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.
Down draft gasifier
(Co-current)

Filled with fuel

Dirty fire

Hot coals convert tars, oils and smoke to gas

Gases (CO, H2) pulled out bottom

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

CO₂  H₂O
Combined heat and power

5KW of electrical power
Heat for space and water
That's 1/5000 the size of St Paul

Biomass Power

Today, the average house uses less than 1kw (average)
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)

Camp stove
Pellet stove

Likely to be batch fed or

Clean fire
Dirty fire
Filled with fuel

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)

\[
\begin{align*}
\text{CO} + \text{H}_2\text{O} &= \text{CO}_2 + \text{H}_2 \\
2\text{C} + \text{O}_2 &= 2\text{CO} \\
\text{C} + \text{H}_2\text{O} &= \text{CO} + \text{H}_2 \\
\text{C} + 2\text{H}_2\text{O} &= \text{CO}_2 + 2\text{H}_2
\end{align*}
\]
In all cases only extract heat after combustion is complete.

In fact insulation is probably necessary!

If the only products are CO₂ and H₂O, 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
Wood

• Wax – 26-30 carbons
• Petrolatum ~25 carbons
• BioOil
• Mineral oil ~15 carbons (lighter fluid)
• Gasoline 4-12 carbons
• Propane 3 carbons
• Methane (natural gas) 1 carbon

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

Cellulose

Lignin (glue)

Hemicellulose

Coupling agent
Empirical formula for wood

\[ \text{C}_6\text{H}_9\text{O}_4 \]

6.2% Hydrogen by weight

Water (H\textsubscript{2}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**

<table>
<thead>
<tr>
<th></th>
<th>1/deg F</th>
<th>970 vaporize,</th>
<th>.485/degF</th>
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<tbody>
<tr>
<td><strong>MC also lbs. of water</strong></td>
<td>0</td>
<td>20</td>
<td>50</td>
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<tr>
<td><strong>lbs of wood</strong></td>
<td>100</td>
<td>80</td>
<td>50</td>
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<tr>
<td><strong>lbs. water created</strong></td>
<td>56</td>
<td>44.8</td>
<td>28</td>
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<tr>
<td><strong>Total lbs. of water</strong></td>
<td>56</td>
<td>64.8</td>
<td>78</td>
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<tr>
<td><strong>btu available</strong></td>
<td>860,000</td>
<td>688,000</td>
<td>430,000</td>
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<td><strong>lost as steam</strong></td>
<td>67,704</td>
<td>78,343</td>
<td>94,302</td>
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<tr>
<td><strong>net Btu</strong></td>
<td>792,296</td>
<td>609,656</td>
<td>335,698</td>
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<p>| 8%                      | 11%    | 22%            |</p>
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<th>MC wet basis</th>
<th>Bomb BTU</th>
<th>Extra water</th>
<th>Created water</th>
<th>NET BTU</th>
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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

Net Revenue Assumptions:
- Acetic Acid - $1.73/gallon
- Ethanol - $1.15/gallon
- Pulp - $100/ton net profit
- Renewable Fisher Tropsch Fuel - $57/bbl

$3.3 Billion
- Extract Hemicelluloses
- New Products
  Chemicals Polymers

$5.5 Billion
- BL Gasifier
- Wood Residual Gasifier
- Combined Cycle System
- Process to Manufacture Liquid Fuels and Chemicals

$3.8 Billion
- Power Export
- Power Export
- Liquid Fuels/Chemicals

66 x 10^6 MT CO₂

Black Liquor & Residuals

Syngas

Steam, Power & Chemicals

Pulp
$5.5 Billion

$1.73/gallon
$43.16/MWH
$1.15/gallon
$40.44/MWH
$100/ton net profit
$57/bbl
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