Soil carbon sequestration with biochar from waste - the potential of thermo-chemical conversion technologies

Lars Stoumann Jensen & Sander Bruun
lsj@life.ku.dk

New buzzwords in a climate struck world...

“Bioenergy” ... “Biomass-fuels”
“CO₂-neutral energy” ... “Carbon footprint”

But many derived problems...

Whilst in some cases being more CO₂ neutral than fossil fuels, bioenergy may often
• compete directly with food production
• divert biomass carbon from recycling to soil
• lead to land use change with huge soil C emissions as a consequence

Soil carbon sequestration with biochar represents a potential solution
Kyoto article 3.4 (LULUCF additional activities)

- How much does soil C mean in Denmark?
  - 157 t C/ha in farmed topsoil (0-100 cm avg.)
  - 2,7 mio. ha farmed area = 1550 mio. t CO₂-equiv.
  - Danish Kyoto reduction target:
    - 70 mio. t CO₂-equiv. emitted * 21 % reduction
    - = 15 mio. t CO₂-equiv.
  - Total Danish CO₂ target may be reached with just a relative increase in soil C by 1 % per year!

- Denmark has chosen to adopt Kyoto-protocol article 3.4
  - Relatively few other countries have adopted 3.4
  - Significant documentation monitoring and verification required
  - Once adopted, no step back!
  - Need for new soil C sequestration mechanisms if reduction target is not met!

Development of carbon stocks in Danish mineral soils (modelled)

Net change: 1,9 mio t C/year extra sequestered
Large CO₂ quota value for Denmark!

Ref. year 1990: \[ \Delta C = -1,54 \text{mio t C/y} \]
(5 y avg.)

Commitment period 2008-12:
\[ \Delta C = 0,35 \text{mio t C/y} \]

"Warm years"

Ban on straw field burning

Avg. climate (1961-90)
Actual climate

(Gyldenkærne, Petersen og Olesen, 2007, MSt AR 5)
Development of carbon stocks in Danish mineral soils (modelled)

However:
- Increasing temperature may jeopardise article 3.4 gains!
- Bioenergy will remove more C inputs = less soil C seq.
- Need for technology alternatives, producing both bioenergy and soil C sequestration

Bioenergy with biochar – net CO₂ removal?

- Bioenergy with biochar can result in a net removal of CO₂ from the atmosphere, but only if
  - The biomass is biogenic
  - A significant net energy output is produced
  - The biochar is recalcitrant and highly stabilised in soil
Pyrolysis and biochar from plant residues

- International biochar initiative (IBI) promotes biochar as an official UNFCCC mitigation-strategy / Clean Development Mechanism (CDM)
- Discussed at COP14 in Poland and to be discussed in Copenhagen Dec 2009 at several COP15 side events

A more sustainable Carbon cycle

(W. Kwapinski, www.carbolea.ul.ie)
More flexible outputs...

THERMAL CONVERSION

COMBUSTION

Pyrolysis

Gasification

Vapors

Condensation

Chemicals

Biochar

Biomass Liquids

Power Generation

Chemical Separation

Advantages of Pyrolysis:

- generally a simple,
- low-cost technology,
- capable of processing a wide variety of feedstocks,
- offers the unique advantage of giving a:
  - liquid-fuel that can be stored and transported,
  - Bio-char,
  - gas-fuel.
Yield of Pyrolysis

Table: Typical product yields (dry wood basis) obtained by different modes of pyrolysis of wood

<table>
<thead>
<tr>
<th>Mode</th>
<th>Conditions</th>
<th>Liquid</th>
<th>Gas</th>
<th>Char</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast pyrolysis</td>
<td>moderate temperature, around 500°C, short hot vapour residence time ~1 s</td>
<td>75 %</td>
<td>13 %</td>
<td>12 %</td>
</tr>
<tr>
<td>Intermediate pyrolysis</td>
<td>moderate temperature, around 500°C, moderate hot vapour residence time ~10-20 s</td>
<td>50 %</td>
<td>30 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Slow pyrolysis (carbonisation)</td>
<td>low temperature, around 400°C, very long solids residence time</td>
<td>30 %</td>
<td>35 %</td>
<td>35 %</td>
</tr>
<tr>
<td>Gasification</td>
<td>high temperature, around 800°C, long vapour residence time</td>
<td>5 %</td>
<td>85 %</td>
<td>10 %</td>
</tr>
</tbody>
</table>

(W. Kwapinski, www.carbolea.ul.ie)

What is biochar and its effects?

- Biochar is the solid that remain after light gases and tar have been released from the biomass
- Charcoal like, high carbon content
- Positive effects on soil quality and plant productivity:
  - Increase surface area and porosity = higher water and nutrient adsorptive capacity
  - Improved filtering of pollutants
  - Increase activity of autotrophic and symbiotic microorganisms = increased crop productivity
- Extremely slowly degradable in soil = a way of sequestering biomass derived carbon
The soil carbon challenge
– depletion of soil humus, especially in S. Europe

- **Organic matter** in soils (humus) is essential for soil fertility and influences resource use efficiency (water, energy) and CO₂ storage (C sequestration)
- **Worldwide** soil humus levels are being depleted, due to deforestation, intensive cropping, removal of biomass for bioenergy
- **In Europe** especially the Mediterranean soils are low in humus
- **Biochar may serve as an important organic matter input**

The soil carbon challenge
– also on certain soils in Denmark

- **Dexter Ratio = clay / org. C** has been proposed as an indicator of soil C saturation
- Low values indicate soils depleted in complexed C
- **In Denmark** especially loamy soils, low in humus are identified as depleted
- **Dominant in eastern parts with few animals, close to metropolitan areas with lots of organic MSW**

(Schanning et al. 2009)
Stability of biochar in soil

Fraction of biomass C remaining (incl. loss during pyrolysis)

Biochar prod. from straw at 225°C
Biochar prod. from straw at 300°C
Plant material (straw)

Biochar more resistant to decay than raw biomass

Biochar stability and effects on decomposition - investigated using $^{14}$C labelling

$^{14}$C
Plant residues

$^{14}$CO$_2$

$^{14}$C

CO$_2$

Soil organic matter

$^{14}$C (40 y ago)

$^{14}$C
Biochar
Biochar degradability in soil - depends on degree of thermal alteration

Respiration of plant material / biochar (\(^{14}\)C-labelled)

Decomposition of plant residues in soil is not affected by biochar application

Respiration from straw (\(^{14}\)C-labelled)
Decomposition of biochar is not affected by plant residue addition

Respiration from biochar (¹⁴C-labelled)

Decomposition of soil organic matter (SOM) is not affected by biochar addition

Respiration of SOM (soil humus ¹⁴C-labelled 40 y ago)
Conclusions and final remarks

- Soil C sequestration has significant potential for climate change mitigation – but may be jeopardised by global warming
- New and more efficient waste bioenergy technologies needed, which combine energy production and soil C sequestration
- Gasification / pyrolysis technology with biochar production has significant potential

- Biochar recalcitrance depends on degree of thermal alteration
- Biochar addition to soil does not alter decomposition of other added organic residues or old soil humus
- **Still need for more system analyses in order to assess sustainability**