



# Energy Efficient Wood Heating Appliances for Home and Business

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# 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

- ❖ Types of wood fuels
- ❖ Types of Wood Burning Appliances
- ❖ Heat distribution
- ❖ Comparison of energy sources
- ❖ Sizing a wood heating appliance
- ❖ Smoke Emissions
- ❖ Firebox Management



Credit: Ohio State University

# 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: NREL



Credit: NREL



Credit: University of Illinois

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# Types of Wood Fuels

- ❖ **Cord wood**
- ❖ **Green mill residue**
  - ❖ Hogged bark, chips from slabs & 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, tops/branches, sawmill/clean chips
  - ❖ Typically high moisture (~50%)
- ❖ Energy content varies with H<sub>2</sub>O, density and ash

# Direct Use - Wood

## ❖ Cord wood / logs

- ❖ 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 – 13,800,000 to 30,700,000 Btu / cord

  - ❖ Different species vary in density (lbs / cord)

    - ❖ Boxelder – 2632 lb / cord; Oak 4200 lb / cord

- ❖ All wood about 7000 Btu / lb. @ 20% moisture



# Cord of Wood

## ❖ Unit of measure – Cord (volume)

❖ Full Cord - 4 ft x 4 ft x 8 ft or 128 cu ft

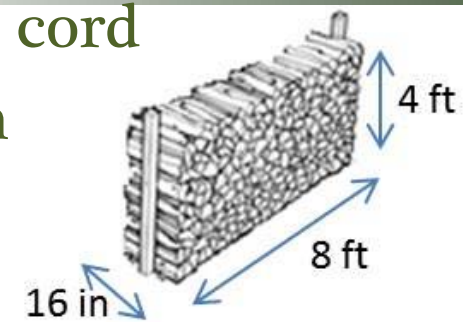
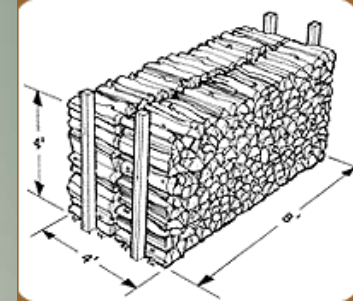
❖ Face Cord, Fireplace cord, stove cord

❖ 4 ft x 8 ft x firewood log length

❖ 16” logs - 1/3 of a cord

❖ 12” logs – 1/4 of a cord

❖ A full cord of stacked wood typically contains  
70-90 cu. ft. of solid wood



# Cord wood

- ❖ “Low cost” ???
- ❖ Labor intensive
  - ❖ Handle 3 to 6 times
- ❖ Harvesting
  - ❖ Cut, transport, split, pile/stack
- ❖ Air dry - Minimum 1 summer usually 2
  - ❖ Plan requirements 1-2 yrs ahead
- ❖ Refueling labor
- ❖ Ash disposal (greater volume)
- ❖ Energy content depends on species
- ❖ High emissions – new regulations



Credit: JoAnn Sandberg



# 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

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)



## 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

- ❖ 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 – round wood, sawdust, wood residue
- ❖ Unit of measure – Tons or pounds
  - ❖ Bulk in tons or 40-50 pound bags
- ❖ Moisture
  - ❖ 8 to 10% depending on grade
- ❖ Energy content
  - ❖ Average – 8000 Btu / lb
- ❖ Grades (Pellet Fuels Institute)
  - ❖ Utility, standard, premium
  - ❖ Difference is mainly ash content 6%, 2%, 1%
- ❖ Uniform product
  - ❖ 1/4" diameter x 1" to 1-1/2" long
  - ❖ Density 38 – 46 lb/cu. ft.



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

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)





# 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 40-50 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 °F
- ❖ Unburnt residue
  - ❖ Smoke or creosote
- ❖ Complete combustion requires 3 “T”s
  - ❖ Temperature – 1100 to 1500°F 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?

- ❖ Cord wood, pellets, wood chips
- ❖ 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 needed location



Outdoor Hydronic Heater

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)



Pellet furnace

Credit: HarmanStoves



Pellet boiler & bin

Credit: Josh Kaurich

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# 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
- ❖ Use with thermal store
  - ❖ To meet peak needs



Source: [www.renewenergies.com](http://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](http://www.tractorbynet.com)

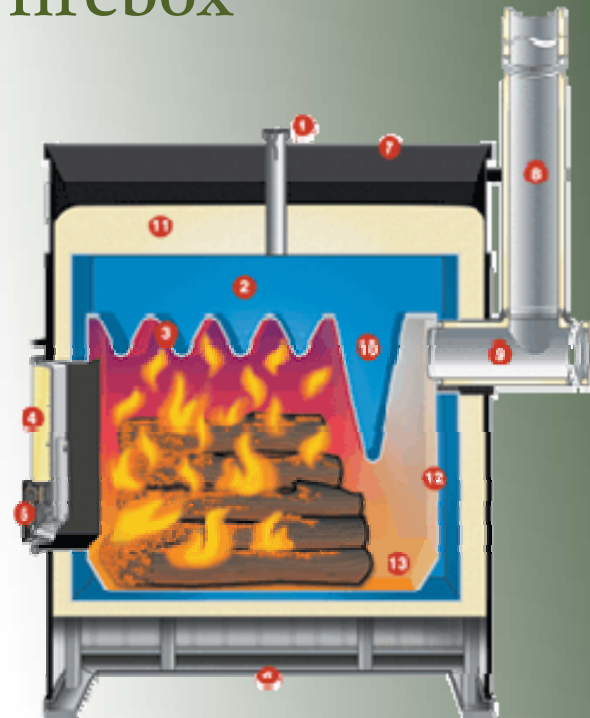
# Outdoor Wood-Fired Boilers

- ❖ 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%
- ❖ Fuel with scrap materials?
  - ❖ NO Glue (plywood, OSB)
  - ❖ NO paint
  - ❖ NO Chemical contamination
  - ❖ NO Pressure-Treated wood
- ❖ Increasing regulation due to smoke emissions



# Non-Certified Wood Boiler Firebox

- ❖ Water Jacket surrounding firebox
- ❖ Low temperatures
- ❖ Incomplete combustion
- ❖ High emissions
- ❖ Condensation of gases
- ❖ Creosote build-up
- ❖ Low efficiency





# Outdoor Wood Boiler Emissions



[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)





# 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/owhlist.html>
- ❖ New EPA proposal
  - ❖ Emission limit 0.32 lb / MMBtu (2015)
  - ❖ Emission limit 0.10 lb / MMBtu (2020)



# 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.ntml>

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)



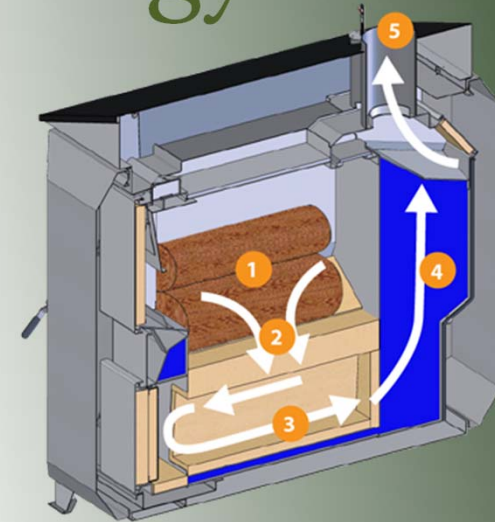
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# Heating Value

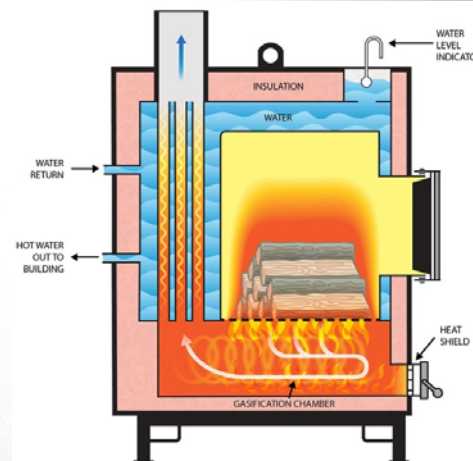
- ❖ High Heat Value (HHV) – (or gross energy)  
Assumes all products of combustion are reduced to pre-combustion temperatures and water vapor is condensed
- ❖ Low Heat Value (LHV) – High heat value minus latent heat of vaporization of water

# 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
  - ❖ Lower smoke emissions
- ❖ 4 – Heat Exchanger
  - ❖ Separate from fire box
  - ❖ Higher heat transfer
- ❖ 5 - Chimney Exhaust



Source: [www.profab.org](http://www.profab.org)  
[www.heatmasterss.com](http://www.heatmasterss.com)



[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)

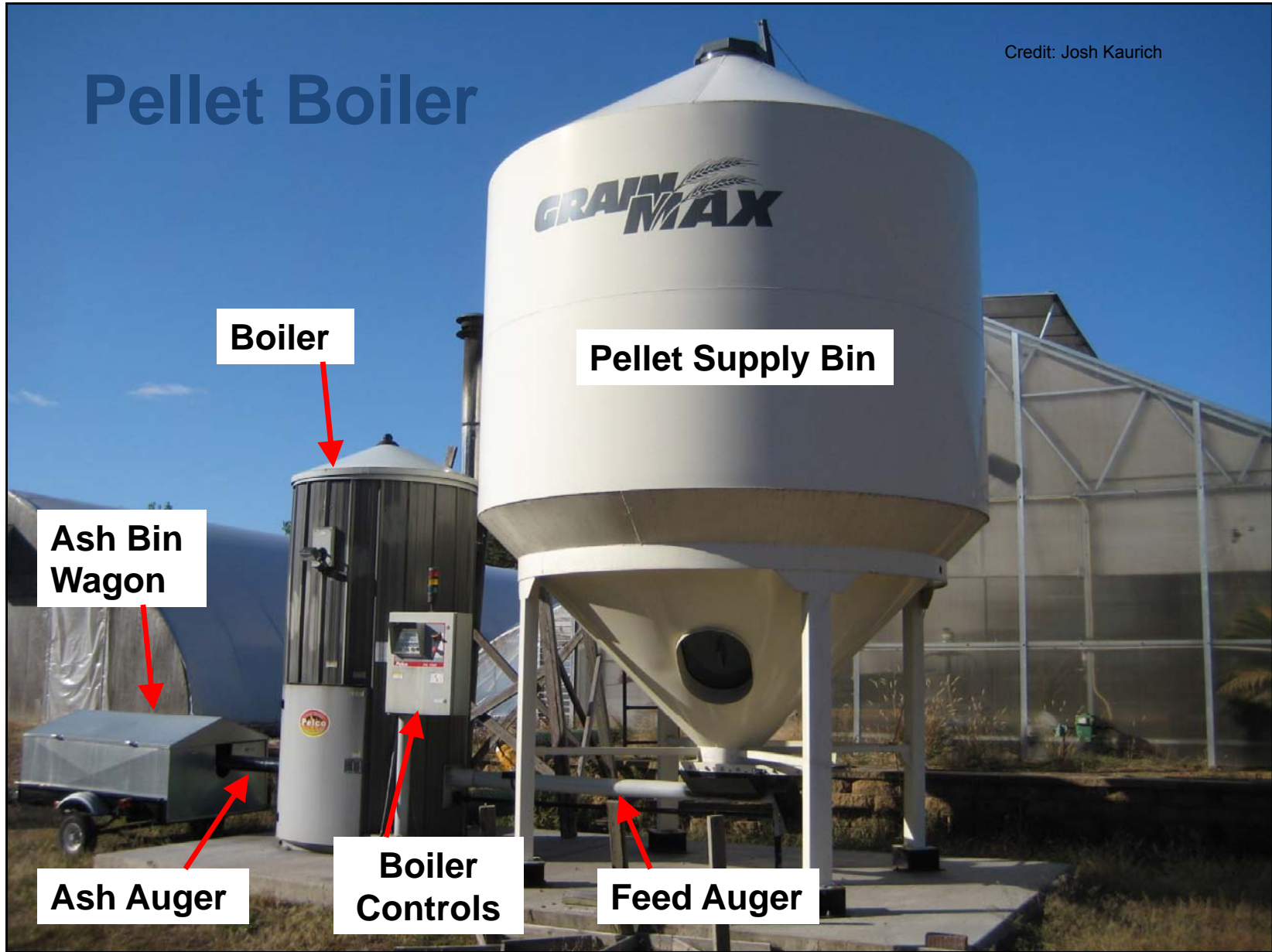
Wisconsin  
Statewide Wood  
Energy Team

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# Pellet Boiler

Credit: Josh Kaurich



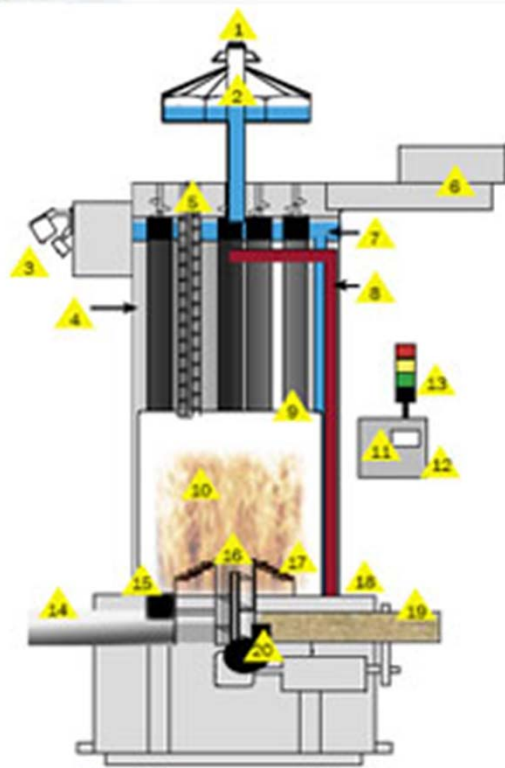


**Pellet / corn furnace ~165,000 Btu**

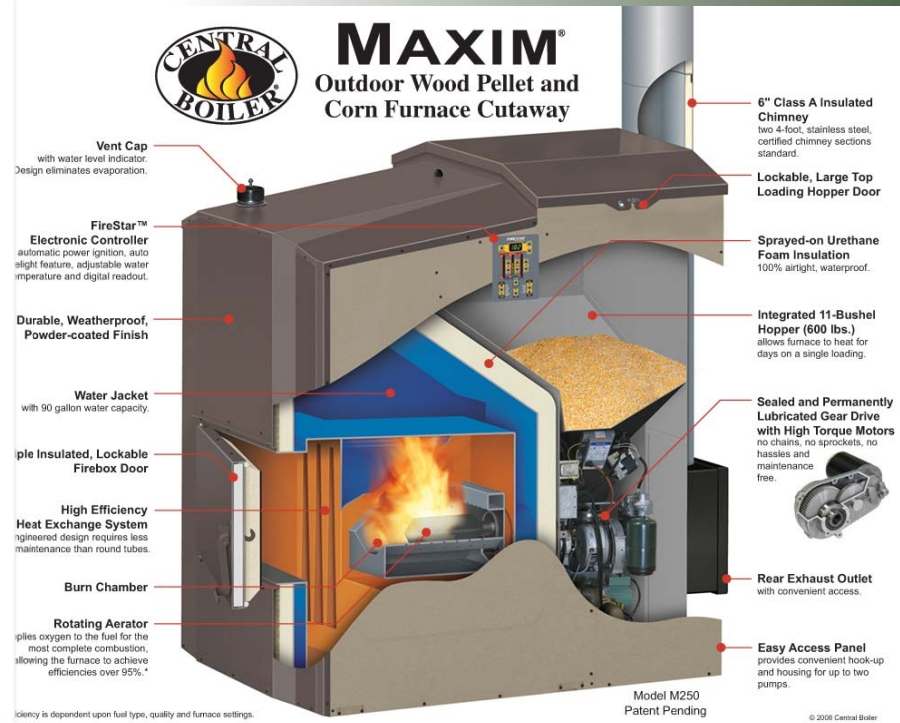
Credit: Vern Grubinger, University of Vermont

# Anatomy of a pellet Boiler

Bottom Feed



Top Feed



Source: [www.profab.org](http://www.profab.org)



# Pellet/corn furnaces

Credit: Vern Grubinger, University of Vermont

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





## 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](http://www.danvillek12vt.org)

# Wood Chip Feed System

Storage bin with walking floor



Barron High School,  
Barron, WI

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)





## Stand Alone Stoves

### ❖ Advantage

- ❖ Lower cost
- ❖ Easy to install
- ❖ Fast payback
- ❖ Supplemental heating

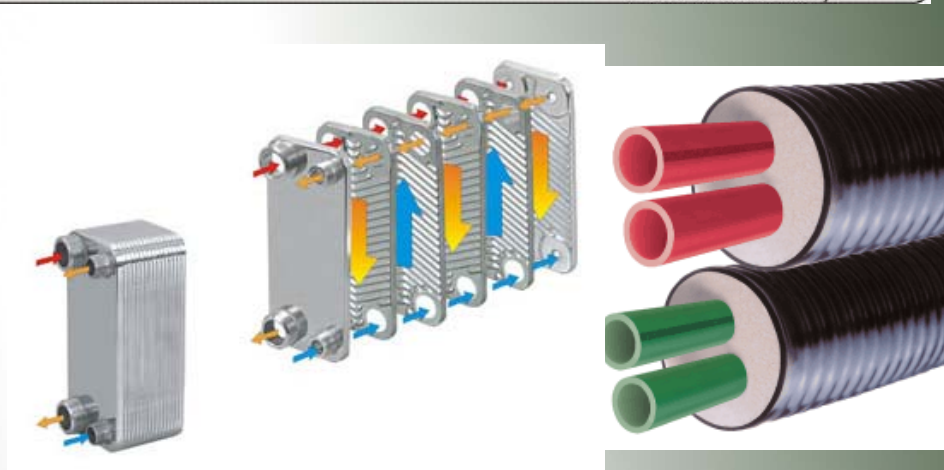
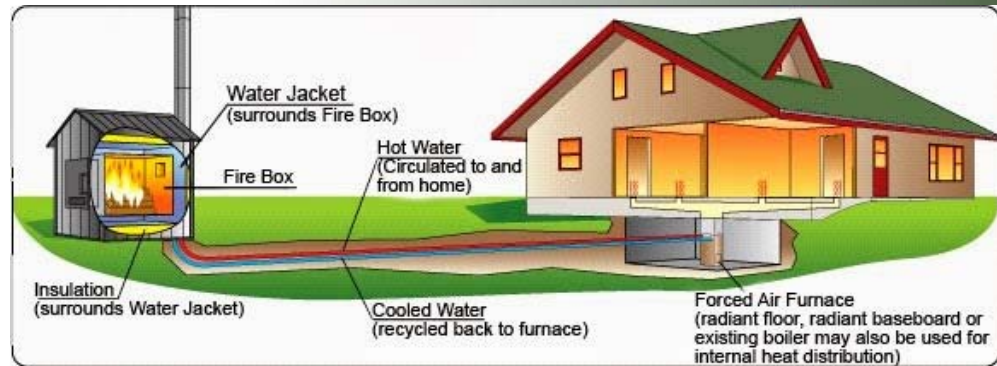
### ❖ Disadvantage

- ❖ 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](http://www.thermpex.com)

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)





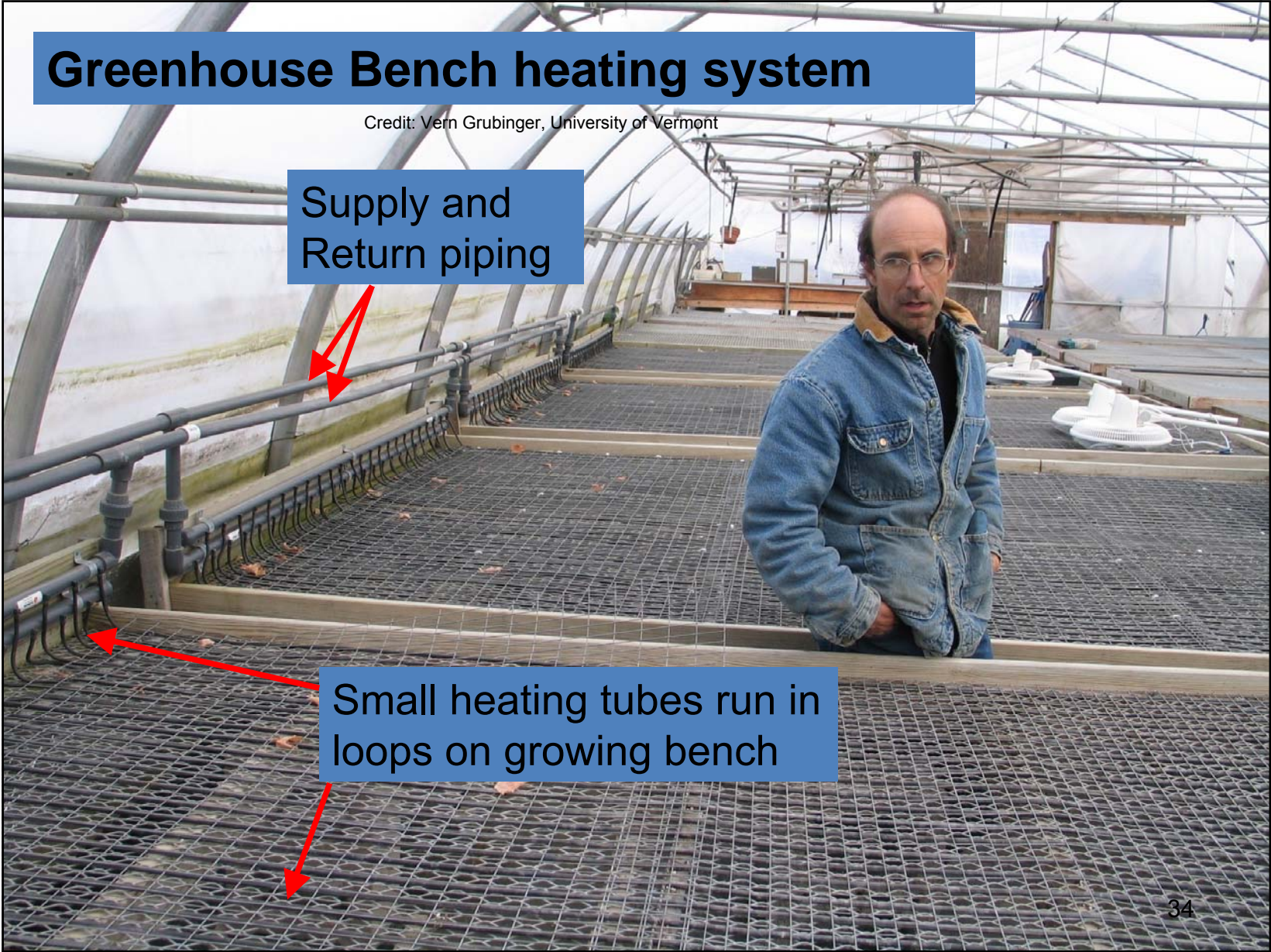
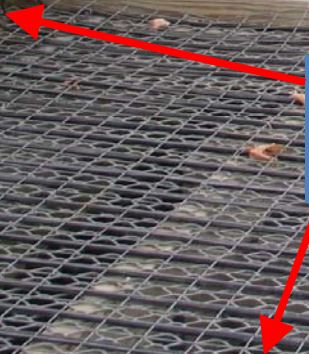
# Greenhouse Bench heating system

Credit: Vern Grubinger, University of Vermont

Supply and Return piping



Small heating tubes run in loops on growing bench



# Issues with Wood combustion

- ❖ Can't ramp up and down rapidly
- ❖ Cycling
  - ❖ Excess emissions
  - ❖ Lower efficiency
- ❖ Works best with steady burn
- ❖ Back-up required for peaks and low usage
- ❖ Solution: Thermal Storage





# Thermal Storage

- ❖ Typically water in insulated tank
- ❖ Buffer between fluctuating demand and boiler
- ❖ Smooth demand curve
- ❖ Reserve to cover peaks or turndown periods
- ❖ Automated boilers – demand less than low fire level
  
- ❖ Capacity depends on size and temperature above distribution temperature
  - ❖ Typically 120F to 170F → ~400 Btu/gallon water storage
  - ❖ Greater the temp difference – more energy stored
  - ❖ Lower the distribution temp – better efficiency



# Thermal Storage Sizing

## ❖ Cord Wood Boiler

❖ 400 to 550 gal per 100,000 Btu/hr capacity

❖  $V = 738 (w) (n) / \Delta T$

❖  $V$  = Volume of storage;  $w$  = lb of wood (20%) loaded into combustion chamber;  $n$  = combustion efficiency (%)

## ❖ Automated wood chip boiler

❖ 100 gal per 100,000 Btu/hr capacity

## ❖ Automated wood pellet boiler

❖ 75 gal per 100,000 Btu/hr capacity

## ❖ Minimum size to reduce cycling

Resource: John Siegenthaler, 2009, Integrating Wood and Water (part 1)

USFS Wood Education & Resource Center, 2014, A Primer on the Use of Thermal Storage with Small-Medium Commercial Biomass Hydronic Systems

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)



# Greenhouse Application



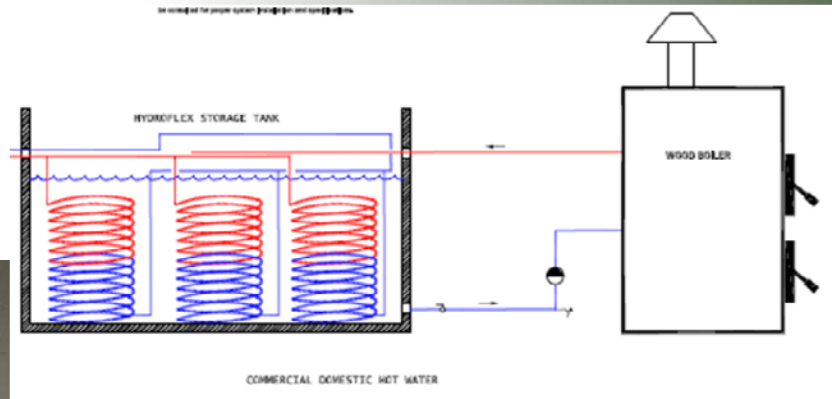
- ❖ Boiler operates at full capacity
- ❖ Heat stored in tank
- ❖ Heat used as needed
- ❖ Boiler runs at max efficiency
- ❖ Low emissions

Credit: [www.omafra.gov.on.ca/english/engineer/facts/14-009.htm](http://www.omafra.gov.on.ca/english/engineer/facts/14-009.htm)

[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)



# Cord wood boiler with thermal storage



[www.wisconsinwoodenergy.org](http://www.wisconsinwoodenergy.org)

Source: <http://www.hearth.com>



# Fuel Comparison

<b>Fuel Type comparison - in order of cost (2015)</b>					
<b>Fuel Type</b>	<b>Energy content</b>	<b>Thermal Efficiency (2)</b>	<b>Unit cost USD (4)</b>	<b>units</b>	<b>Cost per 1,000,000 Btu</b>
Natural Gas	100000/therm	80-94% (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)	63%	225	cord	\$16.23
Wood Pellets	15400000 per ton	70-85% (78%)	200	ton	\$16.65
Propane	91600	80-94% (90%)	1.80	gallon	\$21.83
Corn	380,000 per bushel (@ 15% moisture)	70-85% (80%)	7.00	50#	\$23.03
Heating Oil (#2)	138000	70-85% (75%)	2.50	gallon	\$24.15
OWB - uncertified (5)	22,000,000 per cord (3)	40%	225	cord	\$25.57
Electricity	3413 / kWh	98%	0.12	kWh	\$35.16

1) Meets EPA Phase 2 emissions requirement

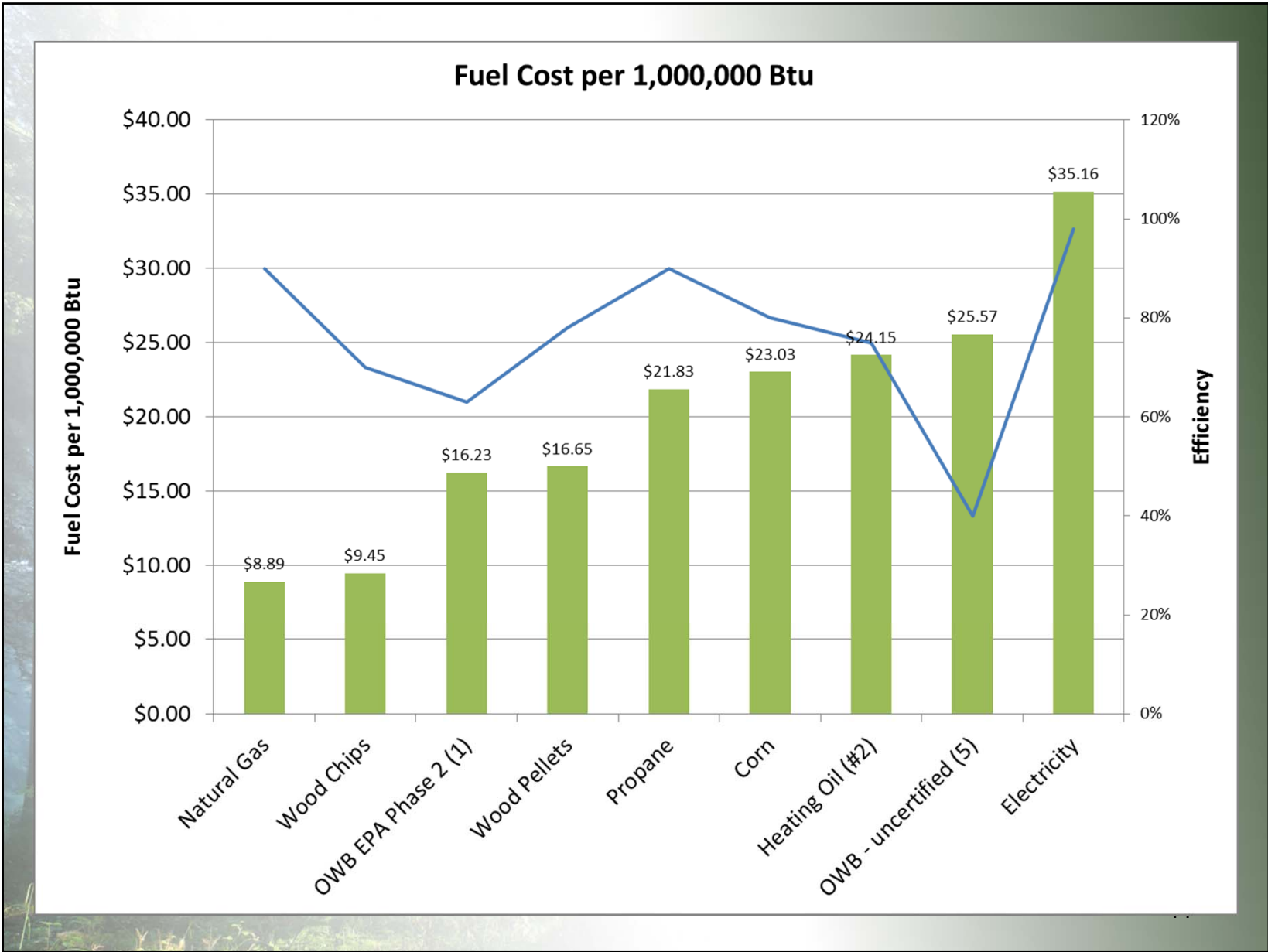
2) (XX%) Efficiency value used to calculate "Cost per 1,000,000 Btu"

3) 6500 Btu/pound (20% moisture)

4) Fuel costs in Madison, WI for 2014-2015 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

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

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

Propane @ \$2.00/gallon

$$\text{❖ } \$ / \text{MMbtu} = \frac{\$2.00 \text{ per gallon} \times 1,000,000}{91,600 \text{ Btu/gallon} \times 0.80}$$

$$= \$ 27.29 / \text{MMBtu}$$

# Sizing a heating system

- ❖ What percent of the heating do you want to replace? Which level will be most economical?
- A. 100%
- B. 90%
- C. 80%
- D. 70%
- E. 60%



# Sizing a heating system

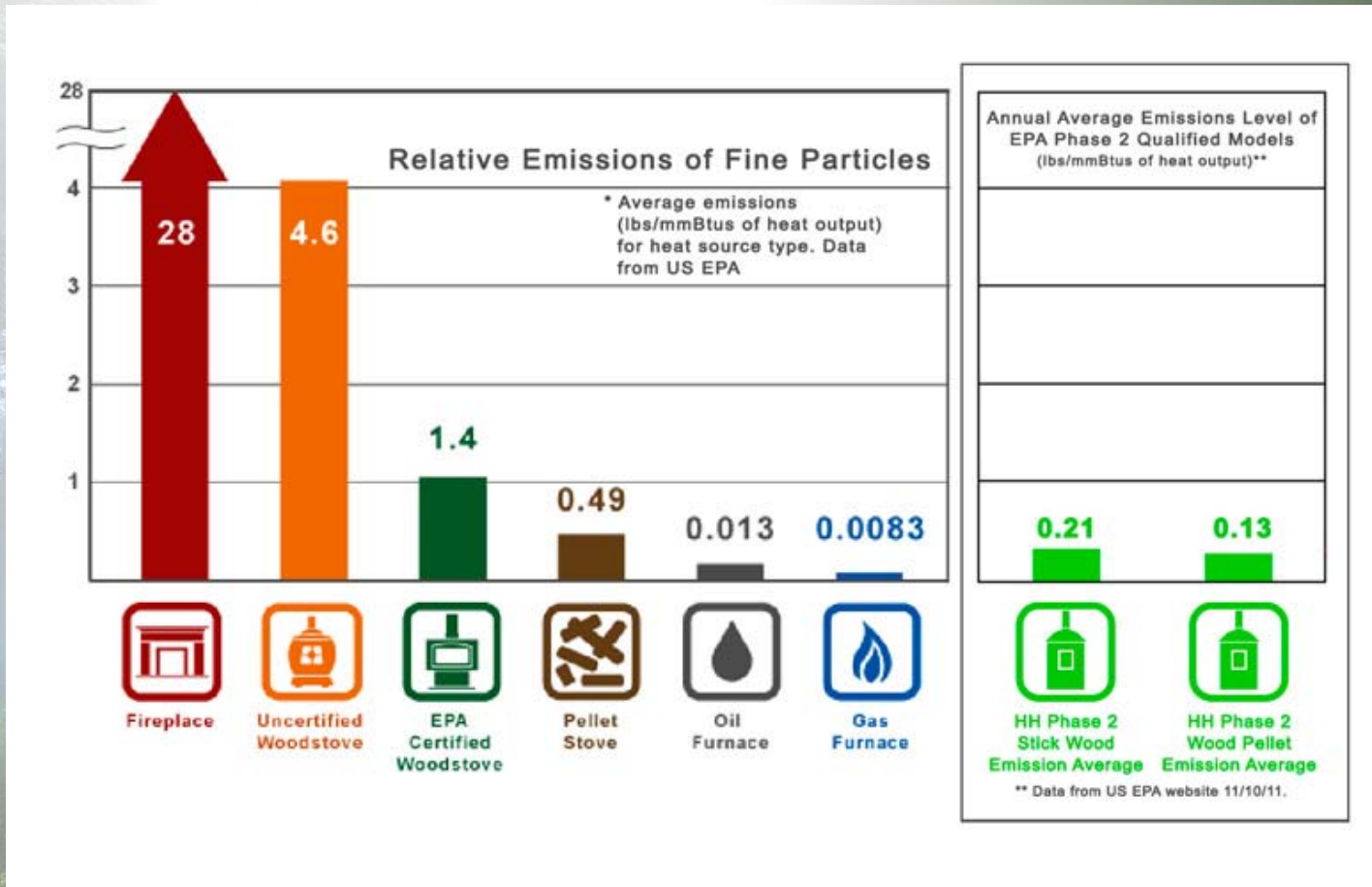
- ❖ Closer to 100% = longer payback
  - ❖ 100% capacity only used a few hours per year
  - ❖ 50% to 80% likely good target to meet average needs
- ❖ Biomass systems designed to run continuously
- ❖ Use Thermal Storage to smooth out peaks and valleys of use.

# 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 used



# Fine Particle Emissions



# Firebox Management

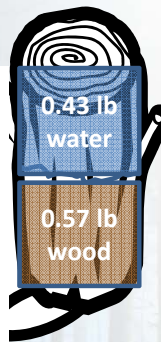
- ❖ Only burn dry, seasoned firewood
  - ❖ 6” wedge or smaller
  - ❖ Wet wood is a waste!
    - ❖ Lower firebox temperatures
    - ❖ Smoke
    - ❖ Creosote Formation
  - ❖ Don't burn trash, painted or treated wood
    - ❖ Foul odors
    - ❖ Toxic air pollutants



# Why wood moisture is important

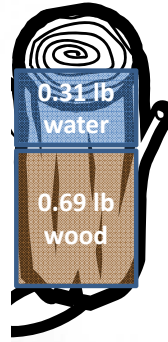
## Net Energy of wood based on % moisture

Green – as cut  
75% moisture



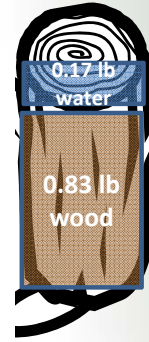
4900 Btu / lb  
5.8 cords

45%  
moisture



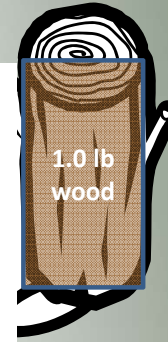
5900 Btu / lb  
4.8 cords

Air-dried  
20% moisture



7100 Btu / lb  
4 cords

Oven Dried  
0% moisture



8600 Btu / lb  
3.3 cords

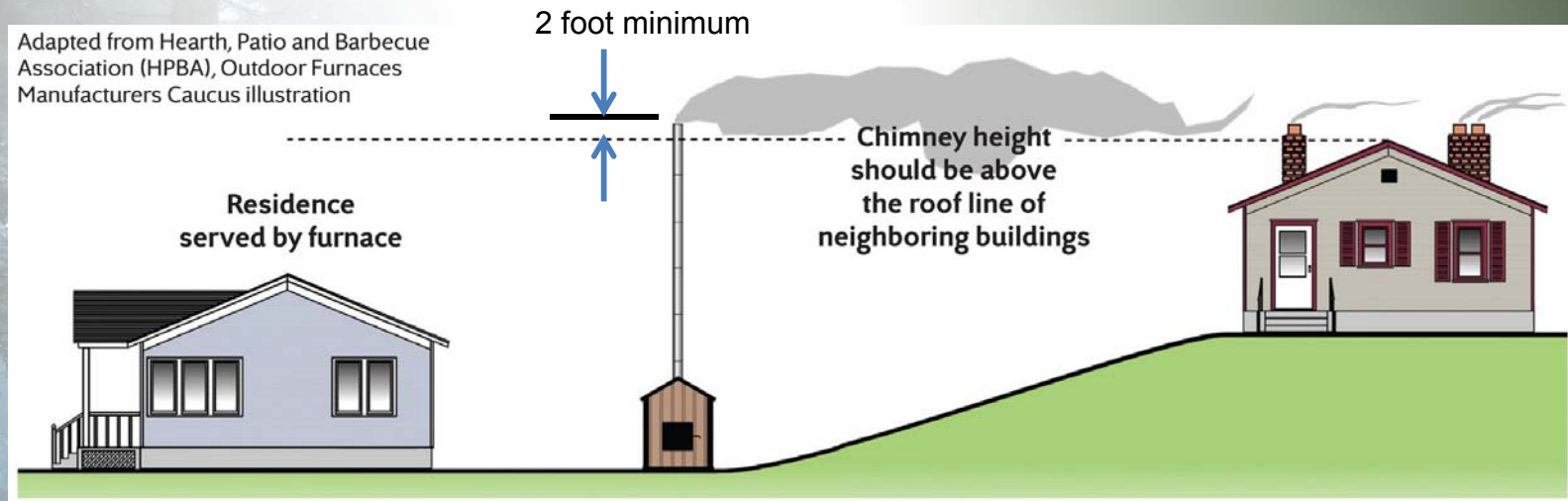
# Firebox Management

- ❖ 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

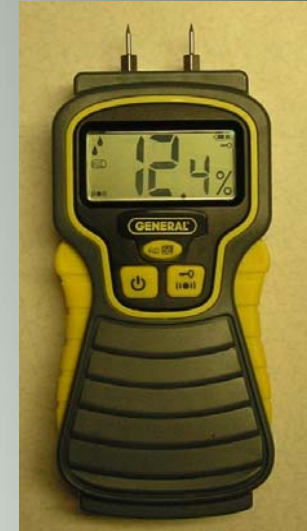
❖ 2 feet higher than highest building within 300 feet





# 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



# 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 but reduced fuel cost result in lower annual cost
- ❖ 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
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# Questions

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