Biochar Systems for energy, agriculture, health and the environment

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Much of the current scientific debate on the harvesting of biomass for bioenergy is focused on how much can be harvested without doing too much damage.
how to design integrated agricultural biomass-bioenergy systems that build soil quality and increase productivity so that both food and bioenergy crops can be sustainably harvested?

Laird 2008

Lehmann and Joseph, 2009
What is biochar?

- Produced from biomass above 300 °C, with pyrolysis (low O₂)
- Contains ~ 60-80% C as black C
- Porous low bulk density, large hydrophobic surface area
- Also contains minerals as ashes
- Highly aromatic, strong adsorption of org. compounds
Biomass + Gas → Heat or Energy

- Combustion: High particulate and dioxins atmospheric emissions
- Pyrolysis: Low particulate and dioxins atmospheric emissions
Unlike other biofuels and bioenergy, biochar does not necessitate valuable agricultural lands, food crops like corn, nor the deforestation of already valuable ecosystems.
Production and sustainability: how is produced biochar?

- Pyrolysis can occur on many different scales (from households to energy plants).
- Small-scale pyrolysis plants can be used on-farm or by small industries (feedstock inputs of 50 to 1000 kilograms per hour).
- At a regional level, pyrolysis units can process up to 8000 kilograms of feedstock per hour (Talberg 2009).

Source: World Bank
Production and sustainability: biochar production

- The commercial production of biochar is still very limited today.
- The main part of the process aims primarily to produce syngas, a low calorific power mix of CO, CO$_2$, H$_2$, CH$_4$ and N$_2$, which is used to power an endothermic engine in order to produce electricity and heat.

<table>
<thead>
<tr>
<th>approach</th>
<th>conditions</th>
<th>liquid</th>
<th>solid</th>
<th>gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(bio-oil)</td>
<td>(biochar)</td>
<td>(syngas)</td>
</tr>
<tr>
<td>Slow</td>
<td>Moderate temperature ~500°C</td>
<td>30</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Long vapour residence time ~5–30 minutes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate temperature ~500°C</td>
<td>50</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Vapour residence time ~10–20 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>Moderate temperature ~500°C</td>
<td>75</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Short vapour residence time ~1 second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasification</td>
<td>High temperature &gt;750°C</td>
<td>5</td>
<td>10</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Vapour residence time ~10–20 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Brown 2009
Stoves

Fuels and cooking

Charcoal (biochar)

Soil improvement
value-chain

BiocharPlus

Fuel producer

Get fuel

Small Medium Enterprise

Test fuel

Get biochar

Final user

Farm or Forest

Distribute biochar

Carbon Market

Sell Carbon Credits

Produce stoves

Sell stoves

Provide fuel

Burn fuel

Get fuel

Test fuel

Get biochar
Biochar use in agriculture: some history

Amazzonia, Manaus Area…. Terra Preta
More fertile soils

Differences are very clear also today

$KAK(BC) = 3 \times KAK(OBS)$

$P_p$ available

$C_{org}$

$\text{8 ha}$

$=>$ Different P and C pools !!!
Not only in Amazzonia, but also in Sierra Leone
Is biochar able to increase plant productivity and yield?

Significant diff. From control

Application rate (t ha$^{-1}$)

+ 10%
pH ranges of soils

Changes in soil pH

However results have to be handled carefully as:

- Published articles are likely to be drawn from the pool of statistically significant results (papers with no significant findings are often not considered for publication) (Rosenthal and Rosnow, 1991)
- No studies were found with experiments for more than 2 years (90% of studies showed results over 1 growing season)
- Most of the papers are based on trials in tropical and subtropical latitudes
Biochar and health

• Indoor air pollution kills 1.3 million people per year, mostly women and children > than malaria, and almost = tuberculosis and AIDS (WHO, 2006)

• It is the most important cause of death among children under 5 years of age in developing countries (WHO, 2000).

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Table 2. Indoor levels of pollutants during cooking hours in the houses using different types of fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>N</th>
<th>TSP (mg m(^{-3}))</th>
<th>CO (mg m(^{-3}))</th>
<th>NO(_2) ((\mu)g m(^{-3}))</th>
<th>HCHO ((\mu)g m(^{-3}))</th>
<th>SO(_2) ((\mu)g m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(\bar{X})</td>
<td>CV</td>
<td>(\bar{X})</td>
<td>CV</td>
<td>(\bar{X})</td>
</tr>
<tr>
<td>Cattle dung</td>
<td>20</td>
<td>A 3.47†</td>
<td>0.68</td>
<td>174†</td>
<td>0.80</td>
<td>348†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G 2.75†</td>
<td>1.44†</td>
<td>319†</td>
<td>0.67</td>
<td>670†</td>
</tr>
<tr>
<td>Wood</td>
<td>20</td>
<td>A 2.63†</td>
<td>0.94</td>
<td>189†</td>
<td>0.58</td>
<td>344†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G 1.98†</td>
<td>1.56†</td>
<td>325†</td>
<td>0.38</td>
<td>652†</td>
</tr>
<tr>
<td>Coal</td>
<td>20</td>
<td>A 1.19†</td>
<td>0.35</td>
<td>110†</td>
<td>0.56</td>
<td>165†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G 1.10*</td>
<td>0.35</td>
<td>147†</td>
<td>0.56</td>
<td>109*</td>
</tr>
<tr>
<td>Kerosene</td>
<td>20</td>
<td>A 0.52†</td>
<td>0.42</td>
<td>137†</td>
<td>0.72</td>
<td>184†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G 0.46†</td>
<td>1.08†</td>
<td>133</td>
<td>1.12*</td>
<td>87*</td>
</tr>
<tr>
<td>LPG</td>
<td>20</td>
<td>A 0.50†</td>
<td>0.32</td>
<td>24†</td>
<td>1.00</td>
<td>183†</td>
</tr>
</tbody>
</table>

\(N = \) number of samples/houses surveyed.
\(A = \) arithmetic value; \(\bar{X} = \) mean; \(G = \) geometric value; \(CV = \) coefficient of variation.

Levels of pollutants are compared with those LPG using houses as control.

*\(P < 0.05; \dagger P < 0.01.\)
Emissions of Carbon Monoxide (CO) & Particulate Matter (PM) from TLUD (Top-Lit UpDraft) Gasifiers and Other Cookstoves
(Measured by the Standard 5-Liter Water Boiling Test (WBT))

TLUD Gasifier Data

CO (g)

Three-stone fire
Proposed Benchmarks
Anderson TLUD-ND (2005)
BP Oorja TLUD-FA (estimate)
Andreatta TLUD-ND (2007)
Expected in Households

Simple Improved Cookstoves
Rocket Stoves (many)
Reed TLUD-FA
Karve TLUD-ND (2006)
Wendelbo TLUD-ND (2008) (different test)

PM (mg)

**IARC Classification of PAHs**

- **Group 1: Carcinogenic to humans**
- **Group 2A: probably carcinogenic to humans**

**Occupational Safety and Health Administration limit**

SOGLIA: 0.001 ug m\(^{-3}\) (DM 25.11.94)

**Benzo(a)pyrene**

Concentrazione totale IPA (ug m\(^{-3}\))

SOGLIA: 0.001 ug m\(^{-3}\) (DM 25.11.94)
Biochar and environment

- Reduced deforestation
- Reduce CO$_2$ emissions
- Reduced N$_2$O emissions after soil application
- C storage
Carbon sequestration

- One-pool decay model: **291 years**
- Two-pool model:
  - **3 years** for the fast-cycling pool \((C_{fast} = 17\%\) and
  - **870 years** for the slow-cycling pool
- The nominal turnover time of biochar is shorter than previously assumed, on order of **hundreds of years**

<table>
<thead>
<tr>
<th>Size</th>
<th>Decomposition rate</th>
<th>Mean residence time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labile C pool</td>
<td>3 ± 0.6%</td>
<td>0.0093% day⁻¹</td>
</tr>
<tr>
<td>Recalcitrant</td>
<td>97 ± 0.6%</td>
<td>0.0018% year⁻¹</td>
</tr>
</tbody>
</table>

- Overall mean: **107 years**
- Two-pool model:
  - **108 days** for the fast-cycling pool \((C_{fast} = 3\%\) and
  - **556 years** for the slow-cycling pool
- The calculated MRTs are much shorter than previously assumed

n = 54 datasets from 16 studies

Singh et al., 2012, *Biogeosciences*

n = 128 datasets from 24 studies

Wang et al., 2015, *GCBB*
Future challenges

- Pyrolysis plants are still limited both in EU and Africa
- Most of the efforts aimed to introduce improved and pyrolytic cookstoves in developing countries have not been successful yet as:
  - final users do not perceive indoor air pollution as a high-priority health hazard;
  - non-health considerations dominate household decision-making;
  - stated demand for NTCSs is more price-elastic than stated demand for other essential goods and services.
- Biochar use is still constrained by some knowledge gaps and limitations
- The research on biochar as soil conditioner still needs to be locally implemented, especially in developing countries
- Carbon finance could fund the provision of capital for pyrolysis systems
Thanks for your attention

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This presentation will be available at the website:
https://sites.google.com/site/biocharplusproject/