BIOMASS CONVERSION TO BIOCHAR IN LARGER CUSTOM-BUILT KILNS

Paul Taylor
The Biochar Revolution
OBJECTIVE

- To explore biochar ovens which can process a range of feedstocks: wood, bark, leaves, manure, straw, grass, hulls, soil, clay, mineral additives
- Using residual materials on location on and near small properties
- To make enhanced biochars that fit into small scale agronomic systems: Composting, Aquaponics, Vermiculture, Sanitation, Animal Husbandry, Land remediation, Intensive beds, Roof gardens, Farms ...
- With low and tested emissions
- At minimal capital expense
- Leading to widespread experimentation in methods & applications
- Helping in a bottom up push to commercialization of biochar systems
# 3 METHODS OF HEATING

## Internal heat transfer
- **200 L Drum TLUD**

## External heat transfer
- Folke-Gunther double barrel

## Circulated gas heating
- Adam Retort

<table>
<thead>
<tr>
<th></th>
<th>TLUD</th>
<th>Double Drum</th>
<th>Adam Retort</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feedstock size</strong></td>
<td>Chips. Difficult to run on mixtures</td>
<td>Chunks, sticks, not sawdust</td>
<td>Logs, Limb wood</td>
</tr>
<tr>
<td><strong>Air access</strong></td>
<td>Yes, must quench or snuff char at end</td>
<td>No</td>
<td>Can be controlled</td>
</tr>
<tr>
<td><strong>Scale</strong></td>
<td>Up to 200L. Scale by multiple units</td>
<td>200L require larger outer drum</td>
<td>Small farm, 2 m3, 300 kg biochar</td>
</tr>
<tr>
<td><strong>Heat transfer</strong></td>
<td>Close coupled, efficient</td>
<td>Not efficient, unless insulated</td>
<td>Efficient and controlled</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Progressive, easy to control</td>
<td>May all go at once</td>
<td>Use mixed size feedstock</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>700oC Can be cooled with mister</td>
<td>400oC</td>
<td>400oC</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>2 hrs</td>
<td>2 hrs</td>
<td>B hrs</td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td>Clean burning</td>
<td></td>
<td>Can be made low emission</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Simple, cheap, recycled drums</td>
<td>Simple, cheap, recycled drums</td>
<td>$5000-8000</td>
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</table>
2 m³ KILN DESIGN FOR COMPOSITE BIOCHARS

- Small LPG torch to start burning of syngas
- Hot flue gas with air for tar cracking
- Flue gases from fire box heat, dry & roast the feedstock
- Flue gases can also heat and crack the pyrolysis gases
- Air tube for secondary combustion air
- Small LPG burner ensures excess gases are combusted

Mesh cart rolling on wheels loaded with biomass
2 m3 KILN on BambooBusy Farm

Temperature profile inside kiln

<table>
<thead>
<tr>
<th>Time</th>
<th>Ref Loc</th>
<th>Temp</th>
<th>Loc</th>
<th>Temp</th>
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<tbody>
<tr>
<td>13:20</td>
<td>5h</td>
<td>65</td>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>13:25</td>
<td>5f</td>
<td>63.5</td>
<td>3</td>
<td>81.5</td>
</tr>
<tr>
<td>13:33</td>
<td>5f</td>
<td>68.6</td>
<td>2</td>
<td>88.5</td>
</tr>
<tr>
<td>13:35</td>
<td>5f</td>
<td>69.8</td>
<td>1</td>
<td>85.0</td>
</tr>
<tr>
<td>13:40</td>
<td>5f</td>
<td>74</td>
<td>4h</td>
<td>60</td>
</tr>
<tr>
<td>13:45</td>
<td>5f</td>
<td>77</td>
<td>7f</td>
<td>48</td>
</tr>
<tr>
<td>13:53</td>
<td>5f</td>
<td>75.6</td>
<td>8f</td>
<td>84.5</td>
</tr>
<tr>
<td>13:55</td>
<td>5f</td>
<td>74.2</td>
<td>8f</td>
<td>85.2</td>
</tr>
<tr>
<td>14:00</td>
<td>5f</td>
<td>73.8</td>
<td>9h</td>
<td>105</td>
</tr>
<tr>
<td>14:05</td>
<td>5f</td>
<td>73.7</td>
<td>6f</td>
<td>145</td>
</tr>
<tr>
<td>14:08</td>
<td>5f</td>
<td>73</td>
<td>6f</td>
<td>149</td>
</tr>
</tbody>
</table>

Thermocouple probe

Water jets for cooling
Firebox

Woodgas burning around air inlet tube above cart

COMMISSIONING

Residual biochar
Bamboo horizontal
Clay, straw, manure
Mass-Energy Balance to Pyrolyze 200 kg of feedstock

~ 2 cu m bamboo    ~ 1 cu m of loose packed hog fuel or limb wood

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Mass Flows kg</th>
<th>Specific energy MJ/kg</th>
<th>Energy MJ</th>
<th>%</th>
<th>Time hrs</th>
<th>Power @ 60% kW</th>
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<tbody>
<tr>
<td>Energy content</td>
<td>Moist wood</td>
<td>200</td>
<td>13</td>
<td>2600</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water evaporation</td>
<td>Water–25%</td>
<td>50</td>
<td>2.6</td>
<td>130</td>
<td>5%</td>
<td>2</td>
<td>30</td>
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<tr>
<td>Heating thru 260°C</td>
<td>Dry wood</td>
<td>150</td>
<td>0.5</td>
<td>75</td>
<td>3%</td>
<td>1.15</td>
<td>30</td>
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<tr>
<td>Heat loss from kiln</td>
<td></td>
<td>1.5kW/m2</td>
<td></td>
<td>130</td>
<td>5%</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>Energy content</td>
<td>Biochar</td>
<td>50</td>
<td>26</td>
<td>1300</td>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy content</td>
<td>Syngas</td>
<td>100</td>
<td>13</td>
<td>1300</td>
<td>50%</td>
<td>1</td>
<td>360</td>
</tr>
</tbody>
</table>

- 16% of syngas energy is needed to dry/initiate pyrolysis, only 10% for heat loss.
- In an efficient batch retort syngas is a poor match to the pyrolysis process.
- Useful to have a dual batch retort where syngas from 1 initiates pyrolysis in 2.
- 4-6 kg of propane (at 50 MJ/kg) can initiate pyrolysis in 200 kg of feedstock.
1 m³ KILN CONCEPT FOR COMPOSITE BIOCHARS

0.9m cube cart inside 1.2m cube kiln

Wall, door and roof panels of cement board with refractory insulation (50mm wool/CaSil)

Syngas transferred through an 18 cm diam. flue pipe into a flare stack

Heat loss:
50 mm insulation, 700°C inside ~ 120°C outside, 1.5 kW/m²

38 MJ/h ring burner, 10 kW

Tube burner, 90 cm, 56 MJ/h, 15 kW
INFIELD PYROLYSERS

- Developed as a low cost method of eliminating pollution produced when crop residues and greenwaste from land clearing are burnt in the field.
- A novel method of firing the ovens has been developed that ensures maximum biochar yields and nutrient availability.
- Based on traditional Nepali and African farmer practice:

  Dig ground  
  Lay straw on soil  
  Lay smoldering dung on biomass  
  Put leaf litter on smoldering dung  
  Cover with soil and let smolder for 3 days.  
  Dig into soil. Let stand 15 days before planting
Pyrolyser is placed over a mixture of manure, clay & minerals put between layers of hay to maximize nutrient availability.
LARGE INFIELD PYROLYSER (The Big Roo)

CONCEPT

- Reduce emissions when crop residues & greenwaste are field burned.
- Covers 7m³, ~2 tons biomass
- Carried and placed by tractor
- External gasifier provides hot air for drying / torrefaction to ~200°C, <15% moisture
- Small genset powers fan, sends flue gas into kiln
- Top of biomass is ignited through lower airholes, later closed
- Volatiles mix with air and burn at the top of kiln, radiating heat to drive pyrolysis, which progresses downwards

LPG burner to crack smoke, ignite syngas
150mm Secondary air pipes
Rigidized refractory wool
Heat shield with gas holes
Water sprays
150mm holes for start-up air. Burner inserted to ignite top
40mm square tube Frame with sheet steel
Baffle with hot air from diesel engine flowing up the side
LARGE SHEET-METAL INFIELD PYROLYSER

CONSTRUCTION DETAILS – PROTOTYPE

- **2mm mild steel sheet** bolted to 40mm square tube frame with expansion holes
- Two 600x600mm flues, flare shrouds not shown
- **Secondary airpipes of 150mm SS exhaust pipe** with graduated air holes for equal pressure
- **2mm mild steel sacrificial shield** with 0.6m² of gas slots supported on ledges at tops of walls
- **Hot air pipes of 150mm heavy gauge steel** with graduated air holes welded to 3mm baffle plate
- **Weighs 765kg + exterior pipes, fan, generator, controls**
- **Cost: $20,000**
Insulation on top half is placed on outside and protected with corrugated iron.
Transportable container based pyrolyzer

- 13m³ per batch, 1 ton of biochar
- Batch processing takes ~ 4hrs.
- High fixed carbon content > 90%.
- Thermal energy output of ~ 52GJ total over 4hr (3.6MW).
- Cost: $250,000
PYREG Continuous Pyrolyser

- 1000 tons per year
- Water content <50%
- Particle size <30 mm
- 150kW heat out
- 40 ft container platform
- US$400,000 in Europe

Greenwaste, sewage sludge, slaughterhouse waste, paper sludge, bark, pine needles, foliage, cereal residues, straw, rapeseed, sugar beet waste, olive production waste, nutshell, digestate, screenings, coffee production waste, compost, beer barley residues, miscanthus, rubber, ...
OPEN SOURCE CONTINUOUS PYROLYSER
To Provide Biochar and Process Heat for Farmers & Co-ops

- Designed to be manufactured in small engineering workshops.
- Transported by truck or tractor around the farm.
- It has one motor to drive the screw and one fan.
- Feed in and biochar removal can be manual or automated.
- Control can be manual or automated.
- Cost ~ $A30,000
LPG burner preheats the chamber to 600°C.
- Feedstock comes in from an external hopper.
- Primary air comes through holes in flat steel sheets beside the troughs and through 2 jets on the end wall.
- Syngas from pyrolysing biomass in the trough and Primary air mix and partially combust above the bed.
- Radiant flux above the bed causes biomass to dry, torrefy and pyrolyse as the material moves along the trough.
- Secondary air flows over the hot side walls, enters the reactor at the outlet and mixes with the remaining unburned syngas.
- Paddles stir the charring biomass and sweep it to the bottom of the trough, mixing with the drying biomass.
- The biochar drops over a weir at the end of the trough.
- Temperature of the biochar is controlled by changing the feed rate, the flow rate of water mist onto the charring bed and the amount of primary air entering the chamber.
- Temperature of the burning gas is maintained above 700°C to ensure complete combustion.
- Syngas can be extracted from the back of the reactor.
OPEN SOURCE PYROLYSER

- Handle variety of feedstocks, moisture contents < 30%, diameter < 50mm
- Optimal process conditions with particle diameter 5-15mm, moisture content of 12-20%
- Minimum output 60 kg/hr of biochar at 15% moisture, scalable up to 200 kg/hr
- Operate continuously with a final pyrolysis bed temperature variable from 350°C to 500°C
- Capability of running at higher temperatures when process heat is required
- Heat output applied to fire a boiler, drying, heating (greenhouses, animal sheds, hydroponics units).
Design refined with Computation Fluid Dynamics (CFD)

Velocity Profiles

Gas Temperature Profiles

Biomass feed
Bed Temperature Due to Radiation

- Modeling by Prof Farid Christo using Fluent CFD package.
- Modeling used to refine the design to ensure emissions were minimal and achieve a more uniform temperature profile along the bed.
- Bed temperature can be controlled by changing the amount of air and throughput of biomass.
- Water spray jets allow steam activation of the surfaces and can moderate the bed temperature to produce both high and low temperature biochars.
CO ~140ppm and NOx less than 20ppm in initial tests with wheat straw & chicken manure.
Biochar Production Integration in Large-scale Production of Meat

Providing process heat for animal pens and combining the biochar with compost into a granulated pellet.
Biochar Reactor with Internal Heat Exchanger Reactor

Can Take Straw and Manure
Integrating Vermiculture, Aquaponics & Biochar

- Rainwater tank
- Aeration ponds
- Biochar reactor
- Biochar in stocking
- Worm farm
- Worm juice to hydroponics troughs
- Warm water to fish tank
- Biochar & worm castes used as medium in porous pots
- Fish tanks
- Aerators
- Pumps
- Worms to feed fish
Aeration Ponds

Biochar Filter

Fish Tank

Worm Farm

Biochar Sock in Fish Tank

Pak Choi in Pot with Biochar Compost

Ell-gro Channels with pots
DESIGN CRITERIA

• What is your use for biochar – pot plants, garden, farm trials?
• What is your soil type, and what biochar qualities do you need?
• How much biochar will you make, how often?
• Where will you locate the biochar maker? Enough space, water?
• What could be impact on neighbours and how will you control it?
• How will you do biochar pot or plot trails? Record results?
• Who will participate with you in the project?
• What tools do you have?

• What recycled materials can you find to build a pyrolyser with?
• What feedstock is available and will you use?
• Is the feedstock chunky, will you chip it, is it fine?
• Where, and how much, feedstock will you store and dry?
• How will you quench the biochar?
• How will you condition the biochar?
• How will it fit into your compost and garden operation?
• How can you make it a learning experience for your family and community?
THANK YOU
STAGES – YIELD PROFILE FOR BIOMASS PYROLYSIS

Drying

 Conditioning

 Torrefaction

 Exothermic Pyrolysis

 Char Conditioning

 Sample ashed in air at 600°C
 Proximate Analysis (% wet)

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>20</td>
</tr>
<tr>
<td>Volatiles</td>
<td>52</td>
</tr>
<tr>
<td>Biochar</td>
<td>28</td>
</tr>
<tr>
<td>Ash</td>
<td>5</td>
</tr>
</tbody>
</table>

% of initial weight remaining

Energy In

Biochar

Energy out

Energy In

Ash

Temperature
Small property holders, farmers, community gardeners seek small-scale biochar production:

- To process waste biomass into biochars suitable for their soils,
- To enhance their farms and gardens,
- With modest budgets in the $100’s to $30,000 range.

Commercial biochar industry is not easy without government support.

Has more chance if biochar is processed into mixtures or enhanced biochars that carry agronomic benefits at economic application rates.

Traditional biochars made from mixed feedstocks - including grasses, manure, ash, soil, clay, woodsmoke – in a range of temperatures.

Traditional application of biochar is widespread - it worked!
Farmers & NGOs desire a low emission design allowing experience in biochar production & use. Most farmers have capacity to build from handy equipment and materials or from kit parts.

**Design Criteria.**

- Cost < $A30,000
- Transported by truck or tractor around the farm
- Handle variety of feedstocks, moisture contents < 30%, diameter < 50mm
- Optimal process conditions with particle diameter 5-15mm, moisture content of 12-20%
- Minimum output 60 kg/hr of biochar at 15% moisture, scalable up to 200 kg/hr
- Operate continuously with a final pyrolysis bed temperature variable from 350°C to 500°C
- Capability of running at higher temperatures when process heat is required
- Either manual operation or semi-automation.
- The kiln should be inherently safe.
- Heat output applied to fire a boiler, drying, heating (greenhouses, animal sheds, hydroponics units).
Open Source Pyrolyser for Farmers and Co-operatives

Model with biochar bin

Model with screw conveyer for continuous biochar takeoff

Water Spray

20x 15mm holes in the outside wall

2x 50mm primary air pipes

LPG start up burners

2.5m Baffle

Secondary air heated in the gap between heatshield and external wall before mixing with syngas

2x 150mm Primary air pipes

Biochar cooling/storage
Design refined with Computation Fluid Dynamics (CFD)
Contours shown for selected design along central cross sections

Temperature (°C)

Velocity Vectors (m/s)

Streamlines

Gas species mole fractions

CO

CO₂
Problem – stranded biomass

Current solution

Testing

Double drum test reactor

Full-scale Transportable System
Key findings:

- The mobile biochar machine processes 13m³ per batch, or 1 ton of biochar
- Novel process overcomes heat transfer obstacle
- Batch processing takes ~ 4hrs.
- Target temperature of all processed feedstock ~ 500°C.
- High fixed carbon content over 90%.
- Thermal energy output of ~ 52GJ total over 4hr (3.6MW).
- After burner temperature ~ 1000°C + excess air reduces volatile emissions to a minimum.
- Designed for unmanned operation.
- Cost: $250,000

- Selling char
- Doing field trials
- 2 more units under construction