What is Biomass fuel
- Direct use – wood, grains
- Bulky – straw, prairie grass, hay, sawdust
- Density for use – pellet / cube
- By-products – 
  - Cherry pits, sunflower hulls, nut hulls, rice hulls
- Processed fuels – Oils or sugars

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

Material Characterization
- Unit of measure – Cord, tons, pounds
- Moisture
  - Reduces net energy content
  - Water must be evaporated before burning will initiate
- Energy content – Btu / unit of measure
  - Low Heating Value (LHV) – net energy after moisture is evaporated
  - High Heating Value (HHV) – net energy if moisture is condensed after combustion
- Size and shape
- Ash content (pellets)
- Chemical contents: Chloride

Types of Wood Fuels
- Energy content varies with H2O, density and ash
- 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%)
### Direct Use - Wood

- **Cord wood / logs**
  - Unit of measure – Cord
  - 4 ft x 4 ft x 8 ft stack of wood – 128 sq 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
- **Moisture**: 50% as harvested
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- **Different species vary in density** (lbs / cord)
  - Basswood – 2100 lb / cord; Hickory 4160 lb / cord
- **All wood about 7000 Btu / lb. @ 20% moisture**
- **“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**
- **High emissions – new regulations**

### 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

### Direct Use - Grains

- **Corn**
  - Unit of measure – Bushels or pounds/tons
  - Bulk in bushels or 50 pound bags
  - 56 lbs per bushel @ 15.5% moisture content
  - Moisture
    - 15.5% std; also available at 12% by some retailers
  - Energy content
    - 6810 (15%) to 7130 (12%) Btu per pound
  - Advantages
    - Readily available
    - No processing
  - Disadvantages
    - Slag / Clinkers (solid ash)
    - Drying required for storage / proper combustion
    - Need wood pellets to start burning
    - Flame out at lower feed rates / higher moisture levels

### Direct Use - Grains

- **Wheat**
  - Bushel – 60 lbs @ 13.5% moisture
- **Oats**
  - Bushel – 32 lbs @ 14% moisture
- **Barley**
  - Bushel – 48 lbs @ 14.5% moisture
- **Rye**
  - Bushel – 56 lbs @ 14% moisture
- **Soybeans**
  - Bushel – 60 lbs @ 13% moisture
- **Sunflowers**
  - Per 100 lbs or cwt. @ 10% moisture

### Calculating Heat values

- **Corn**
  - Bone-dry – 8250 Btu per pound
  - If corn is 15% moisture then one pound of corn:
    - 0.85 pounds corn
    - 0.15 pounds water
    - Water require 1050 Btu / pound to evaporate
    - 0.85 x 8250 – (1050 x 0.15) = 6855 Btu / pound
  - There may be further losses to transfer heat to air or water in boiler or furnace.
    - Typical efficiencies = 80%
**Densification**

- Pellets / cubes
  - Facilitates handling
  - Reduces transportation costs
  - Use of by-products / low value materials
  - Uniform product
  - Bulk Handling – grain handling equipment
  - Dry storage needed
  - Automatic stoking
  - Low emissions / low smoke
  - Higher thermal efficiency – 80% to 90+%
  - Higher cost / energy input

**Densification**

- Pellets
  - 1/4” to 5/16” diameter x 1” to 1-1/2” long
  - Wood, Prairie grasses, paper
  - Use in pellet stoves/boiler
- Cube or Briquette
  - 1” x 1-1/4” cube
  - Used to replace coal
  - Industrial boilers

**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

**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

**Biomass Fuels**

- Corn
- Wood Pellets
- Prairie Grass Pellets
- Small Grains (Rye & Vetch)

**What is a boiler versus a furnace?**

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

### Boilers
- One boiler can heat multiple greenhouses
- One system for under-bench/floor heating and supplemental water/air heat exchanger
- Can be located outside the greenhouse
  - Maximize growing space
- Boilers can be in central location
  - One fuel storage system
- Store heat in tank of heat transfer fluid

### Furnaces
- Heats air directly
  - Reduces heat exchange losses
- Located in or adjacent to greenhouse
  - Takes up growing space?
- No leaks to worry about
- May need multiple furnaces per greenhouse
  - Multiple fuel storage bins or labor to fill furnace hoppers

### Outdoor Wood Boiler Emissions
- Outdoor Wood-Fired Boilers
  - Fuel: 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 emissions rate / Smoke
    - Reduce with firebox management
  - Low Efficiency
    - pre-2008 Efficiency range: 20 to 50%
    - 2008 EPA Standards for outdoor boilers
    - Great for use with floor heating
    - Can use with Air Exchanger
    - Fuel with scrap materials?
    - Increasing regulation due to smoke emissions

- EPA Qualified Outdoor Boilers
  - 90% lower emissions
  - Low emissions = higher efficiency
    - Average efficiency of qualifying boilers ~ 70%
  - Many states are restricting sales to EPA qualifying models
  - White tag / Orange tag
  - EPA information
    - www.epa.gov/woodheaters/
    - List of qualifying outdoor wood stoves
    - www.epa.gov/owhh/models.htm

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### Pellet Boiler
- Pellet Supply Bin
- Ash Bin Wagon
- Boiler Controls
- Feed Auger
- Boiler
- Ash Auger
Pellet/corn furnaces
Keep your old system for backup and COLD nights!

500,000 Btu Pellet / corn furnace
Credit: Vern Grubinger, University of Vermont

Pellet Boilers / Furnace Advantages

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

How is the heat distributed?

- Furnace – Ducts and fans
- Poly bags – may not be suitable depending on outlet temperature.
- Boiler
  - Water to air heat exchanger
  - Bench-top or under-bench or floor heating
  - Develop a micro climate
  - Warm roots increases growth
  - May still need water to air heat exchangers for cold spells.

Water to air heat exchanger
Credit: Focus on Energy

Source: www.thermpex.com

Poly bags – may not be suitable depending on outlet temperature.
**Bench heating system**

Supply and Return piping

Small heating tubes run in loops on growing bench

**Supply and Return piping**

Supply and return piping for the bench heating system.

**3,000 gallon tank stores heat in water, which allows furnace to run hot**

3,000 gallon tank stores heat in water, allowing the furnace to run hot.

**Wood Chip Boiler**

- Higher capital investment
- Higher maintenance
- Many moving parts
- Suited for industrial 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 plus of chips
- Availability of supply??

Credit: Vern Grubinger, University of Vermont

**Stand Alone Stoves**

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

- **Disadvantage**
  - Hopper 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

**Fuel Comparison**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy Content Btu per unit</th>
<th>Boiler Thermal Efficiency</th>
<th>Unit Cost1</th>
<th>Cost per 1,000,000 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>380,000 / bu</td>
<td>70-85% (80%)</td>
<td>$5.00 / bu</td>
<td>$16.45</td>
</tr>
<tr>
<td>Wood Pellets</td>
<td>15,400,000 / ton</td>
<td>70-85% (80%)</td>
<td>$22.08/ton</td>
<td>$17.82</td>
</tr>
<tr>
<td>Outdoor Wood Boiler - typical</td>
<td>19,200,000 / full cord</td>
<td>40%</td>
<td>$200/full cord</td>
<td>$24.04</td>
</tr>
<tr>
<td>Outdoor Wood Boiler – EPA P2</td>
<td>19,200,000 / full cord</td>
<td>60%</td>
<td>$200/full cord</td>
<td>$13.94</td>
</tr>
<tr>
<td>Electricity</td>
<td>3413 / kWh</td>
<td>100%</td>
<td>$0.11/kWh</td>
<td>$32.23</td>
</tr>
<tr>
<td>Propane</td>
<td>91,500 / gallon</td>
<td>70-85% (78%)</td>
<td>$1.70/gallon</td>
<td>$23.82</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>100,000 / Therm</td>
<td>70-85% (75%)</td>
<td>$1.15 / Therm</td>
<td>$14.74</td>
</tr>
<tr>
<td>Heating Oil</td>
<td>138,000 / gallon</td>
<td>70-85% (75%)</td>
<td>$2.55/gallon</td>
<td>$24.15</td>
</tr>
</tbody>
</table>

1) Costs available in Madison, WI – October 2008. 2) Full Cord has a volume of 4 feet x 4 feet x 8 feet or 128 cubic feet 3) 1 Therm (100,000 Btu) equals approximately 1 CCF – hundred cubic feet equals 4) (XX%) Efficiency value used to calculate “Cost per 1,000,000 Btu” 5) Based on purchasing and heating wood from vendor
Sizing a heating system

- What percent of the heating do you want to replace?
  - Full Replacement
  - Some proportion of total heating
- System capacity can be smaller
  - Runs continuously to be most efficient

Case Study #1

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

Options for Biomass Heating

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)

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 to avoid cost of bulk storage - $4.20 / 50 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

<table>
<thead>
<tr>
<th>Heating System</th>
<th>System Cost</th>
<th>Biomass Quantity</th>
<th>Biomass Energy Cost</th>
<th>Propane Cost (gallons)</th>
<th>Propane Cost</th>
<th>Total Savings</th>
<th>Simple Payback (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Residential pellet stove</td>
<td>$4,030</td>
<td>282 40# bags</td>
<td>$1,194</td>
<td>639</td>
<td>$1,178</td>
<td>$722</td>
<td>6.0</td>
</tr>
<tr>
<td>B) Pellet furnace</td>
<td>$6,030</td>
<td>355 40# bags</td>
<td>$1,491</td>
<td>318</td>
<td>$1,178</td>
<td>$1,087</td>
<td>5.7</td>
</tr>
<tr>
<td>C) Outdoor wood boiler/EPA Certified</td>
<td>$13,030</td>
<td>6 cords</td>
<td>$318</td>
<td>318</td>
<td>$636</td>
<td>$1,048</td>
<td>7.9</td>
</tr>
<tr>
<td>D) Outdoor wood boiler</td>
<td>$16,314</td>
<td>10 cords</td>
<td>$318</td>
<td>318</td>
<td>$636</td>
<td>$1,048</td>
<td>11.1</td>
</tr>
</tbody>
</table>

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

### Case Study #2

- Gutter-connected T-shaped 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

### Outdoor Wood Boiler Option

- 75% efficient Boiler
- Require 389 cords of wood
- Would increase labor requirements
- Handling and refueling
- No “Free” wood source
- Not included in analysis

### Average Night Heating Requirement 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>September</td>
<td>8,244,853</td>
<td>702,071</td>
</tr>
<tr>
<td>October</td>
<td>15,016,403</td>
<td>1,251,534</td>
</tr>
<tr>
<td>November</td>
<td>22,012,150</td>
<td>1,834,346</td>
</tr>
<tr>
<td>December</td>
<td>29,167,064</td>
<td>2,430,589</td>
</tr>
<tr>
<td>January</td>
<td>31,150,243</td>
<td>2,595,854</td>
</tr>
<tr>
<td>February</td>
<td>28,137,214</td>
<td>2,344,809</td>
</tr>
<tr>
<td>March</td>
<td>21,901,552</td>
<td>1,825,129</td>
</tr>
<tr>
<td>April</td>
<td>15,348,874</td>
<td>1,282,406</td>
</tr>
<tr>
<td>May</td>
<td>5,862,478</td>
<td>488,540</td>
</tr>
</tbody>
</table>
Heating Demands

- Based on Madison, WI the recommended design temperature for a heating system is -20°F
- Recommend design temperatures available from National Greenhouse Manufacturers Association
  - www.ngma.com
  - Under “downloads” - Heating systems standard
- Heating requirement - 4,200,000 Btu/hr

Options for Biomass Heating

Option A
- Meet 100% of heating requirements
  - Two pellet boilers – 3.5 MBtu/hr & 1.5 MBtu/hr
  - 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
  - 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>

Resources

- U of Wisconsin Extension Bulletins
  - Biomass Energy for Heating Greenhouses, A3907-04
  - Biomass Heating in Greenhouses: Case Studies, A3907-05
- Pellet Fuels Institute – www.pelletheat.org
- Educational material, pellet manufacturers list
- Biomass for combustion calculator
  - www.ruralenergy.wisc.edu/esa
- Focus on Energy – www.focusonenergy.com
- Installer list, factsheets, grant information
- Burning Shelled Corn—A Renewable Fuel
  - http://energy.cas.psu.edu/shellcorn.html

Pellet Boiler Image
Questions

This presentation was developed by:
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Comments and suggestions should be directed to sasanford@wisc.edu
The contents of this presentation can be used in whole or in part for greenhouse grower education.