Energy Efficient Wood Heating Appliances for Home and Business

Scott Sanford
Sr. Outreach Specialist
Rural Energy Program
Disclaimer

• Products mentioned in this presentation do not reflect an endorsement of that product.

• Likewise, a lack of acknowledge does not imply that a product is not recommended.

• Photo Credit: Scott Sanford unless noted otherwise
Outline

• What make an efficient appliance?
• Types of wood fuels
• Types of Wood Burning Appliances
• Heat distribution
• Smoke Emissions
• Firebox Management
• Case Study of two greenhouses
Biomass Fuels

- A fuel derived from plant material
  - Wood (cord, chips, pellets)
  - Grains (corn, rye, wheat,…)
  - Cherry pits, sunflower hulls
  - Prairie grass (switchgrass, miscanthus)
  - Crop fodder (corn stalks)
  - Straw (wheat, oat, barley)
  - Oils

Credit: University of Illinois
Types of Wood Fuels

- **Cord wood**
- **Green mill residue**
  - Hogged bark & sawdust
  - High moisture (>20%)
  - Store outside in piles
- **Dry mill residue**
  - Low moisture (< 10%)
  - Sawdust, trimmings, wood from wood products companies
- **Wood Chips**
  - Whole tree chips, round wood chips, clean chips
  - Typically high moisture (~50%)
  - Energy content varies with $H_2O$, density and ash
Direct Use - Wood

- Cord wood / logs
  - Unit of measure – Cord
    - 4 ft x 4 ft x 8 ft stack of wood – 128 cu ft
  - Moisture – 50% as harvested
    - Air Dried - ~ 20% (1 – 2 years)
  - Energy content – varies with tree species
    - Average – 22,300,000 Btu / cord @ 20% moisture
    - Range – 14,700,000 to 30,700,000 Btu / cord
    - Different species vary in density (lbs / cord)
      - Basswood – 2100 lb / cord; Hickory 4160 lb / cord
      - All wood about 7000 Btu / lb. @ 20% moisture
Cord wood

- “Low cost” ???
- Labor intensive
  - Handle 3 to 6 times
- Harvesting
  - Cut, transport, split, pile/stack,
- Air dry - Minimum 1 summer / 2 better
  - Plan requirements 1-2 yrs ahead
- Refueling labor
- Ash disposal
- Energy content depends on species
- High emissions – new regulations
# Burning Characteristics of Select Wood Species

<table>
<thead>
<tr>
<th>Wood Species</th>
<th>Weight (lbs/cord)</th>
<th>Energy per dry cord (Million Btus)</th>
<th>Relative smoke emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green</td>
<td>Air dried</td>
<td></td>
</tr>
<tr>
<td>Green Ash</td>
<td>4184</td>
<td>2880</td>
<td>20.0</td>
</tr>
<tr>
<td>Birch</td>
<td>4312</td>
<td>2992</td>
<td>20.8</td>
</tr>
<tr>
<td>Boxelder</td>
<td>3589</td>
<td>2632</td>
<td>18.3</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>4640</td>
<td>2272</td>
<td>15.8</td>
</tr>
<tr>
<td>American Elm</td>
<td>4456</td>
<td>2872</td>
<td>20.0</td>
</tr>
<tr>
<td>Black Locust</td>
<td>4616</td>
<td>4016</td>
<td>27.9</td>
</tr>
<tr>
<td>Sugar/Rock Maple</td>
<td>4685</td>
<td>3680</td>
<td>25.5</td>
</tr>
<tr>
<td>Silver Maple</td>
<td>3904</td>
<td>2752</td>
<td>19.0</td>
</tr>
<tr>
<td>Bur Oak</td>
<td>4960</td>
<td>3768</td>
<td>26.2</td>
</tr>
<tr>
<td>White Oak</td>
<td>5573</td>
<td>4200</td>
<td>29.1</td>
</tr>
<tr>
<td>White Fir</td>
<td>3585</td>
<td>2104</td>
<td>14.6</td>
</tr>
</tbody>
</table>

Source: M. Kuhns & T. Schmidt, Heating with Wood, University of Nebraska-Extension
Direct Use – Green Wood Chips

- **Local availability**
  - Low cost

- **Moisture Content**
  - Green ~ 50% moisture
  - Lower energy content
    - 4500 Btu/lb

- **Bulk handling**
  - Augers
  - Loaders

- **Storage**
  - Outside pile
  - Bunker / covered

Source: NREL
Densification
Pellets / Cubes

- Use of by-products / low value materials
  - Sawdust, wood chips, waste wood
- Facilitates handling
- Reduces transportation costs
- Uniform product
- Automatic stoking
- Low emissions / low smoke
- Higher thermal efficiency – 80% to 90+% 
- Bulk Handling – grain handling equipment
- Higher cost / energy input
Wood Pellets

- Material – Sawdust, wood residue
- Unit of measure – Tons or pounds
  - Bulk in tons or 40-50 pound bags
- Moisture
  - 6 to 10% depending on grade
- Energy content
  - Average – 8000 Btu / lb
- Grades (Pellet Fuels Institute)
  - Utility, standard, premium, super premium
  - Difference is mainly ash content 6%, 2%, 1%, 0.5%
- Uniform product
  - 1/4” to 5/16” diameter x 1” to 1-1/2” long

Biomass Pellets

• Materials
  • Prairie grass mixes (Switchgrass, Miscanthus, hay)
  • Straw (wheat, oat, barley, rye)
  • Corn fodder (stalks & cob)
  • Nut hulls, sunflower hulls
  • Wood residue

• Unit of measure
  • Bulk in tons or 50 pound bags

• Moisture
  • 8-11% typical

• Energy content
  • 7200 to 8000 Btu per pound
  • Higher energy contents typically include some wood residue

• Chloride content – Often higher than PFI standard of 300 ppm max
  • High temperature corrosive agent – boiler corrosion over time
How does wood burn?

- Heat drives off moisture
- Wood undergoes Pyrolysis
  - Breaks down into organic gases
  - 85% of mass and 60% of heat value in gases
- Charcoal burns at 1100 ºF
- Unburnt residue
  - Smoke or creosote
- Complete combustion requires 3 “T”s
  - Temperature – 1100 to 1500ºF to ignite pyrolysis gas
  - Turbulence – 10-12 lbs air per lb of pyrolysis gas
  - Time – 2 to 4 sec in high temp zone
What is a boiler versus a furnace?

- Boiler heats a fluid (water, glycol/water solution, steam)
  - Hydronic Heater (water heater)
  - Fluid can be pumped to the location where it is to be used.
- Furnace heats air
  - Air blown through ducts to location needed

Outdoor Hydronic Heater

Pellet furnace
Credit: HarmanStoves

Pellet boiler & bin
Credit: Josh Kaurich
Boilers

- One boiler can heat multiple locations
- One system for floor heating and supplemental heating with heat exchanger
- Multiple boilers can be in central location
  - One fuel storage system
- Can be located outside
- Store heat - insulated tank
  - To meet peak needs

Source: www.renewenergies.com
Furnaces

• Heats air directly
  • Reduces heat exchange losses
• Located in or adjacent to building
• No water leaks to worry about
• May need multiple furnaces per building
  • Lower capacity
• Multiple fuel storage bins
  • More labor to fill furnace hoppers

Source: www.tractorbynet.com
Outdoor Wood-Fired Boilers

- **Fuel:** cord wood, wood scrape materials, pallets
- **“Cheaper” Fuel? – What is the true cost?**
  - Labor & equipment to collect & harvest fuel
  - Labor to re-fuel
  - Disposal of Ash
- **High Smoke emissions rate**
  - Reduced with firebox management
- **Low Efficiency – Average 40%**
  - pre-2008 efficiency range: 20 to 50%
- **Great for use with floor heating**
- **Can use with Air Exchanger**
- **Fuel with scrap materials?**
  - NO Glue, NO paint, NO Chemical contamination,
  - NO Pressure-Treated wood
- **Increasing regulation due to smoke emissions**
Outdoor Wood Boiler Emissions
EPA Certified Outdoor Boilers

- EPA Voluntary Emissions Reduction Program
  - 90% lower emissions
- Low emissions → higher efficiency
  - Average efficiency of qualifying cord wood boilers - ~ 70%
- Many states restricted sales - EPA certified models
  - White tag / Phase 2

- EPA information
  - [http://www.epa.gov/burnwise/](http://www.epa.gov/burnwise/)

List of qualifying outdoor wood stoves
- [http://www.epa.gov/burnwise/owhhlist.html](http://www.epa.gov/burnwise/owhhlist.html)

- New EPA proposal
  - Emission from 0.32 to 0.06 lb/MBTU (2015)
White Tag

- Outdoor Wood Boilers
  - Graphical comparison to standard limits
  - Maximum output rating
  - 8-hour output rating
  - 8-hour average Eff.
  - Annual Efficiency
  - Fine particle emissions

http://www.epa.gov/burnwise/guidewhitetagownn.html
Gasification Technology

1 – Firebox – fire brick lined
   • Absorbs heat to maintain higher combustion temperatures

2 – Fire nozzle
   • Entrance to lower burn chamber

3 – Secondary Burn Chamber
   • Burns at 2000 °F
   • Low smoke

4 – Heat Exchanger
   • Separate from fire box
   • Higher heat transfer

5 - Chimney Exhaust

Source: www.profab.org
Pellet Boiler

Ash Bin

Wagon

Ash Auger

Boiler Controls

Boiler

Feed Auger

Pellet Supply Bin
Pellet / corn furnace ~165,000 Btu

Credit: Vern Grubinger, University of Vermont
Anatomy of a pellet Boiler

Source: www.profab.org
Pellet/corn furnaces

Keep your old system for backup and COLD nights!

Credit: Vern Grubinger, University of Vermont
Advantages of Pellet Boilers / Furnace

- Fuel homogenous
- Variety of fuel pellet sources
  - Wood
  - Paper
  - Biomass
- Adjustable burn rate
  - Feed auger speed
- Low emissions
- High efficiency
  - 80% typ., up to 90+%  
- Low labor – automatic stoking and ash removal

Credit: Focus on Energy
Wood Chip Boiler

- Higher capital investment
- Higher maintenance
- Many moving parts
- Suited for larger applications
- Uses low cost product
- Labor to re-fill charge hoppers required daily
- Wood chips – 25 to 50% moisture
- Need storage for tractor trailer load++ of chips
- Availability of supply??
- Capacities ~ 500,000 Btu and greater

Source: www.danvillek12vt.org
Wood Chip Feed System

Storage bin with walking floor

Barron High School, Barron, WI
Stand Alone Stoves

- **Advantage**
  - Lower cost
  - Easy to install
  - Fast payback
  - Supplemental heating

- **Disadvantage**
  - Hopper size may be too small to last all night
  - May not be thermostatically controlled – overheating
  - Heat distribution not optimal
  - Low Btu output - ~ 30,000 to 70,000 Btu/hr
How is the heat distributed?
Bench heating system

Supply and Return piping

Small heating tubes run in loops on growing bench

Credit: Vern Grubinger, University of Vermont
3,000 gallon tank stores heated water, which allows furnace to run hot / cycle less

Credit: Vern Grubinger, University of Vermont
# Fuel Comparison

## Fuel Type comparison - in order of cost (2013)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy content</th>
<th>Seasonal Efficiency (2)</th>
<th>Unit cost USD (4)</th>
<th>units</th>
<th>Cost per 1,000,000 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>100000/therm</td>
<td>70-94% (90%)</td>
<td>0.80</td>
<td>Therm</td>
<td>$8.89</td>
</tr>
<tr>
<td>Wood Chips</td>
<td>3780 (50%) - 6190 (25%) / lb</td>
<td>50 - 75% (70%)</td>
<td>50</td>
<td>ton (50%)</td>
<td>$9.45</td>
</tr>
<tr>
<td>OWB EPA Phase 2 (1)</td>
<td>22,000,000 per cord (3)</td>
<td>69%</td>
<td>225</td>
<td>cord</td>
<td>$14.82</td>
</tr>
<tr>
<td>Wood Pellets</td>
<td>15400000 per ton</td>
<td>70-85% (80%)</td>
<td>190</td>
<td>ton</td>
<td>$15.42</td>
</tr>
<tr>
<td>Propane</td>
<td>92000</td>
<td>70-94% (90%)</td>
<td>1.60</td>
<td>gallon</td>
<td>$19.32</td>
</tr>
<tr>
<td>OWB - pre-2008 (5)</td>
<td>22,000,000 per cord (3)</td>
<td>40%</td>
<td>250</td>
<td>cord</td>
<td>$28.41</td>
</tr>
<tr>
<td>Corn</td>
<td>380,000 per bushel (@ 15% moisture)</td>
<td>70-85% (80%)</td>
<td>9.00</td>
<td>50#</td>
<td>$29.61</td>
</tr>
<tr>
<td>Heating Oil</td>
<td>138000</td>
<td>70-85% (75%)</td>
<td>3.60</td>
<td>gallon</td>
<td>$34.78</td>
</tr>
<tr>
<td>Electricity</td>
<td>3413 / kWh</td>
<td>100%</td>
<td>0.12</td>
<td>kWh</td>
<td>$35.16</td>
</tr>
</tbody>
</table>

1) Meets EPA Phase 2 emissions requirement
2) (XX%) Efficiency value used to calculate “Cost per 1,000,000 Btu”
3) 6500 Btu/pound (20% moisture)
4) Fuel costs in Madison, WI for 2013-2014 heating season delivered to point of use. Does not include any storage costs
5) Typical Pre-2008 outdoor wood-fired boiler (Does not meet EPA Phase 2 requirement)
Equation for Table

• $ / Mbtu = $ per unit \times 1,000,000
  \text{Energy content/unit x Efficiency}

• Unit – Trading unit (gallons, tons, cords)

Propane @ $2.70/gallon

• $ / MMBtu = \frac{$2.70 \text{ per gallon} \times 1,000,000}{91,600 \text{ Btu/gallon} \times 0.90}

  = $ 32.75 / MMBtu
Sizing a heating system

• What percent of the heating do you want to replace?
  • Full Replacement
  • Some proportion of total heating
  • 90%, 80%, 50%, Other?
Sizing a heating system

- Closer to 100% = longer payback
  - 100% capacity only used a few hours per year
  - 50% to 80% likely good target to meet average needs
- Biomass systems designed to run continuously
- Use Thermal Storage to smooth out peaks and valleys of use.
Smoke Emissions – Why Care?

• Contains
  • Fine Particle matter (PM2.5)
    • Asthma attacks, cancers
  • Carbon Monoxide
  • Nitrogen Oxides
    • Greenhouse Gas
  • Volatile Organic Compounds
  • Carcinogens
  • Odors
  • ~ 100 different compounds

• Smoke = Unburnt Fuel → lower efficiency
  • Less Smoke → Less wood
Fine Particle Emissions

Relative Emissions of Fine Particles

- Fireplace: 28
- Uncertified Woodstove: 4.6
- EPA Certified Woodstove: 1.4
- Pellet Stove: 0.49
- Oil Furnace: 0.013
- Gas Furnace: 0.0083

*Average emissions (lbs/mmBtus of heat output) for heat source type. Data from US EPA

Annual Average Emissions Level of EPA Phase 2 Qualified Models (lbs/mmBtus of heat output)**

- HH Phase 2 Stick Wood Emission Average: 0.21
- HH Phase 2 Wood Pellet Emission Average: 0.13

**Data from US EPA website 11/10/11.
Firebox Management

• Only burn dry, seasoned firewood
  • 6” wedge or smaller
  • Wet wood is a waste!
    • Lower firebox temperatures
    • Smoke
    • Creosote Formation
• Don’t burn trash, painted or treated wood
  • Foul odors
  • Toxic air pollutants
Firebox Management

- Don’t overload firebox
  - Only enough for next 8-12 hours
  - Smaller amounts reduces smoke potential
- Don’t let fire smolder
  - Heat not needed – put out fire
- Clean ash pan regularly
  - Ash can obstruct air intake vents
  - Use metal containers for storing or transporting ash
- Clean chimney regularly
  - Reduce risk of chimney fires
Firebox Management

• Chimney height
  • 2 feet higher than highest building within 300 feet
Why wood moisture is important

Net Energy of wood based on % moisture

Green – as cut
75% moisture

4900 Btu / lb
5.8 cords

45% moisture

5900 Btu / lb
4.8 cords

Air-dried
20% moisture

7100 Btu / lb
4 cords

Oven Dried
0% moisture

8600 Btu / lb
3.3 cords

Why wood moisture is important
Wood Moisture Tester

- Cost ~ $30
- Method
  - Split wood to expose fresh wood
  - Press meter pins into fresh wood
  - Take several readings per piece
  - Test several pieces of wood
  - Average results
Case Study #1

- Freestanding gothic greenhouse
  - 30’ x 96’
- Double poly glazing
- Used Feb to June – veg. & bedding plants
- Currently has two 200,000 Btu power-vented unit heaters (78% Eff.)
- Propane fuel - $2.00 /gallon
- Set point temperature: 70°F day, 60°F night
- Location: Madison, WI
Option A

- Residential/shop pellet stove
  - Rated output - 70,000 Btu/hr
  - Supplement heating
    - operated mainly at night
  - No Thermostat
  - Installed cost $4350
  - Stove efficiency = 80%
  - Wood pellet cost - $4.20 / 40 lb bag ($210 / ton)

Source: www.bixbyenergy.com/stoves/index.php
Option B

- Thermostatically controlled pellet furnace
  - Heating capacity range: 10,000 to 160,000 Btu/hr
  - Furnace efficiency = 80%
  - Air ducted directly into the greenhouse above plants
  - Located at one end of greenhouse
  - Installation cost = $6030
    - Includes 14 bushel fuel bin
  - Bagged pellets assume
    - Avoid cost of bulk storage
  - $4.20 / 40 lb bag
Option C

- EPA Phase 2 outdoor wood boiler
  - Average capacity (8 hour period) – 160,000 Btu/hr
  - Two water to air heat exchangers (HE) in center of greenhouse to distribute heat
  - Thermostatically controlled
    - Pump to HE turns on when greenhouse requires heat
  - Installed cost - $13,050 (boiler, all piping, heat exchanger)
  - Average boiler efficiency = 75%
  - Full Cord of Wood - $150/cord (assuming self harvested)
Option D

- Same as Option C except non EPA qualifying boiler
- Installed cost $11,634
- Estimated Efficiency = 40%
### Average Night Heating Requirements by Month

<table>
<thead>
<tr>
<th>Month</th>
<th>Heating requirements Btu/day</th>
<th>Approx. average hourly heating - Btu/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td>1,643,818</td>
<td>136,985</td>
</tr>
<tr>
<td>March</td>
<td>1,119,650</td>
<td>93,304</td>
</tr>
<tr>
<td>April</td>
<td>732,940</td>
<td>61,078</td>
</tr>
<tr>
<td>May</td>
<td>343,839</td>
<td>28,653</td>
</tr>
</tbody>
</table>

- Day-time heating, on-average, are fully met by solar radiation except for February
- Average February day-time heating – 12,800 Btu/hr
How much heat can Biomass provide?

- Option A – 100% of heating down to ~40°F
  - Estimated 50% reduction in propane use
- Options B, C & D – 100% of heating down to ~ 10°F
  - Average monthly minimum Feb temperature
    - 14.3°F
  - Based on Average Options B, C & D can supply 100% of needs
  - Reality – estimated 20% will be supplied by propane
Summary of Biomass Heating Options

Baseline: 1592 gallon propane @ $2.00/gal = $3184 / year

<table>
<thead>
<tr>
<th>Heating System</th>
<th>System Cost</th>
<th>Biomass Quantity</th>
<th>Biomass Energy Cost*</th>
<th>Propane (gallons)</th>
<th>Propane Cost</th>
<th>Total Savings</th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Residential pellet stove</td>
<td>$4350</td>
<td>282 40# bags</td>
<td>$1184</td>
<td>639</td>
<td>$1278</td>
<td>$722</td>
<td>6.0</td>
</tr>
<tr>
<td>B) Pellet furnace</td>
<td>$6030</td>
<td>355 40# bags</td>
<td>$1491</td>
<td>318</td>
<td>$636</td>
<td>$1057</td>
<td>5.7</td>
</tr>
<tr>
<td>C) Outdoor wood boiler-EPA Certified</td>
<td>$13050</td>
<td>6 cords</td>
<td>$900</td>
<td>318</td>
<td>$636</td>
<td>$1648</td>
<td>7.9</td>
</tr>
<tr>
<td>D) Outdoor wood boiler</td>
<td>$11634</td>
<td>10 cords</td>
<td>$1500</td>
<td>318</td>
<td>$636</td>
<td>$1048</td>
<td>11.1</td>
</tr>
</tbody>
</table>

* $4.20 per 40 pound bag; Cord wood @ $150/cord
Case Study #2

- Gutter-connected greenhouse
- 33,000 square feet
- Double Poly film glazing – roof and walls
- Year-round production
- Heating system – In-floor heating with unit heaters for peaking on cold nights
- Fuel: Propane @ $2.00 / gallon
- Baseline energy use – 85,581 gallons LP gas
  - $ 171,162 annual heating cost
- Cord wood boiler was not considered
  - Increased labor, limited area for fuel storage
Option A

• Meet 100% of heating requirements
  • Two pellet boilers – 3.5 MBtu/hr & 1.5 MBtu/hr
    • Minimum of 4.2 MBtu to meet -20°F design temperature
    • Average efficiency = 78%
  • Use smaller boiler during spring and fall months
  • Large boilers hard to throttle for low demand
    • Estimated 5% of season would use propane heaters
  • Bins for bulk delivery of pellets
  • Installed Cost: $291,000
Option B

• Boilers sized to meet average heating requirement (~80%)
  • Two pellet boilers – 2.5 MBtu/hr & 1.0 MBtu/hr
  • Use smaller boiler during spring and fall months
    • Large boilers hard to throttle for low demand
  • Estimated propane use – 20%
  • Bins for bulk delivery of pellets
  • Installed Cost: $211,000
## Summary of Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Capital Cost</th>
<th>Tons of Wood Pellets</th>
<th>Wood Pellet Cost *</th>
<th>Propane Cost</th>
<th>Energy Savings</th>
<th>Simple Payback years</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$291,000</td>
<td>465</td>
<td>$82,770</td>
<td>$8,558</td>
<td>$79,834</td>
<td>3.6</td>
</tr>
<tr>
<td>B</td>
<td>$211,000</td>
<td>392</td>
<td>$69,776</td>
<td>$34,232</td>
<td>$67,154</td>
<td>3.1</td>
</tr>
</tbody>
</table>

* Bulk Wood pellet cost - $178 / ton in 22 ton loads
Summary

• Energy efficiency options First!
  • High Efficiency Furnace, insulation, windows
  • Better return on investment
• Purchase Efficient Appliances > 75%
• Look at complete economics of all options
  • Include labor and market costs
  • Higher efficiency sometimes costs more
• Firebox management – No/low smoke
• Burning wet wood is a waste! Don’t use it.
Resources

• U of Wisconsin Extension Bulletins
  • Wood Heating Appliances for Home and Businesses, GWO066
  • Biomass Energy for Heating Greenhouses, A3907-04
  • Biomass Heating in Greenhouses: Case Studies, A3907-05
    • http://learningstore.uwex.edu/Energy-Conservation-C29.aspx

• Pellet Fuels Institute – www.pelletheat.org
  • Educational material, pellet manufacturers list


• Biomass for combustion calculator
  • www.ruralenergy.wisc.edu/esa
Questions

This presentation was develop by:
Scott Sanford
Sr. Outreach Specialist
Rural Energy Program
University of Wisconsin-Madison

Comments and suggestion should be directed to sasanford@wisc.edu

The contents of this presentation can be used in whole or in part for greenhouse grower education.