

# Small Heating Systems

**What it takes to burn well**

**1) The most common problem is getting more fuel started than you have air and heat to finish.**

**2) Even if you have enough air (no smoke) you are probably not hot enough to burn CO (1500F). High heat is less necessary with a catalytic converter.**

**The goal is that at some point to be between 1500F and 2300F with sufficient oxygen.**



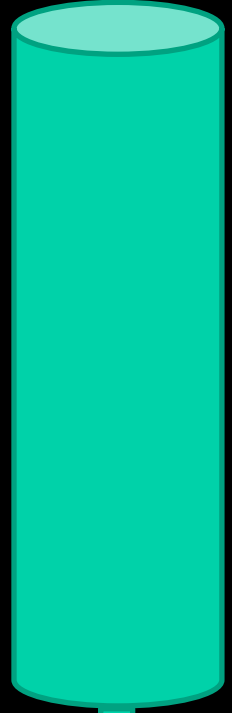


2500 F
2400 F
2300 F
2200 F
2100 F
2000 F
1900 F
1800 F
1700 F
1600 F
1500 F
1400 F
1300 F
1200 F
1100 F

[http://www.blksmith.com/heat\\_colors.htm](http://www.blksmith.com/heat_colors.htm)

# Down draft gasifier (Co-current)

Fuel  
Air



Filled with fuel

Dirty fire

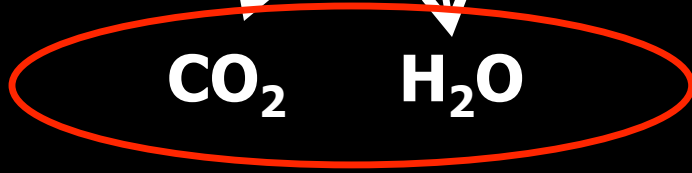
Hot coals convert tars, oils and smoke to gas

Gases (CO, H<sub>2</sub>) pulled out bottom

Burn gas in IC engine, furnace or boiler (need 1500F)

CO<sub>2</sub>

H<sub>2</sub>O





A man with a beard and yellow safety glasses stands on the left side of the enclosure. He is wearing a grey polo shirt and dark cargo pants. He has his hands on his hips and is looking towards the camera.

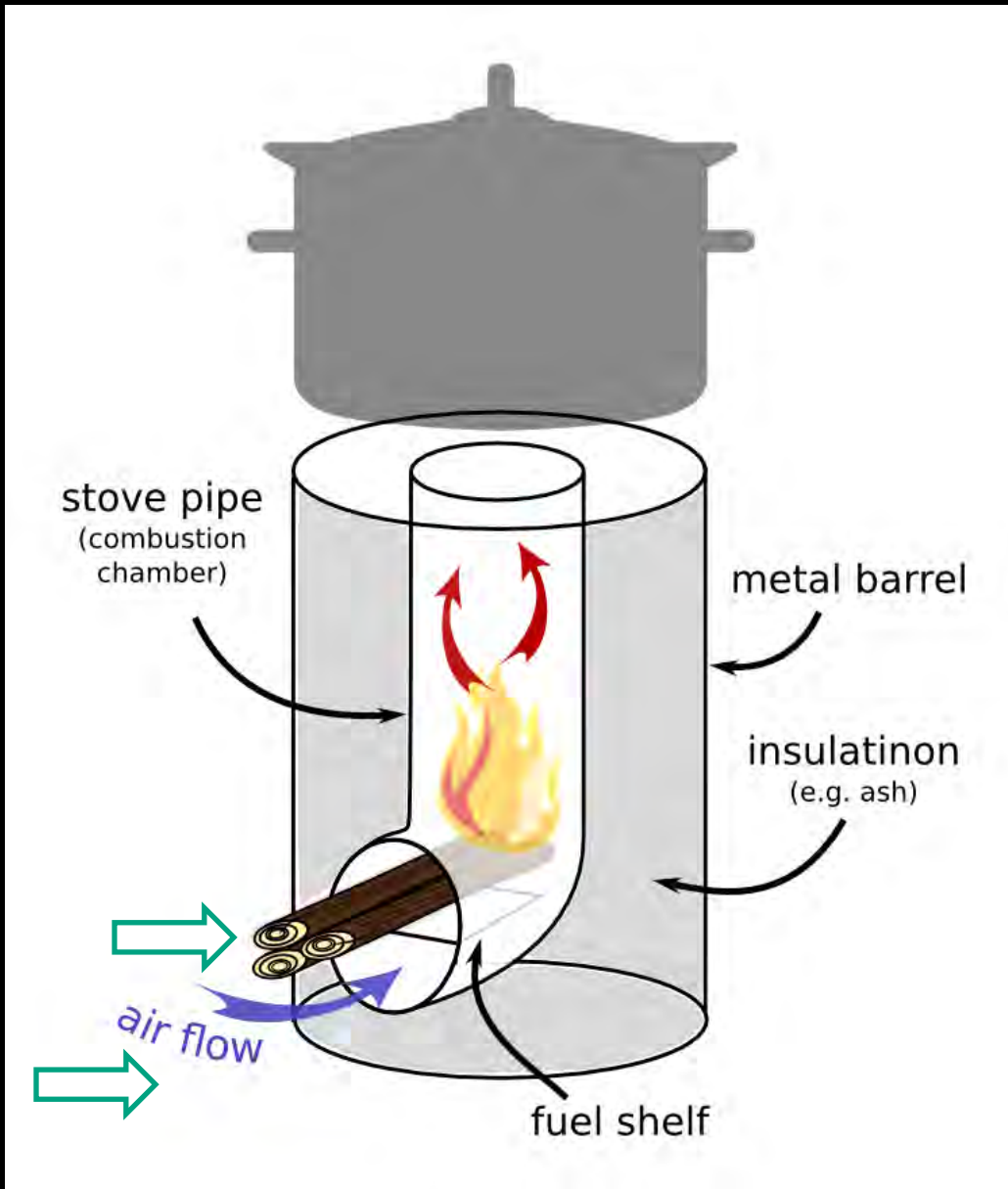
A man with glasses and a blue and red plaid shirt stands on the right side of the enclosure. He is holding a white sheet of paper and looking towards the camera. He is wearing blue cargo pants and black shoes.

The enclosure is a large, white, rectangular metal cabinet with multiple doors and latches. It has a black base and a black handle on the front door. The top of the enclosure is open, revealing internal components. The enclosure is situated on a concrete floor with yellow and black safety tape around its base.

In the background, two other men are working at a table. One man is wearing a black shirt and safety glasses, and the other is wearing a black shirt and safety glasses. They appear to be focused on their work.

On the left side of the image, there are metal shelves filled with various items, including bags, boxes, and tools. A large black fan is visible in the background.

# Rocket Stove



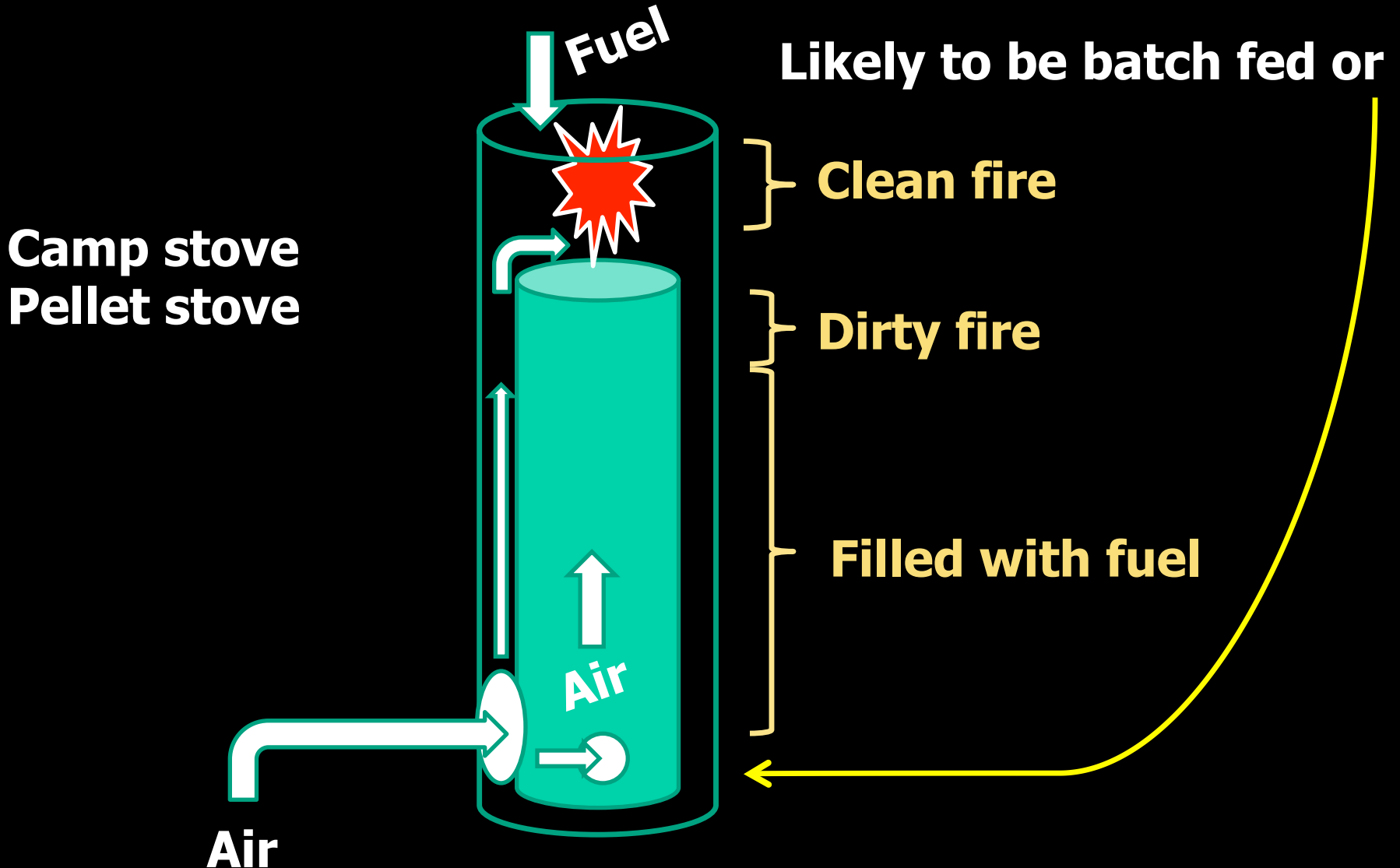
**Similar to a down draft gasifier**

**Fuel and air from same end.**

**(Co-current)**

# Up draft gasifier

(Counter-current; fuel from top air from bottom)



Easier to make harder to burn clean

**Q) more fuel started than you have air to finish**

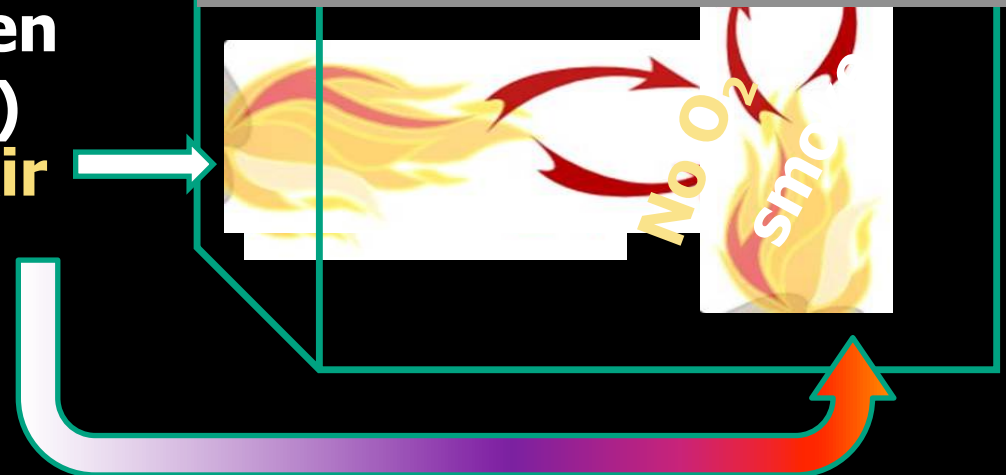
**A) Light on top and/or near exit (easy)**  
**Push when feeding**  
**Might have to add radiation area**

**OR**

**A) Add secondary air supply**

**Difficult to control as  
burning conditions change;  
original design fine when  
flames done (just coals)**

**Air**



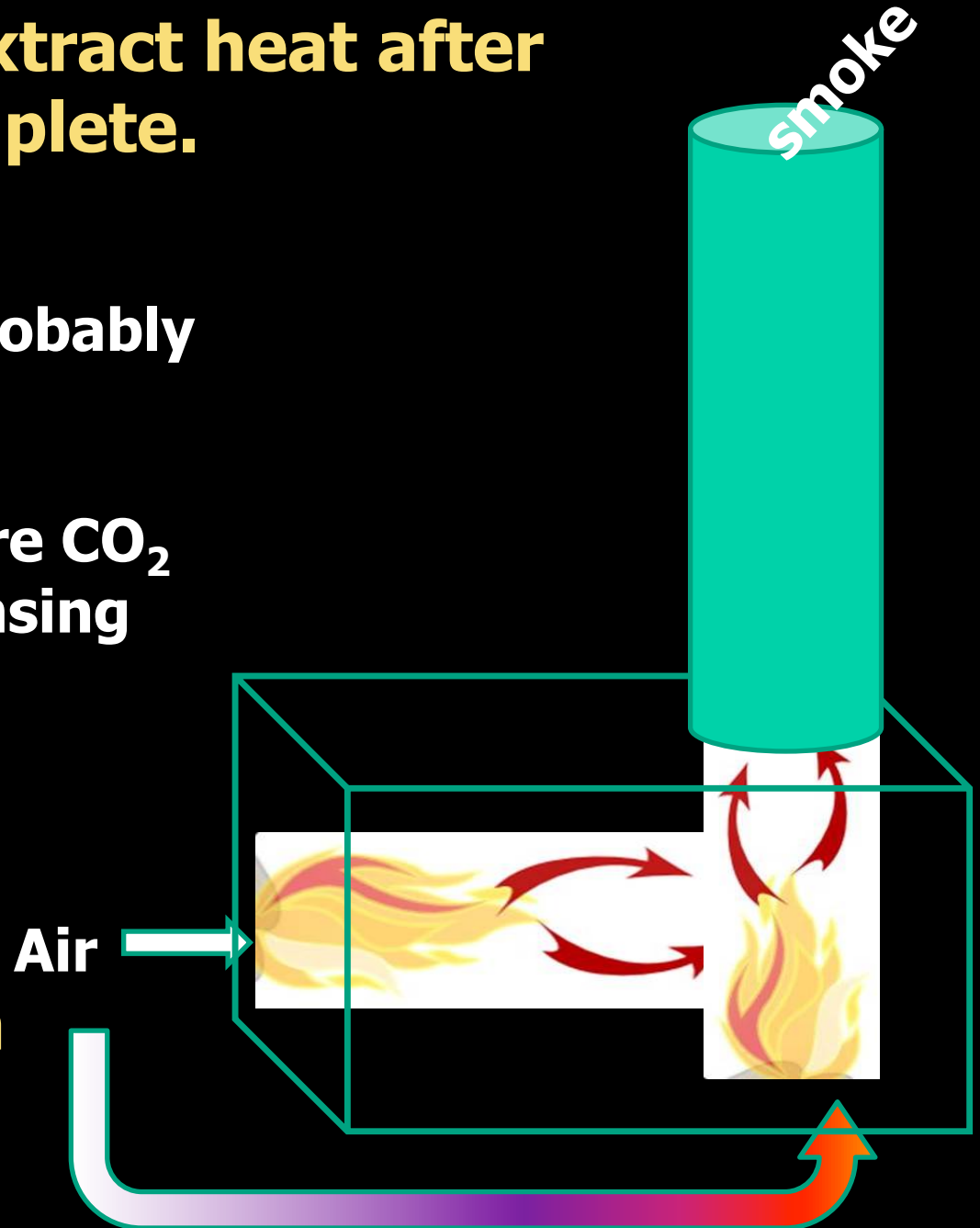


**In all cases only extract heat after combustion is complete.**

**In fact insulation is probably necessary!**

**If the only products are  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , then condensing water is possible**

**A jet of air makes it look like a good fire, but blows ash particulates up chimney.**



## **Startup**

**Burning wood will create smoke until critical zone reaches the proper temperature.**

**PreHeat with other fuel?**

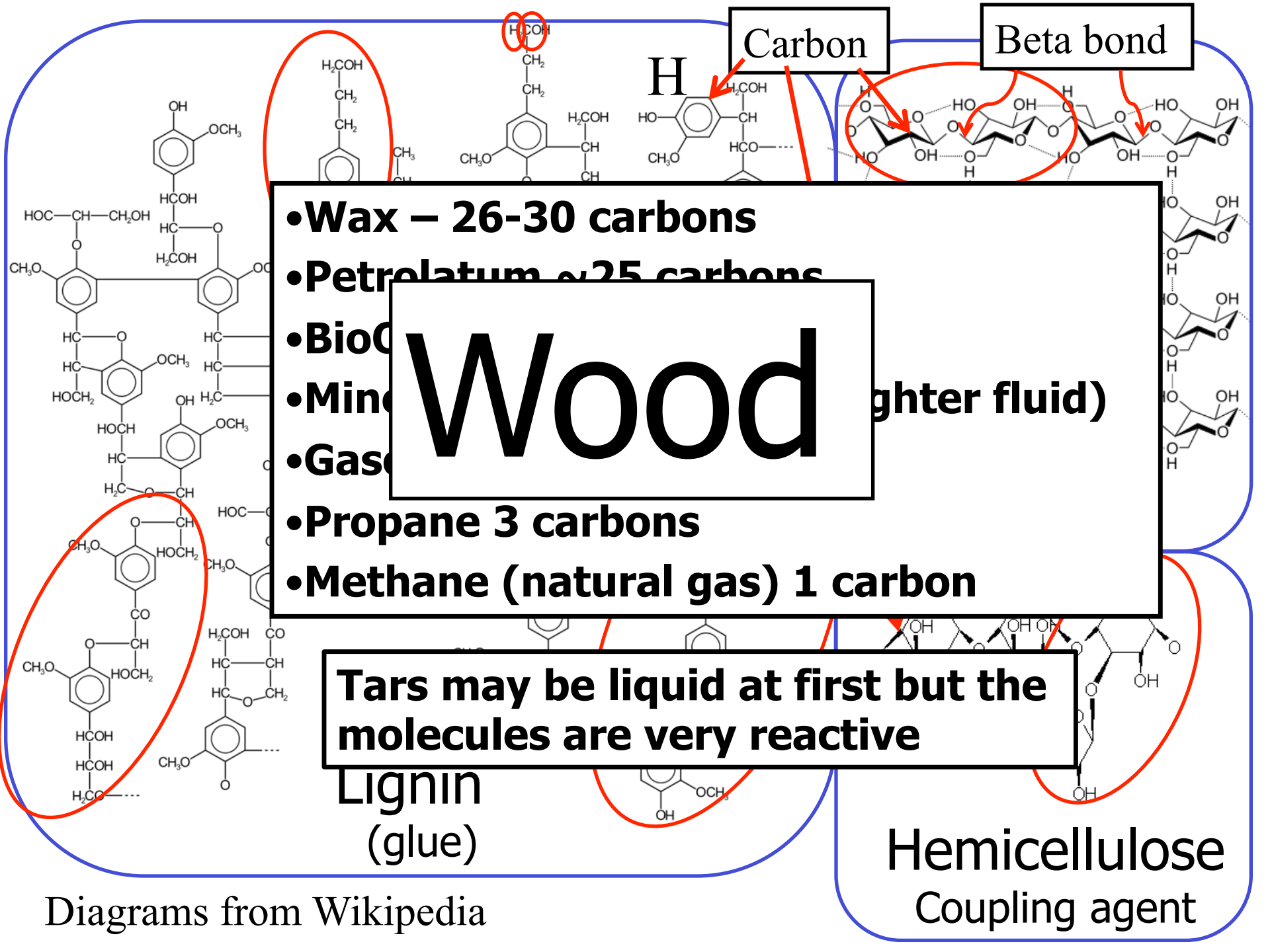
**This is a disadvantage to batch fed stoves, less so if you feed while still hot.**

**If no catalytic converter then CO produced until 1500°F reached.**

**Pellet stoves have low mass in burn zone so it heats up relatively fast.**

**Commercial boilers burn continuously.**

**At all times, Stay below 2300°F to prevent oxidizing atmospheric nitrogen to NOx**



Carbon

Beta bond

- Wax – 26-30 carbons
- Petroleum ~25 carbons
- BioC
- Min
- Gas
- Propane 3 carbons
- Methane (natural gas) 1 carbon

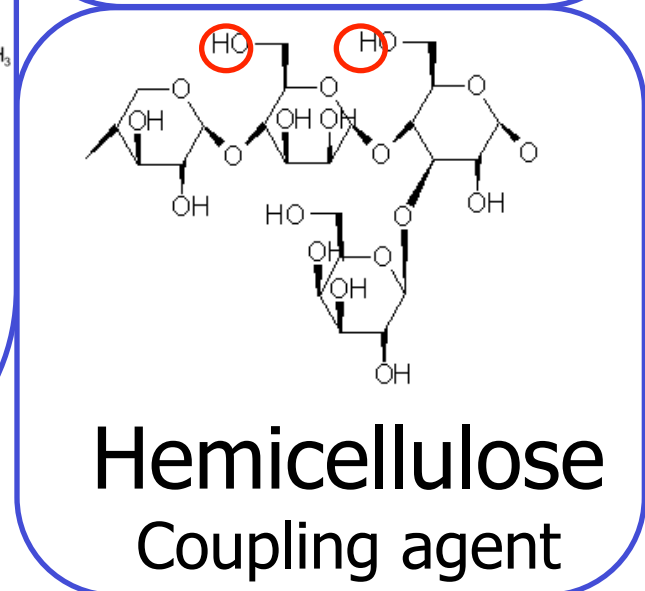
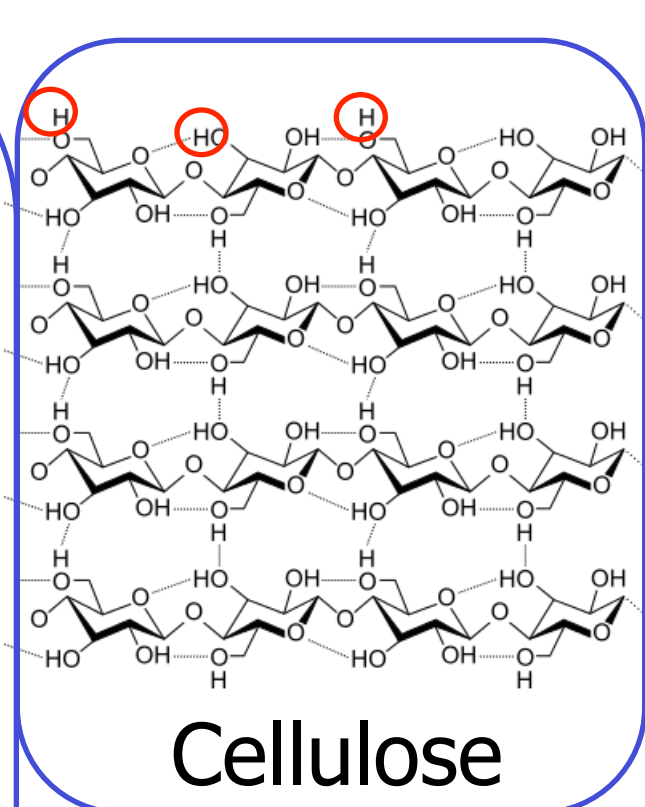
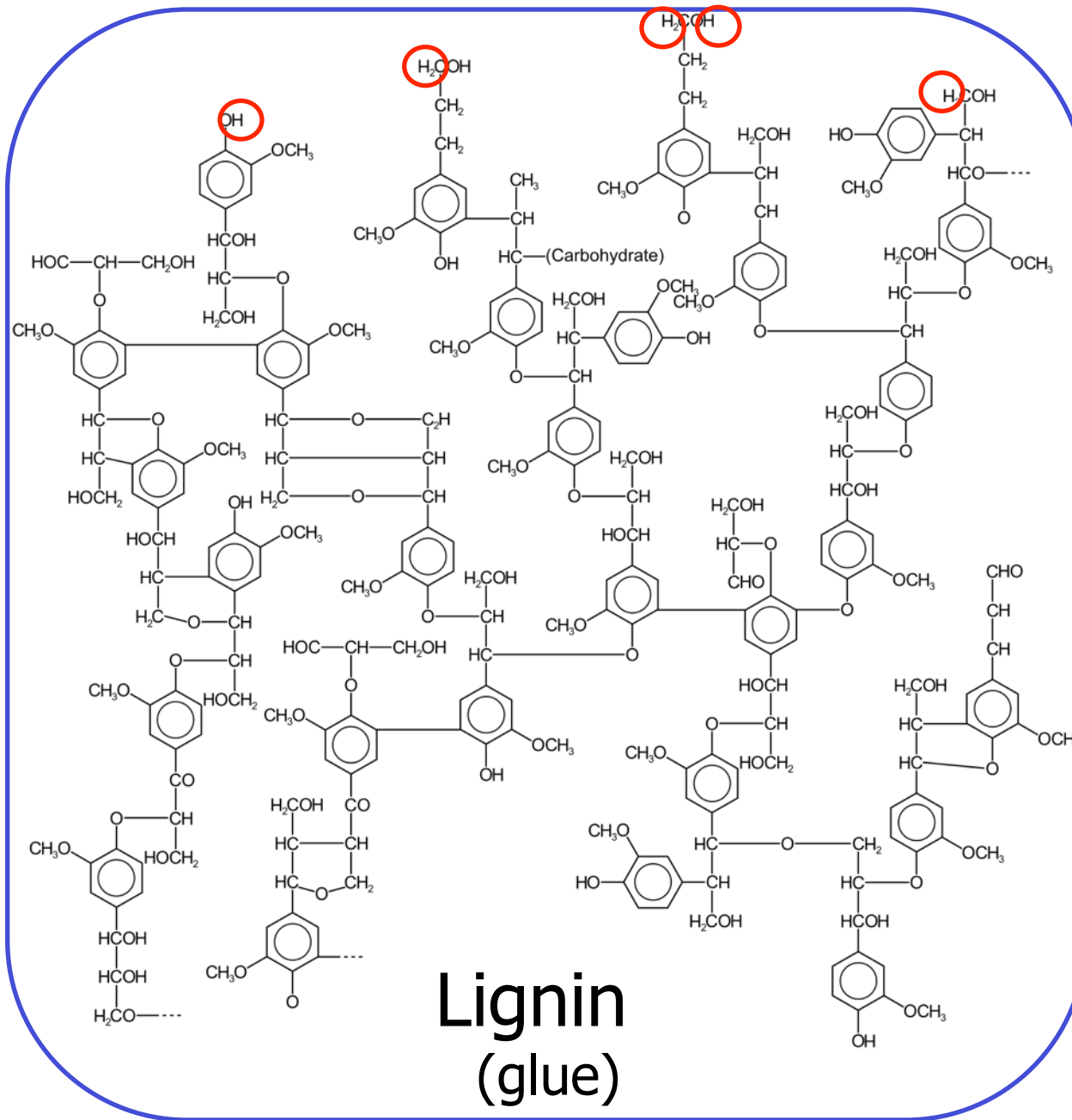
# Wood

Tars may be liquid at first but the molecules are very reactive

Lignin  
(glue)

Hemicellulose  
Coupling agent

**3) Then, what about water?**



Diagrams from Wikipedia

# Empirical formula for wood



**6.2% Hydrogen  
by weight**

**Water (H<sub>2</sub>O) is 18 times  
heavier than hydrogen  
9 fold increase in weight**

**100 lbs. of dry wood has 6.2 lbs. of hydrogen  
which when burned becomes 56 lbs. of water**

**100 lbs. of Wood ~ 8,600 Btu/lb**

**water ~ 1,200 Btu/lb to boil away**

1/deg F, 970 vaporize, .485/degF  
(Btu/lb)

MC also lbs. of water	0	20	50
lbs of wood	100	80	50
lbs. water created	56	44.8	28
Total lbs. of water	56	64.8	78
btu available	860,000	688,000	430,000
lost as steam	67,704	78,343	94,302
net Btu	792,296	609,656	335,698
	<b>8%</b>	<b>11%</b>	<b>22%</b>

Btu/ton/1000 with 350°F stack

MC wet basis	Bomb BTU	BTU loss extra water	BTU loss created water	NET BTU
0	17,200	0	1,354	15,846
5	16,340	121	1,286	14,933
10	15,480	242	1,219	14,020
15	14,620	363	1,151	13,106
20	13,760	484	1,083	12,193
25	12,900	604	1,016	11,280
30	12,040	725	948	10,367
35	11,180	846	880	9,454
40	10,320	967	812	8,540
45	9,460	1,088	745	7,627
50	8,600	1,209	677	6,714
55	7,740	1,330	609	5,801
60	6,880	1,451	542	4,888
86.7615	2,277	2,098	179	0
35.8974	11,026	868	868	9,290



**For your stove/boiler, Use dry wood!  
Light farther down stream.  
If it smokes for more than 5 minutes,  
there is room for improvement.**

**Turning down a flaming  
fire is difficult to do well.**

**Commercial stoves are getting better**

**Mark Knaebe  
Forest Products Lab**



# Some Problems Now

Cold jacket & Low load = smolder



Incomplete Combustion  
= Inefficient & Polluting

New designs = better

# Two efficient wood boilers

Tarm

100,000-200,000 BTU/hr



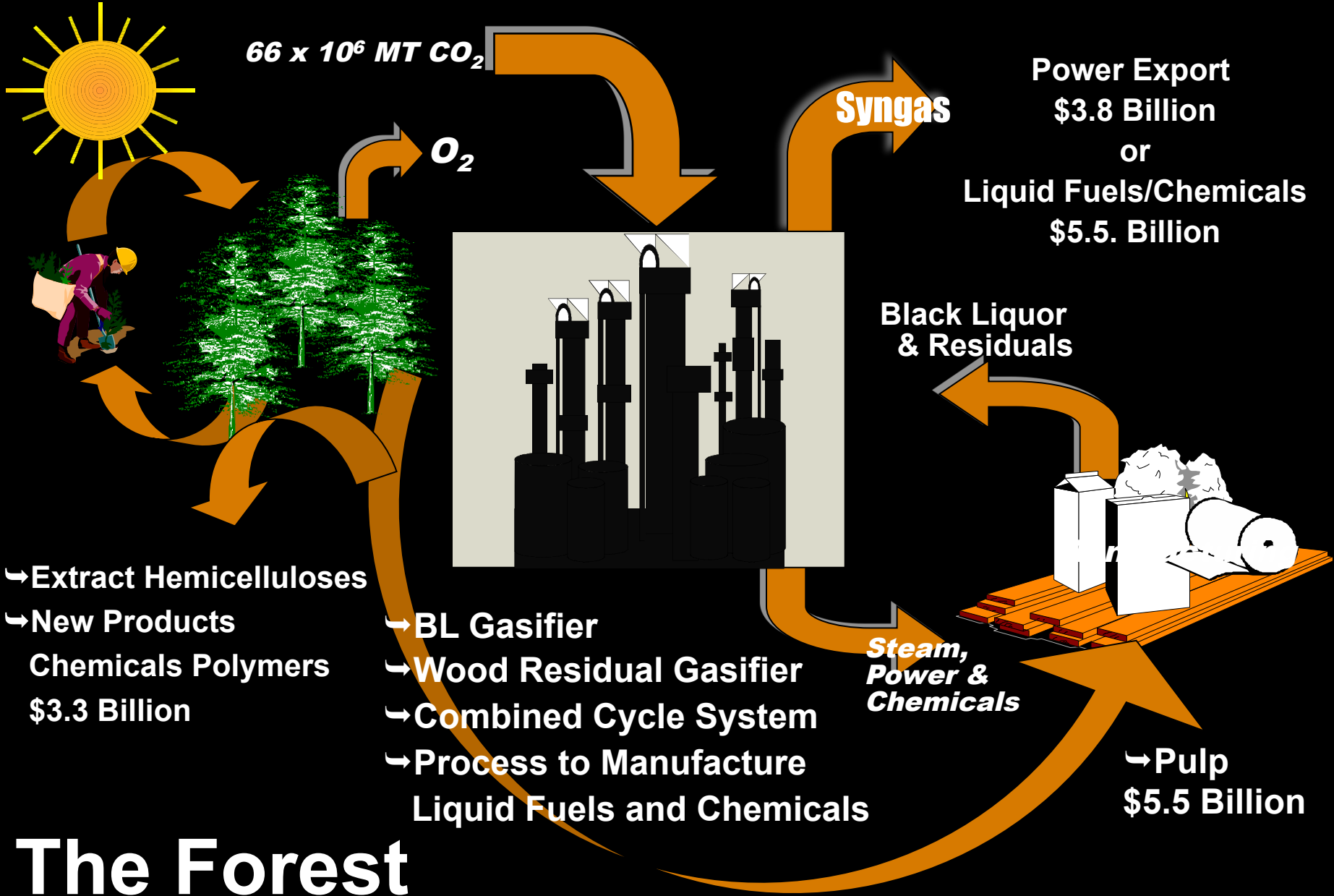
Garn

350,000 - 950,000 BTU/hr



Called gasification units although the time as a gas is very short

Fire at optimal intensity and heat up to 2000 gallons of water & then burn out, never smolder.



# The Forest Biorefinery

↳ Extract Hemicelluloses  
 ↳ New Products  
 Chemicals Polymers  
 \$3.3 Billion

↳ BL Gasifier  
 ↳ Wood Residual Gasifier  
 ↳ Combined Cycle System  
 ↳ Process to Manufacture  
 Liquid Fuels and Chemicals

Power Export  
 \$3.8 Billion  
 or  
 Liquid Fuels/Chemicals  
 \$5.5 Billion

Black Liquor & Residuals

Steam, Power & Chemicals

↳ Pulp  
 \$5.5 Billion

**Net Revenue Assumptions:**

Acetic Acid - \$1.73/gallon	Purchased Electricity - \$43.16/MWH
Ethanol - \$1.15/gallon	Exported Electricity - \$40.44/MWH
Pulp - \$100/ton net profit	Renewable Fisher Tropsch Fuel - \$57/bbl

# Mark Knaebe

Forest Products Technologist  
S&PF Technology Marketing Unit  
Located at the Forest Products Lab  
USDA Forest Service  
One Gifford Pinchot Drive  
Madison WI 53705-2398

608-231-9422

fax 231-9395

[mknaebe@fs.fed.us](mailto:mknaebe@fs.fed.us)

<http://www.fpl.fs.fed.us>

<http://www.fpl.fs.fed.us/tmu>