

Biomass Heating of Greenhouses

Scott Sanford
Sr. Outreach Specialist
Rural Energy Program

College of Agricultural & Life Sciences
University of Wisconsin-Madison

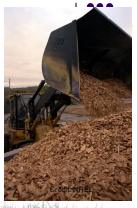
UW Extension
Learning for life

Outline

- What is biomass?
- Types of fuels for combustion
  - Excluding biodiesel or waste oils/grease
- What is a boiler or furnace?
- Outdoor wood-fired hydronic heaters
- Pellet / grain fired boilers / furnaces
- Stand alone stoves
- 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



What is a Biomass fuel

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

Miscanthus x giganteus Credit: University of Arkansas

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 H_20, 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

Direct Use – Cord wood

Credit: JoAnn Sandberg

- "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

Source: NREL

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
    - Annual crop – mechanically harvested and handled
  - Disadvantage
    - 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

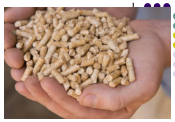
- Corn
  - Bone-dry – 8250 Btu per pound
  - If corn is 15% moisture then one pound of corn:
    - 0.85 pounds corn
    - 0.15 pounds water
  - Water require 1050 Btu / pound to evaporate
  - 0.85 x 8250 – (1050 x 0.15) = 6855 Btu / pound
  - There may be further losses to transfer heat to air or water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

Densification Pellets / cubes

Source: Kevin Shinners, U of Wisconsin

- 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

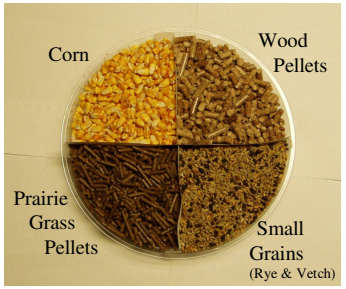
- Material – Sawdust, wood residue
- Unit of measure – Tons or pounds
  - Bulk in tons or 40-50 pound bags
- Moisture
  - 6 to 10% depending on grade
- Energy content
  - Average – 8000 Btu / lb
- Grades (Pellet Fuels Institute)
  - Utility, standard, premium, super premium
  - Difference is mainly ash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

Ref: http://www.pelletheat.org/3/institute/standards/PFI%20Standards.pdf

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



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


Outdoor Hydronic Heater


Pellet furnace
Credit: HarmanStoves


Pellet boiler & bin
Credit: Josh Kaurich

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

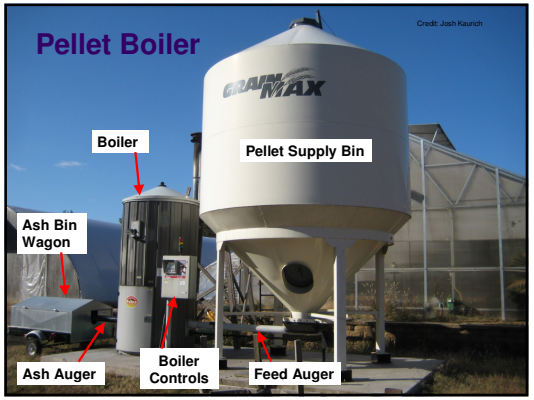
- Fuel: Wood, scrape materials, pallets
- "Cheaper" Fuel? – What is the true cost?
  - Labor / equipment to collect / harvest fuel
  - Labor to re-fuel
  - Disposal of Ash
- High emissions rate / Smoke
  - Reduce with firebox management
- Low Efficiency
  - pre-2008 Efficiency range: 20 to 50%
- 2008 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

Pellet Boiler



Pellet / corn furnace ~165,000 Btu

Credit: Vern Grubinger, University of Vermont

500,000 Btu Pellet / corn furnace

Credit: Vern Grubinger, University of Vermont

Pellet/corn furnaces

Credit: Vern Grubinger, University of Vermont

Keep your old system for backup and COLD nights!

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+%
- Low labor – automatic stoking and ash removal

Credit: Focus on Energy

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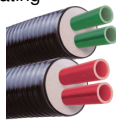
College of Agricultural & Life Sciences, University of Wisconsin-Madison

How is the heat distributed?

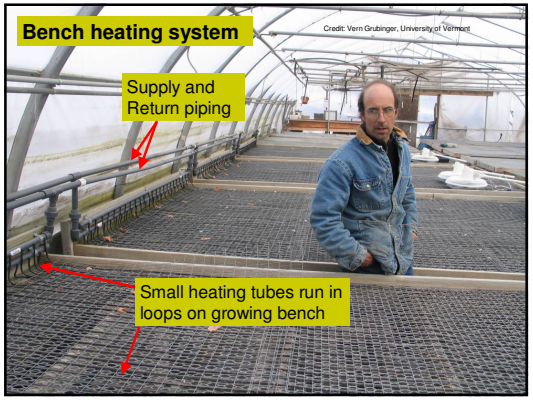
- Furnace – Ducts and fans
  - Poly bags – may not be suitable depending on outlet temperature.
- Boiler
  - Water to air heat exchanger
  - Bench-top or under-bench or floor heating
    - Develop a micro climate
    - Warm roots increases growth
    - May still need water to air heat exchangers for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

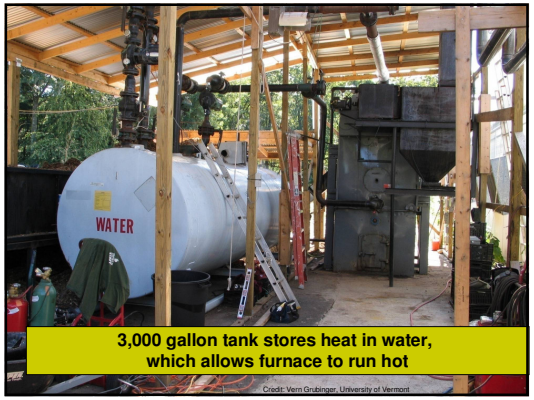


Source: www.thermpex.com

Water to air heat exchanger

Credit: Vern Grubinger, University of Vermont





Wood Chip Boiler


Source:www.danvillek12vt.org

- 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??

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

Fuel type	Energy Content Btu per unit	Boiler Thermal Efficiency[4]	Unit Cost[1]	Cost per 1,000,000 Btu
Corn	380,000 / bu	70-85% (80%)	$5.00 / Bu	$16.45
Wood Pellets	15,400,000 / ton	70-85% (80%)	$220/ton	$17.82
Outdoor Wood Boiler - typical	19,200,000 / full cord[2]	40%	$200/ full cord[5]	$24.04
Outdoor Wood Boiler – EPA P2	19,200,000 / full cord	69%	$200/ full cord[5]	$13.94
Electricity	3413 / kWh	100%	$0.11/kWh	$32.23
Propane	91,500 / gallon	70-85% (78%)	$1.70/gallon	$23.82
Natural Gas	100,000 /Therm[3]	70-85% (78%)	$1.15 / Therm	$14.74
Heating Oil	138,000 / gallon	70-85% (75%)	$2.50/gallon	$24.15

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 cut and split wood from a 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)

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

Options for Biomass Heating

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

Options for Biomass Heating

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)

Options for Biomass Heating

Option D

- Same as Option C except non EPA qualifying boiler
- Installed cost $11,634
- Estimated Efficiency = 40%

Average Night Heating Requirements by Month

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

- 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 ~40F
  - Estimated 50% reduction in propane use
- Options B, C & D – 100% of heating down to ~ 10F
  - 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

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

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

Month	Heating Requirements Btu/day	Approx. average hourly heating Btu/hr
September	8,424,853	702,071
October	15,018,403	1,251,534
November	22,012,158	1,834,346
December	29,167,064	2,430,589
January	31,150,243	2,595,854
February	28,137,714	2,344,809
March	21,901,552	1,825,129
April	15,388,874	1,282,406
May	5,862,478	488,540

Heating Demands

- Based on Madison, WI the recommend 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

Options for Biomass Heating

- 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

Pellet Boiler

Credit: Josh Kaurich
The Flower Farm
Eau Claire, WI

Summary of Options

Option	Capital Cost	Tons of Wood Pellets	Wood Pellet Cost	Propane Cost	Energy Savings	Simple Payback years
A	$291,000	465	$82,770	$8,558	$79,834	3.6
B	$211,000	392	$69,776	$34,232	$67,154	3.1

Resources

- U of Wisconsin Extension Bulletins
  - 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
- Focus on Energy – www.focusonenergy.com
  - Installer list, factsheets, grant information
- Burning Shelled Corn—A Renewable Fuel
  - http://energy.cas.psu.edu/shellcorn.html

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