu per hour. Units above 10 MMBtu per hour are custom engineered for the site. The steady state efficiency of wood chip boiler

systems can range from 50 percent to 75 percent depending on the air to fuel ratio, fuel moisture content and stack temperature. Biomass-fueled boilers with a greater than 1 MMBtu per hour capacity may be subject to DNR regulation (NR415.06); contact your local DNR service center to determine if air emission rules apply.

Chip-fueled boilers have some advantages. They require less labor and the fuel is cheaper than with either cordwood-fueled or wood-pellet-fueled units. Because the wood chips are metered into the combustion chamber as needed, emissions are minimal. However, these units are more expensive to purchase and have more moving parts to maintain. Also, there can be great variation in fuel characteristics of wood chips from load to load, which may require adjustments to achieve maximum efficiency and low emissions.

## Economics of Wood-burning Appliances

The cost of burning wood will depend on the price of fuel plus the purchase price, operation and

maintenance costs and heating efficiency of the combustion equipment.

### The Price of Fuel

Fuel costs often vary from year to year and from one season to the next. Even harvesting wood is not free! It requires equipment and hard work. Equipment purchase and maintenance, labor, and opportunity cost (price wood could be sold for) should all be considered when deciding whether to harvest and process wood for fuel.

Since fuels have different heat values and combustion appliance efficiencies vary, the best way to compare is with cost per million Btu of heat delivered. It can be calculated as follows:

$$\text{Cost per MMBtu} = \frac{1,000,000 \text{ Btu}}{\text{Btu per energy unit}} \times \frac{\text{Cost per energy unit}}{\text{Thermal efficiency}}$$

The Btu per energy unit can be found in Table X, the cost per energy unit should be determined locally. Thermal efficiency can be approximated from the table, from manufacturer's USEPA Hang tag or specification sheet, or from the EPA Burn Wise website (USEPA-c).

Example: An OWB that is 40 percent efficient at burning mixed wood with an energy content of 22,000,000 Btu per cord and wood is purchased or could be sold for \$200 per cord.

$$\begin{aligned} \text{Cost per MMBtu} &= \frac{1,000,000 \text{ Btu}}{22,000,000 \text{ Btu per cord}} \times \frac{\$200 \text{ per cord}}{40\%} \\ \text{Cost per MMBtu} &= \$22.73 \text{ per } 1,000,000 \text{ Btu} \end{aligned}$$

## Equipment, Operation and Maintenance Costs

The price of a combustion unit for a residence can range widely from about \$2000 for an EPA-certified wood stove to between \$10,000 and \$14,000 for an OWB. A system for a large building or greenhouse may cost \$200,000 to \$500,000. The annual cost of the equipment will vary with the equipment type and scale, expected equipment life and the cost of money. For example, if a boiler costs \$14,000 and has an expected life of 15 years, the annual ownership

cost would be \$933 per year (\$14,000 /15 years) plus the cost of money, (the interest you would pay if you took out a loan to pay for the equipment). At a loan rate of 7 percent simple interest, the annual cost would be \$998 (\$933 + \$933 x 0.07).

The operating and maintenance costs vary with the type of equipment, but typically include electricity, spare parts, and cleaning and service labor.

## The Bottom Line

So, the total annual cost of using a wood, pellet or chip stove, boiler or furnace will be the fuel cost plus annual ownership cost plus the operating and maintenance cost. The total annual cost should be compared with other energy efficiency measures

that could reduce heating costs (using a high-efficiency conventional fuel appliance, improving building insulation, installing new windows, etc.).

Table 2 and Figure 3 compare the fuel cost per million Btu for different types of fuel and combustion

$$\text{Total annual cost} = \text{Annual ownership cost} + \text{Fuel cost} + \text{Operating cost} + \text{Maintenance cost}$$

**TABLE 2 – Fuel type comparison – in order of cost (2013)**

Fuel Type	Energy Content (Btu)	Seasonal Efficiency (%) = efficiency value used to determine cost	Unit Cost <sup>4</sup>	Cost Per 1,000,000 Btu
Natural Gas	100,000 per therm	70-94% (90%)	\$0.80 per therm	<b>\$8.89</b>
Wood Chips	3,780 per pound (@ 50% moisture) to 6,190 per pound (@ 25% moisture)	50-75% (70%)	\$50 per ton (50% moisture used to determine cost)	<b>\$9.45</b>
Wood used in OWB – EPA Phase 2 <sup>1</sup>	22,000,000 per cord <sup>3</sup>	69%	\$225 per cord	<b>\$14.82</b>
Wood Pellets	15,400,000 per ton	70-85% (80%)	\$190 per ton	<b>\$15.42</b>
Propane	92,000 per gallon	70-94% (90%)	\$1.60 per gallon	<b>\$19.32</b>
Wood used in OWB – Pre-2008 <sup>2</sup>	22,000,000 per cord <sup>3</sup>	40%	\$250 per cord	<b>\$28.41</b>
Shelled Corn	380,000 per bushel (@ 15% moisture)	70-85% (80%)	\$360 per ton	<b>\$29.61</b>
Heating Oil	138,000 per gallon	70-85% (75%)	\$3.6 per gallon	<b>\$34.78</b>
Electricity	3,413 per kWh	100%	\$0.12 per kWh	<b>\$35.16</b>

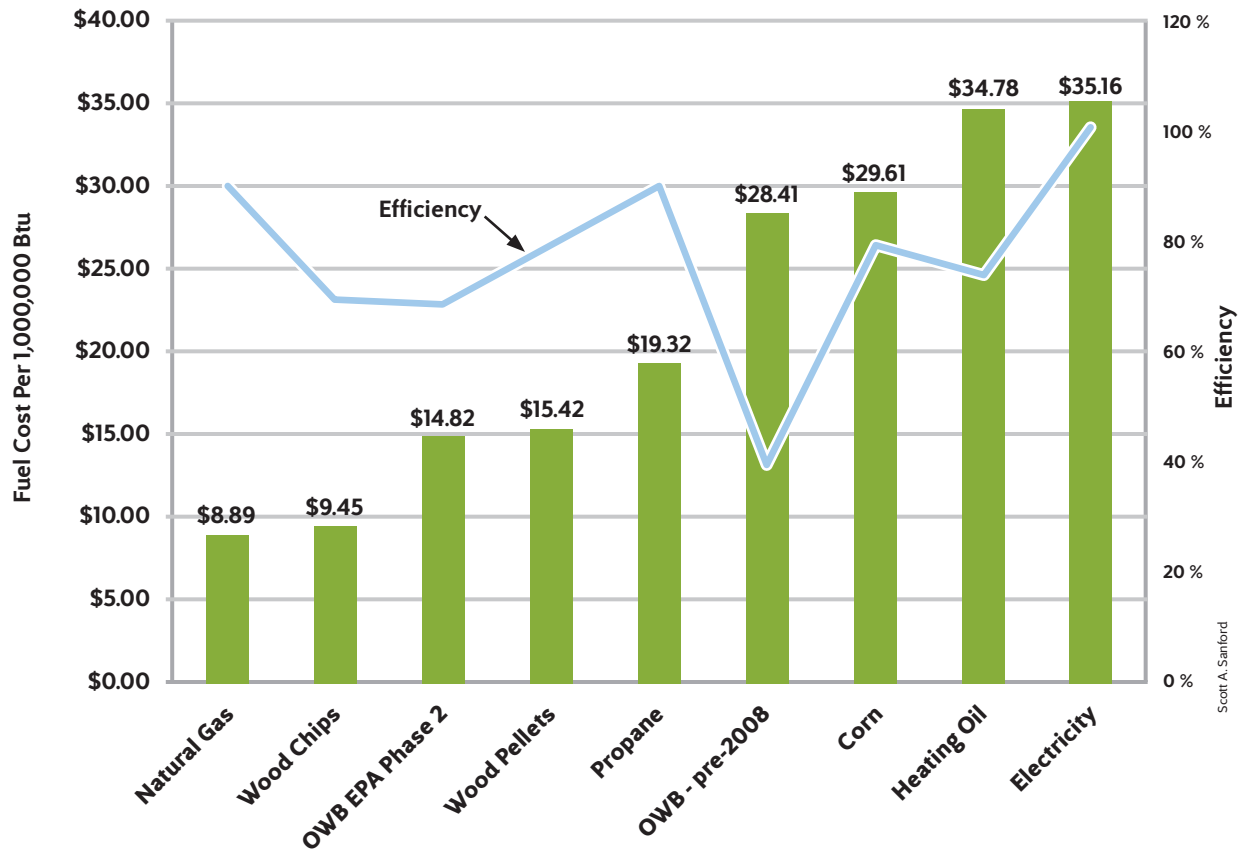
<sup>1</sup> Meets EPA Phase 2 emissions requirement

<sup>2</sup> Typical pre-2008 outdoor wood-fired boiler (does not meet EPA Phase 2 requirement)

<sup>3</sup> 6,500 Btu/pound (20% moisture)

<sup>4</sup> Fuel costs in Madison, WI for 2013-14 heating season delivered to point of use (does not include any storage costs)

**FIGURE 3 – Fuel cost per 1,000,000 Btu** (see Table 2 for energy and fuel cost assumptions)



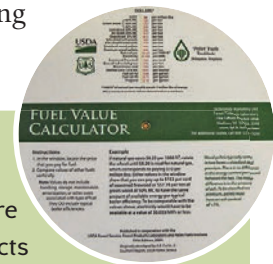
appliances. The chart indicates that natural gas is a very cost-effective fuel. If you choose any other type of heating appliance or fuel you will spend more. However, not everyone has access to natural gas. In many rural areas LP gas, heating oil or electricity are the energy choices. If you currently are using LP gas in a unit with an efficiency of less than 90 percent, upgrading to a high-efficiency condensing unit will likely have a better return on your investment (pay off faster) than investing in a wood-burning heating unit.

If you already are using a high-efficiency LP gas unit and are considering some type of biomass heating appliance, what are your choices? Based on the chart, an EPA-qualified OWB would reduce your fuel cost by 23 percent. But if you purchase a unit that is NOT EPA-qualified, it could increase the fuel cost by 47 percent. Installing a wood pellet boiler would reduce your fuel cost by 20 percent; the equipment cost is often half the cost of an OWB, and the refueling and ash disposal costs are greatly reduced as well, thus reducing the total annual cost.



### Fuel cost calculation tools

The Fuel Value Calculator wheel was developed by the USDA Forest Service to compare a variety of fuels in typical heating units. It is available from the USDA Forest Products Laboratory in Madison, Wisconsin (608-231-9200). A description of how it works can be viewed at <http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf>



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## Smoke Impacts to Neighbors and Communities



Wood smoke is responsible for about 13 percent of all fine particle emissions nationally, and several locations with wood smoke problems exceed EPA's health-based standards. In places such as Keene, N.H., Sacramento, Cal., Tacoma, Wash., and Fairbanks, Alaska, wood combustion can contribute over 50 percent of daily wintertime fine particle emissions. (USEPA-a).

Wood smoke and fine particles penetrate building envelopes creating odors and raising the level of indoor air pollution for wood stove owners and their neighbors (Environment and Human Health, Inc., 2010). The Wisconsin Department of Health Services (WDHS) has determined that when a visible smoke plume impacts a neighboring house or property, the USEPA PM2.5 health standards have been exceeded. Strong smoke odors, along with the visible plume, indicate the presence of a mixture of irritating chemicals. WDHS has determined that a "cause and effect" relationship has been established

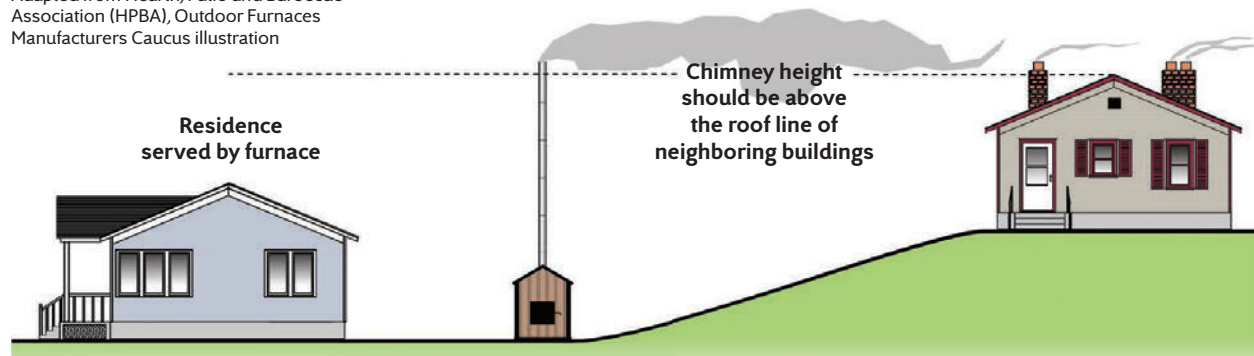
### Responsible firebox management

Practical steps can be taken to minimize the smoke emissions from any wood-burning appliance, which helps reduce air pollution, saves money, and fosters better neighbor relations.

- Only burn dry, seasoned firewood – wet wood will reduce firebox temperatures and cause smoke and creosote formation. Split wood into pieces no larger than a 6-inch wedge and pile or stack them so air can freely move around the wood. Once split, seasoning will require one or two summers, depending on the wood species.
- Don't burn trash or painted or treated wood – these materials can emit toxic air pollutants when burned and often produce foul odors.
- Don't overload the firebox – only put enough wood in for the next 8 to 12 hours. Filling more often with smaller amounts will reduce the amount of fuel to cause smoke. Remember smoke is unburned wood, so smoke up the chimney means wasted wood (and money).
- Don't let a fire smolder – if heat is not needed, put the fire out.
- Make sure chimney height is at least 2 feet higher than any residence or building within 300 feet of an OWB. This will aid in dispersing smoke and ensure the appliance has adequate draw (see Figure 4.).
- Clean out the ash pan regularly - excess ashes can clog air intake vents and reduce heating efficiency. Always use a metal container for storing or transporting ash.
- Keep the chimney clean – this reduces the risk of chimney fires and provides better draft.

**FIGURE 4 – Chimney Height Installation Scenario**

Adapted from Hearth, Patio and Barbecue Association (HPBA), Outdoor Furnaces Manufacturers Caucus illustration



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between wood smoke emissions and adverse health effects to downwind neighbors. That is, if there are visible emissions and odors at a neighboring residence(s), there is a completed exposure pathway and the potential for adverse health effects.

A study of wood smoke emissions in Grand Rapids, Wis., found that fine particle (PM) concentrations measured at a central site over a 24-hour period ranged from 3.0 to 22.6  $\mu\text{g}/\text{m}^3$ , which is below the USEPA air quality standard of 35.5  $\mu\text{g}/\text{m}^3$  (National Ambient Air Quality Standard), although the 1-hour average varied from 1.8 to 86.8  $\mu\text{g}/\text{m}^3$ . However, measurements of PM<sub>2.5</sub> concentration made during mobile



monitoring routinely exceeded 100.0  $\mu\text{g}/\text{m}^3$ , particularly in residential areas, and reached as high as 370.0  $\mu\text{g}/\text{m}^3$ . These measurements, along with other data, indicate that exposure to fine particle pollution can be significant in some residential areas, particularly during morning and evening hours when residents are likely to be at home.

Wood smoke emissions have been shown to negatively affect those with low income and those from vulnerable populations, such as pregnant women, the very young and very old, and people with compromised immune systems or chronic health conditions such as diabetes, lung disease and heart disease (*American Lung Assoc., 2011*).

### Wood smoke ordinances

The Wisconsin Department of Health Services has compiled a list of over two hundred Wisconsin communities that regulate wood smoke, including links to the text of their ordinances. The list is available at <http://www.dhs.wisconsin.gov/eh/Air/owbordinanceReport.htm>

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## Glossary of Terms (underlined where they first appear in this document)

**Auger** – A threaded rod with a continuous helical flight attached to a shaft. The auger in a wood heating system is enclosed in a tube. As it rotates, it pushes material along the length of the tube.

**Catalytic wood stoves** – Stoves with a high temperature catalytic converter in the stack. The converter helps reduce emissions by increasing fine particle combustion.

**Gasification** – When combustible gases are driven from wood fuel under high temperature-low oxygen conditions, and then burned to provide additional heat.

**Non-catalytic wood stoves** – Stoves that circulate air within the firebox to re-burn smoke and gases. This helps reduce fine particle emissions.

**PM<sub>2.5</sub>** (fine particle pollution) – Pollution caused by solid particles or liquid aerosols smaller than 2.5 micrometers (microns) in diameter. These particles can lodge deep in the lungs and cause adverse health effects.

**Pyrolysis** – Decomposition of wood taking place above 400 F in conditions where there is little or no oxygen.

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# Fuel Switching Work Sheet

- A) Amount of Fuel currently used annually: ..... \_\_\_\_\_ gal / Therm / kWh
- B) Energy Content of fuel: ..... \_\_\_\_\_ Btu / unit of fuel
- C) Efficiency of heating appliance:..... \_\_\_\_\_ %
- D) Amount of Usable Heat (A x B x C) ..... \_\_\_\_\_ Btu / year
- E) Energy Efficiency of new heating Appliance ..... \_\_\_\_\_ %
- F) Amount of energy needed (D / E) ..... \_\_\_\_\_ Btu / year
- G) Energy content of new Fuel: ..... \_\_\_\_\_ Btu / unit of fuel
- H) Amount of new Fuel needed (F x G) ..... \_\_\_\_\_ gal / Therm / kWh
- I) Cost per unit or new Fuel ..... \_\_\_\_\_ \$ / Gal / Therm / kWh
- J) Cost of Current Fuel per year ..... \_\_\_\_\_ \$ / year
- K) Estimated new Fuel cost annually (H x J)..... \_\_\_\_\_ \$ / year
- L) Estimated Annual Fuel Savings (J – K) ..... \_\_\_\_\_ \$ / year

## Wood Heating Appliances for Homes and Businesses

### Choosing the Right Equipment

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