COLLEGE OF AGRICULTURAL & LIFE SCIENCES
University of Wisconsin-Madison

# Energy Efficient Wood Heating Appliances for Home and Business


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UW Extension Learning for life

NORTH CENTRAL SARE Sustainable Agriculture Research & Education

# 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

Credit: Ohio State University

# Biomass Fuels

Credit: NREL

- 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: NREL

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 $H_20$, 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

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
- Energy content depends on species
- High emissions – new regulations

# Burning Characteristics of Select Wood Species

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

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

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

# 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

Source: www.tractorbynet.com

- 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

# Outdoor Wood-Fired Boilers

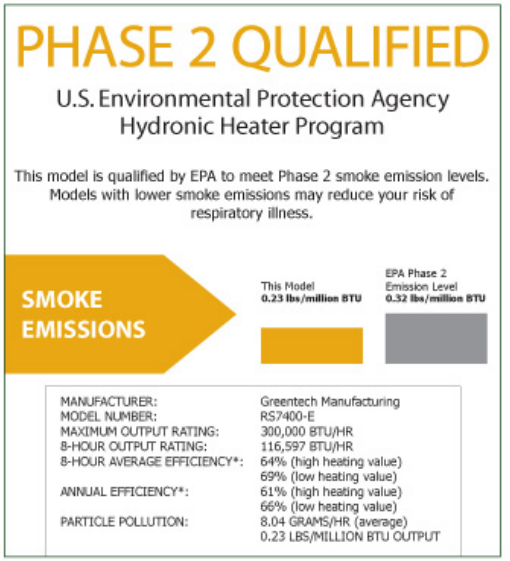
- Fuel: cord wood, wood scrape materials, pallets
- “Cheaper” Fuel? – What is the true cost?
  - Labor & equipment to collect & harvest fuel
  - Labor to re-fuel
  - Disposal of Ash
- High Smoke emissions rate
  - Reduced with firebox management
- Low Efficiency – Average 40%
  - pre-2008 efficiency 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

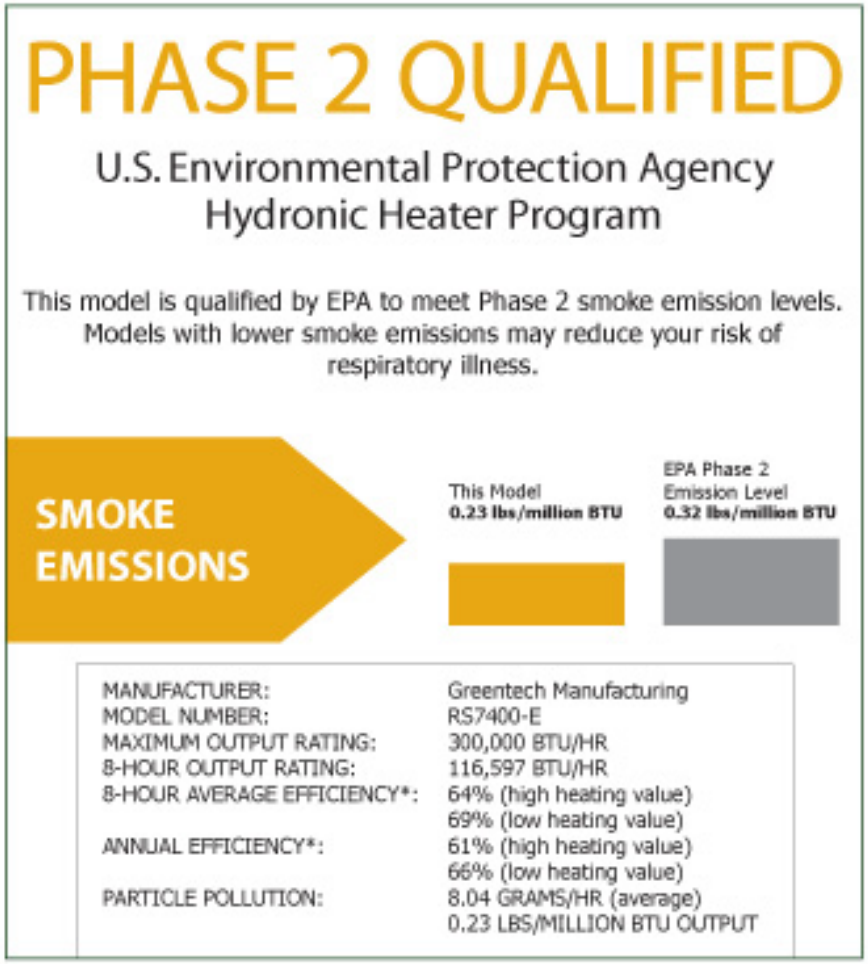
- EPA Voluntary Emissions Reduction Program
  - 90% lower emissions
- Low emissions → higher efficiency
  - Average efficiency of qualifying cord wood boilers - ~ 70%
- Many states restricted sales - EPA certified models
  - White tag / Phase 2
- EPA information
  - http://www.epa.gov/burnwise/

  List of qualifying outdoor wood stoves
  - http://www.epa.gov/burnwise/owhhlist.html
- New EPA proposal
  - Emission from 0.32 to 0.06 lb/MBTU (2015)



# White Tag

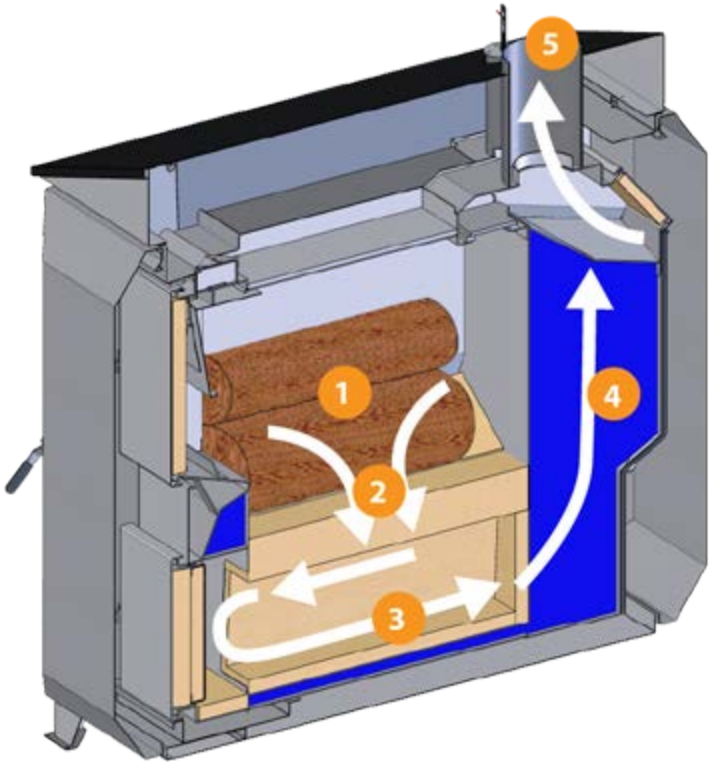
- Outdoor Wood Boilers
  - Graphical comparison to standard limits
  - Maximum output rating
  - 8-hour output rating
  - 8-hour average Eff.
  - Annual Efficiency
  - Fine particle emissions




http://www.epa.gov/burnwise/guidewhiteownn.html

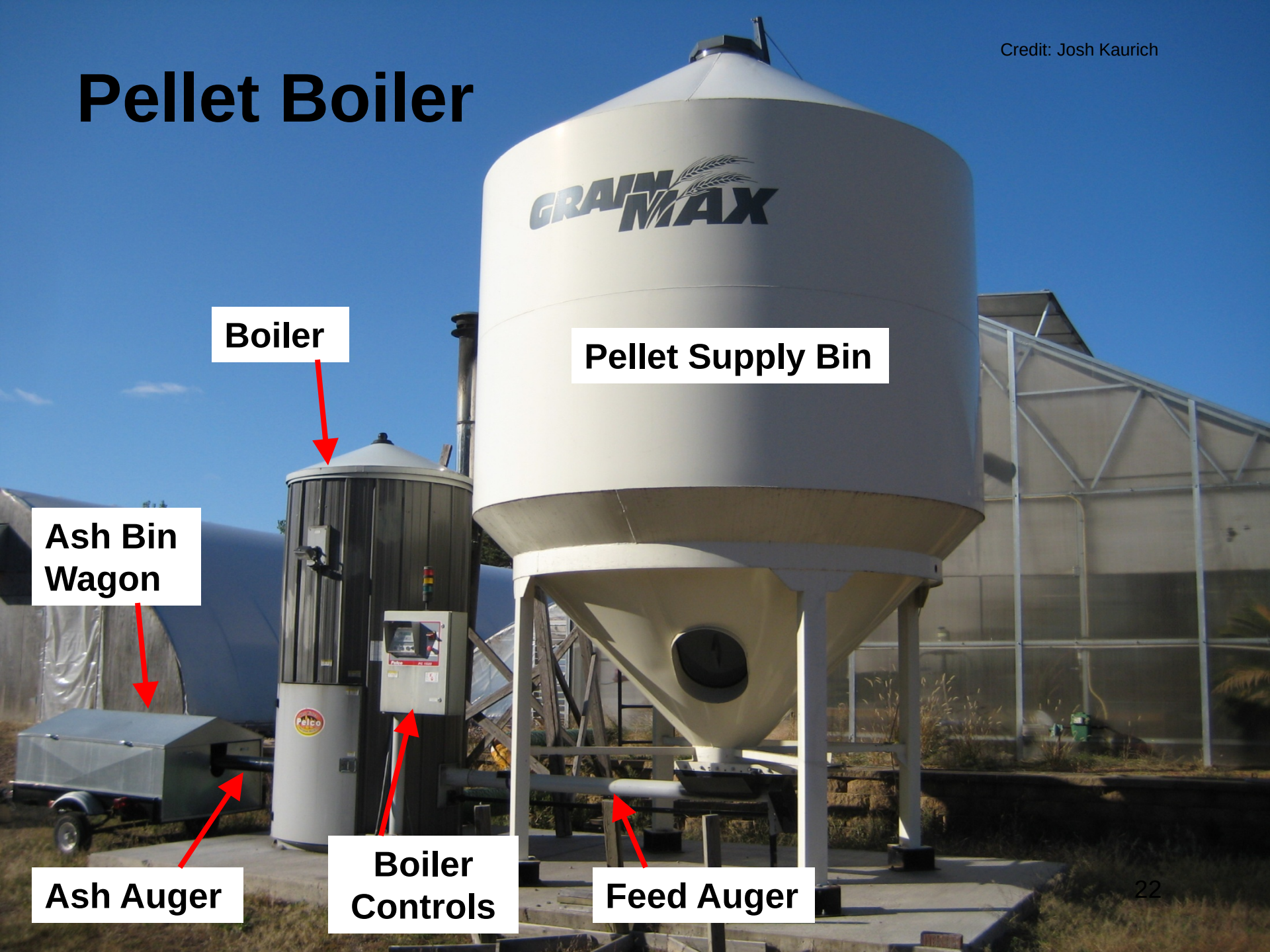
# Gasification Technology

- 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 ºF
  - Low smoke
- 4 – Heat Exchanger
  - Separate from fire box
  - Higher heat transfer
- 5 - Chimney Exhaust




Source: www.profab.org

# Pellet Boiler



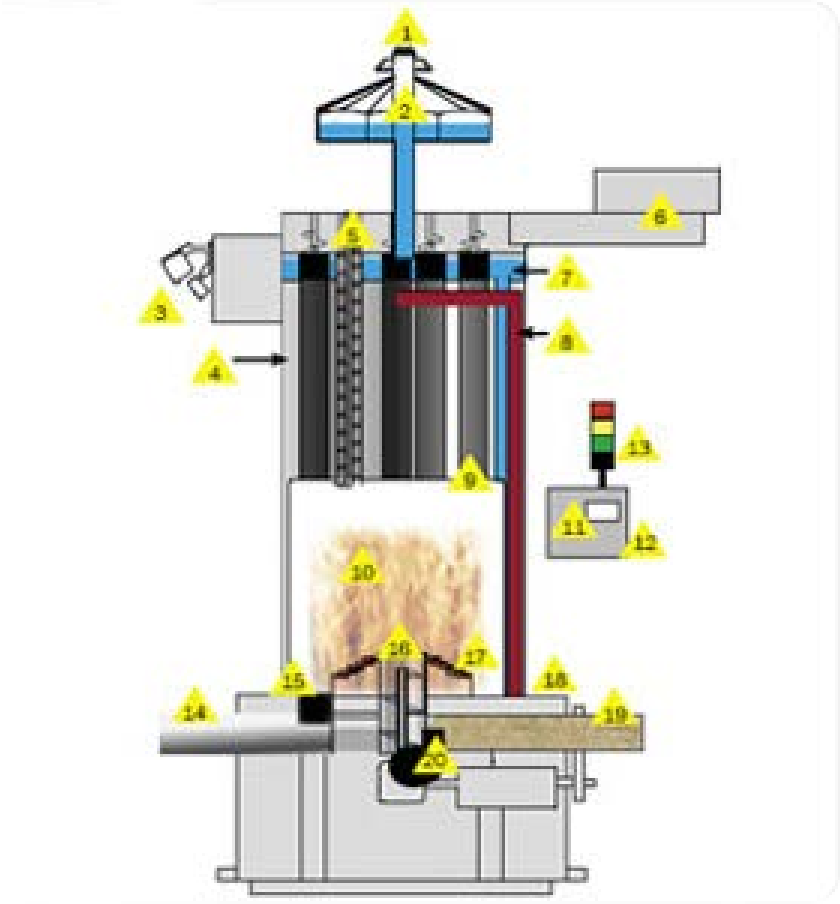

# Pellet / corn furnace ~165,000 Btu



Credit: Vern Grubinger, University of Vermont

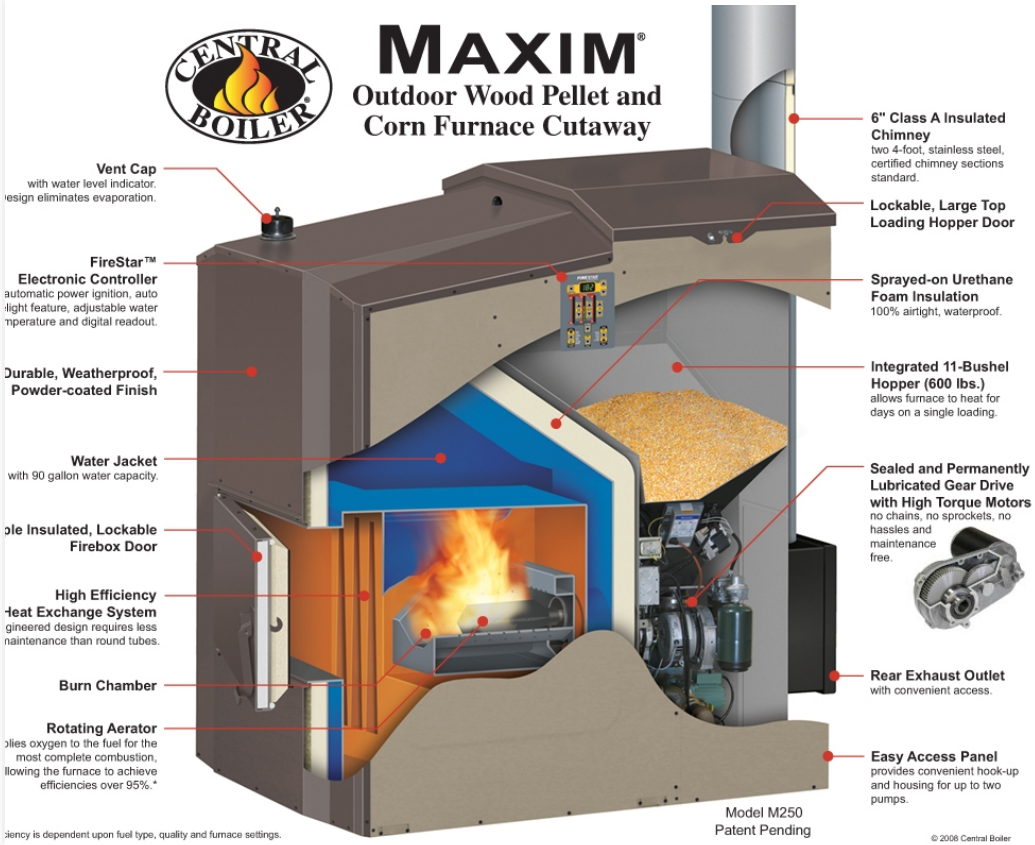
# Anatomy of a pellet Boiler

Bottom Feed




Source: www.profab.org

Top Feed



# Pellet/corn furnaces

Credit: Vern Grubinger, University of Vermont

**Keep your old system for backup and COLD nights!**

# Advantages of Pellet Boilers / Furnace

Credit: Focus on Energy

- 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

# Wood Chip Boiler

Source:www.danvillek12vt.org

- 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

# Wood Chip Feed System

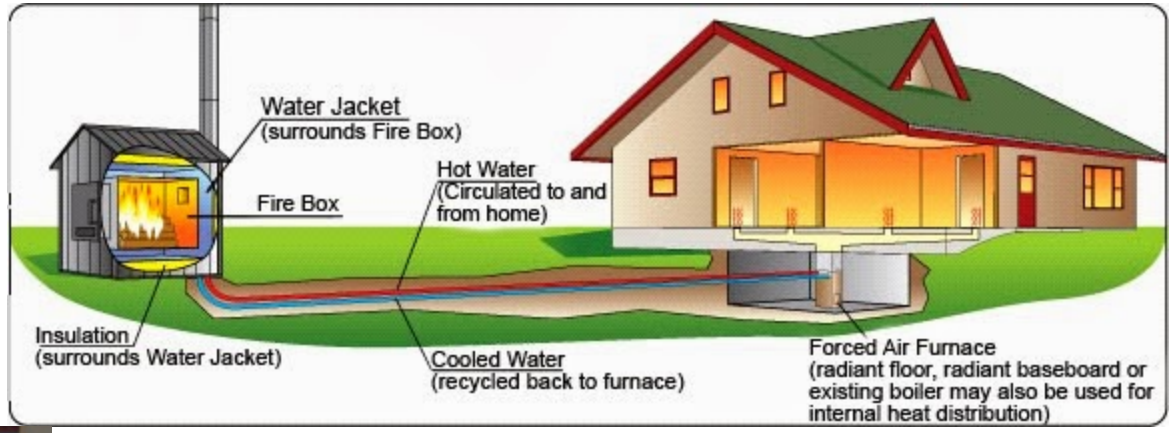
Storage bin with walking floor

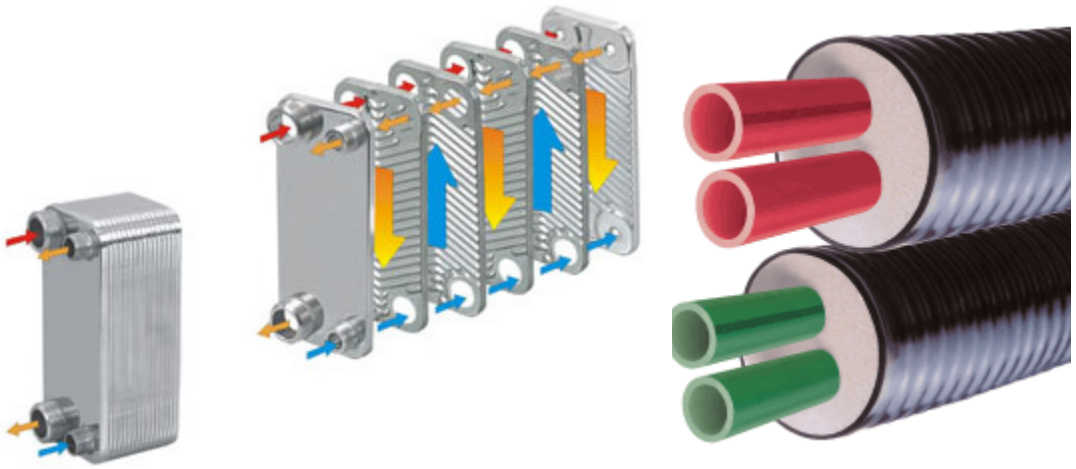
Barron High School, Barron, WI

# 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

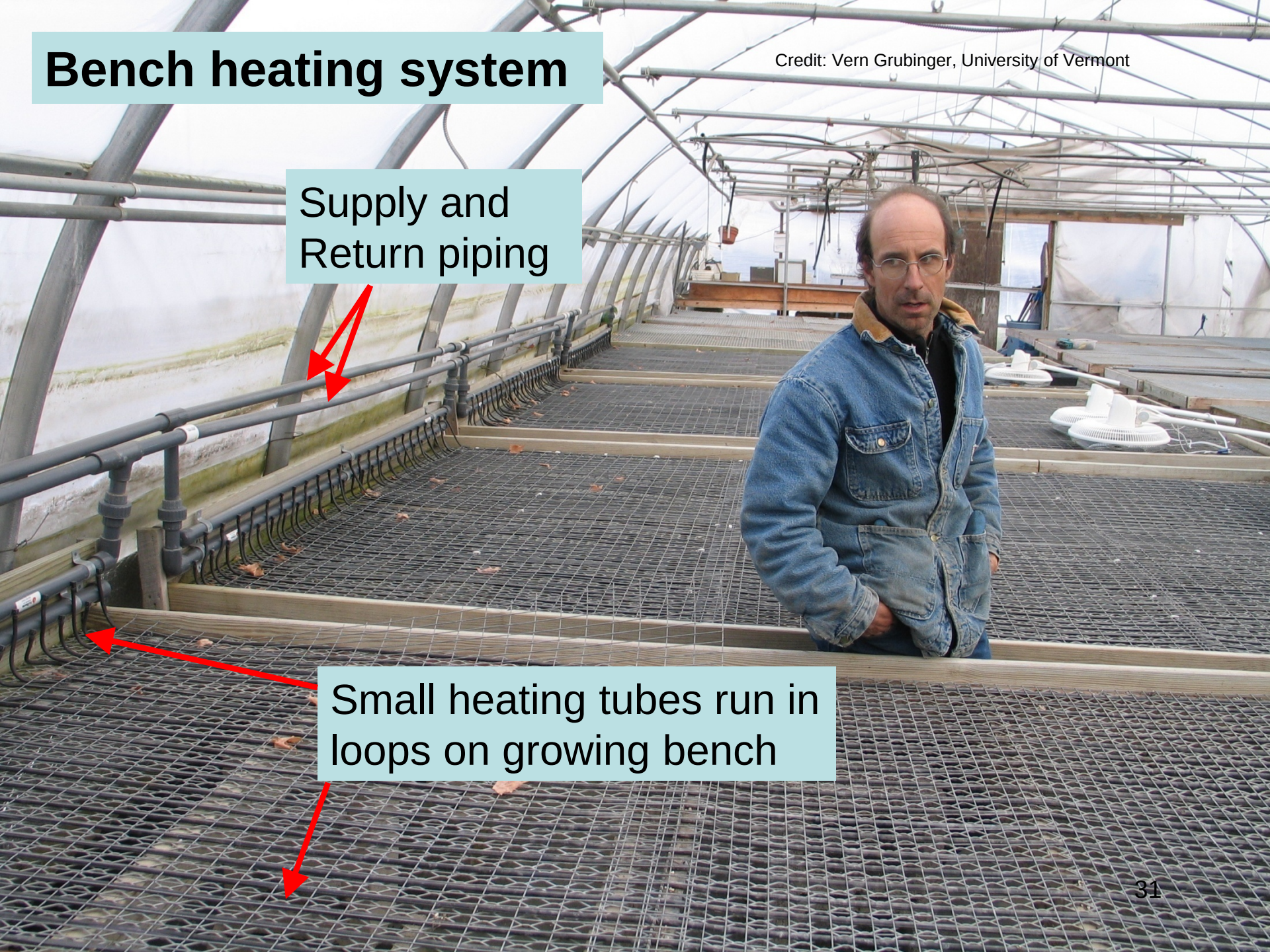
# How is the heat distributed?



Source: www.thermpex.com

# Bench heating system




**3,000 gallon tank stores heated water, which allows furnace to run hot / cycle less**



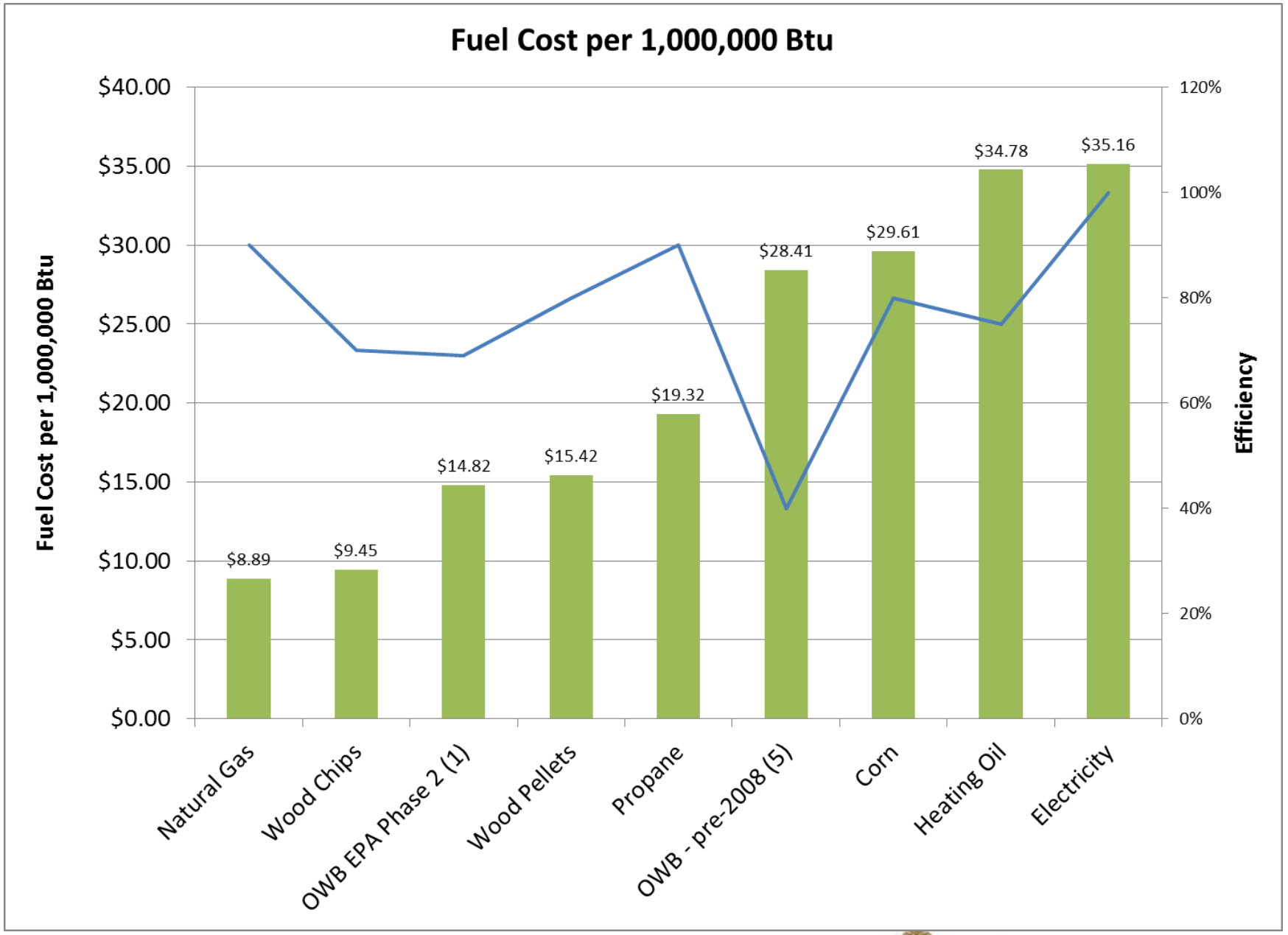
Credit: Vern Grubinger, University of Vermont

# Fuel Comparison

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

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

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)


Fuel Cost per 1,000,000 Btu
Fuel Cost per 1,000,000 Btu
Efficiency
$40.00
$35.00
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$0.00
120%
100%
80%
60%
40%
20%
0%
$8.89
$9.45
$14.82
$15.42
$19.32
$28.41
$29.61
$34.78
$35.16
Natural Gas
Wood Chips
OWB EPA Phase 2 (1)
Wood Pellets
Propane
OWB - pre-2008 (5)
Corn
Heating Oil
Electricity

# Equation for Table

- $ / Mbtu = $ per unit x 1,000,000
  Energy content/unit x Efficiency
- Unit – Trading unit (gallons, tons, cords)

Propane @ $2.70/gallon

- $ / MMbtu = $2.70 per gallon x 1,000,000
  91,600 Btu/gallon x 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?

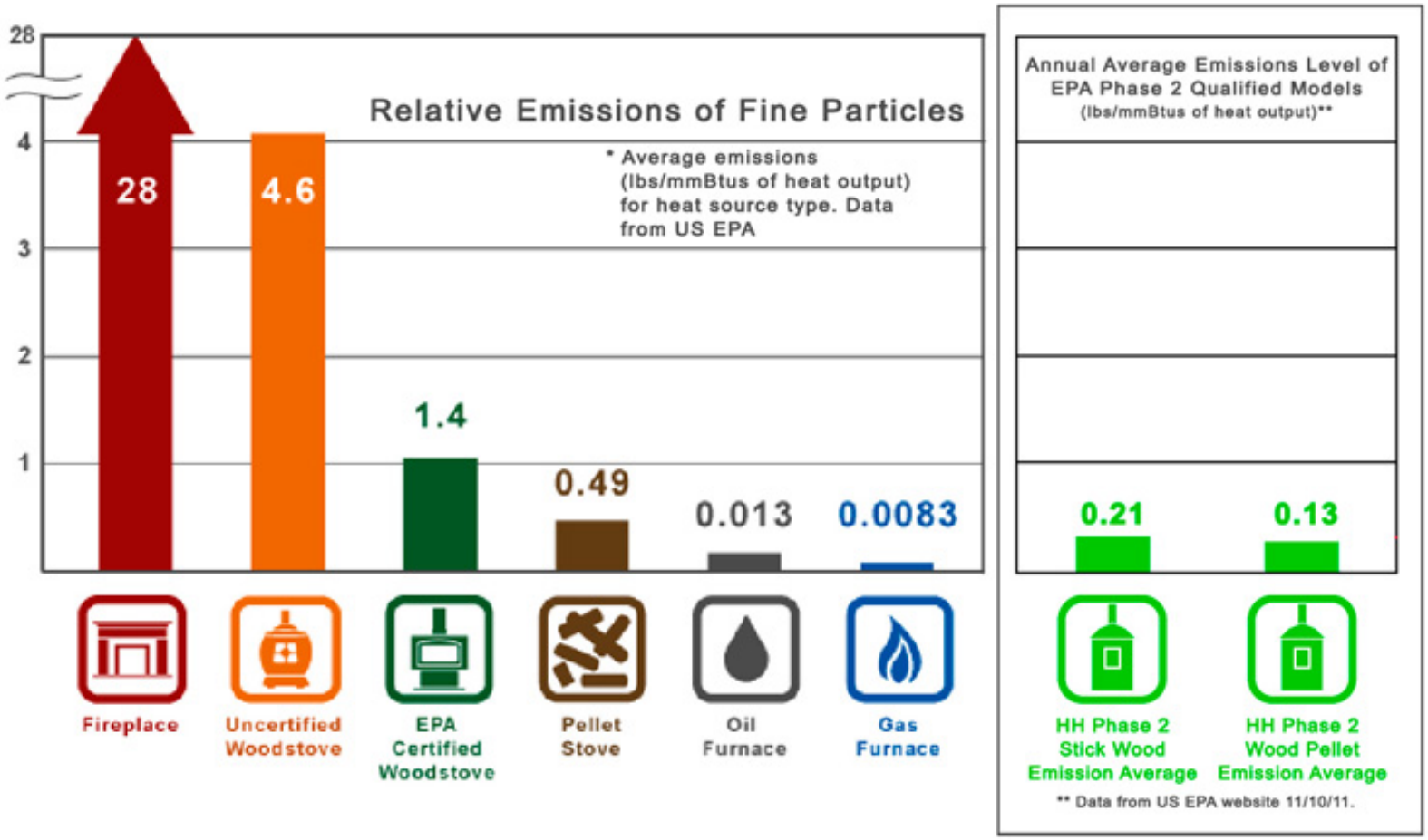
# Sizing a heating system

- 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



# Firebox Management

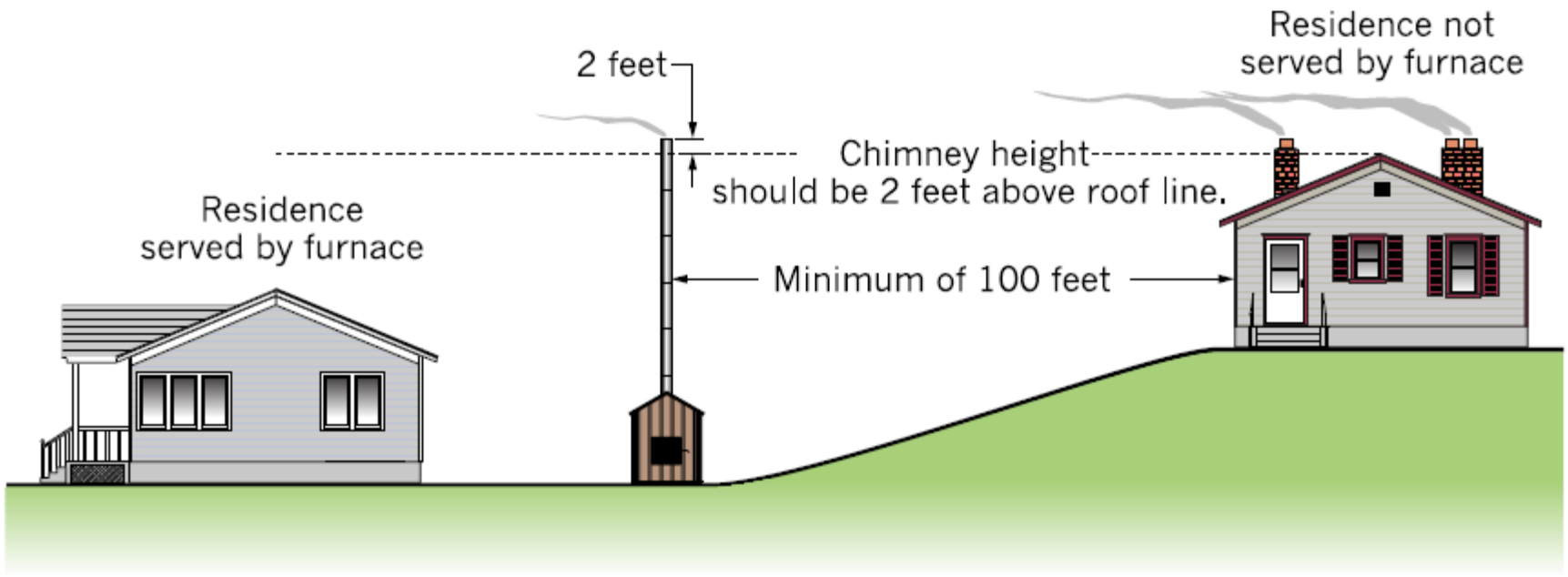
- Only burn dry, seasoned firewood
  - 6” wedge or smaller
  - Wet wood is a waste!
    - Lower firebox temperatures
    - Smoke
    - Creosote Formation
  - Don’t burn trash, painted or treated wood
    - Foul odors
    - Toxic air pollutants

# 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

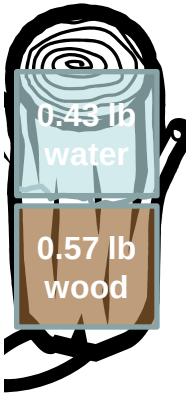
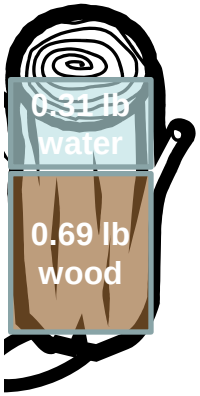
# Firebox Management

- Chimney height
  - 2 feet higher than highest building within 300 feet

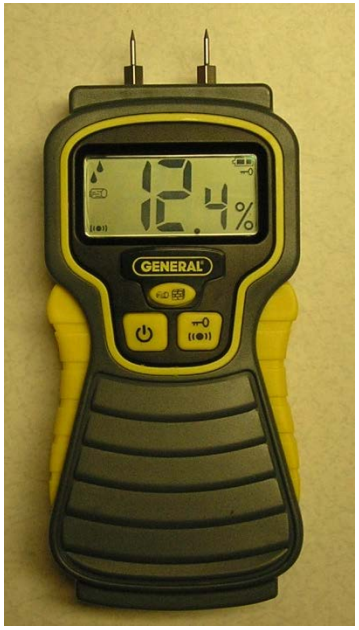


# Why wood moisture is important

## Net Energy of wood based on % moisture

| Green – as cut<br>75% moisture | 45%<br>moisture | Air-dried<br>20% moisture | Oven Dried<br>0% moisture |
|---|---|---|---|
|  |  |  |  |
| 4900 Btu / lb<br>5.8 cords | 5900 Btu / lb<br>4.8 cords | 7100 Btu / lb<br>4 cords | 8600 Btu / lb<br>3.3 cords |

# 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

| 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 |

* $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 -20ºF 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

# 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 |

* 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
- Wood-Chip Heating Systems, T.M. Maker, Biomass Energy Resource Center, Montpelier, VT 2004.
  - http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf
- Biomass for combustion calculator
  - www.ruralenergy.wisc.edu/esa

# Questions

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