BIOCHAR FOR SOIL FERTILITY AND CARBON SEQUESTRATION
A Review of current understanding
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## Structure and Key Message

1) Development Of Classification System And Testing Regime  
2) Understanding Emissions From Pyrolysis Kilns And Potential Toxicity Issues  
3) Understanding The Factors That Affect The Stability Of Biochars In Soils And Measuring Stability  
4) $N_2O$ Reduction And LCA To Assess Overall Emissions Reduction  
5) Improvements In Soils And Plant Yields  
6) Design More Effective Biochars Through Incorporation Of Organo-mineral Complexes  
7) The Economics Benefits Of Biochar Integrated With Energy Production  
8) Co-operation Amongst And Support Of Research And Industry  

The science and the engineering has advanced considerably in the last 3 years to a point where there is confidence in the product and its stability in a range of soils and crop types.
<table>
<thead>
<tr>
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<th>GUIDELINES FOR CHARACTERISING AND TESTING BIOCHARS (SUMMARY OF ANZBR AND IBI DISCUSSION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Carbon, H, O And Ash Content</td>
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<tr>
<td>2</td>
<td>%Recalcitrant (Aromaticity) And Labile Carbon Content</td>
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<td>3</td>
<td>Type And Concentration Of Labile Compounds</td>
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<td>4</td>
<td>Analysis Of Total Major And Minor Plant Nutrients</td>
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<td>5</td>
<td>Heavy Metals</td>
</tr>
<tr>
<td>6</td>
<td>Soluble Cations And Anions</td>
</tr>
<tr>
<td>7</td>
<td>pH, pCEC, EC, Eh (V)</td>
</tr>
<tr>
<td>8</td>
<td>Liming Value</td>
</tr>
<tr>
<td>9</td>
<td>Surface Area</td>
</tr>
<tr>
<td>10</td>
<td>Type And Conc. Of Functional Groups</td>
</tr>
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</table>
1) Feedstock for biochar should be residues with no higher value, or sustainably grown resource (e.g. manures, agrowastes from processing plant, greenwaste)

1) Biomass from non-sustainable sources, or high conservation value ecosystems should not be used.

2) Biochars from different feedstocks and process conditions vary widely in properties e.g. nutrient and liming value, and stability of carbon. Different biochars are suitable for a range of different applications.

3) Biochar must be safe: must pass standard ecotoxicity (e.g. earthworm avoidance) and germination tests

4) Minimise Greenhouse Gas Footprint through using local biomass resources, using energy efficiently

5) Production process and biochar product must comply with relevant OHS requirements, Waste Management Guidelines and EPA Standards

6) Biochar production and utilisation should support sustainable development (e.g. involve local community) and enhance soil health
TOXICITY AND EMISSIONS ISSUES

1) Heavy metals, dioxins and PAH’s not detected above scheduled limits in recent studies of biochars produced from manures, greenwaste, woodwaste, rice husk, paper sludge, cotton waste using the BESTEnergies technology and laboratory pyrolysers operated with optimal time/temperature regimes. Little data on sewage sludge and MSW.

2) Gaseous emissions depend on operating conditions and burners used. Low temperature (<500°C) pyrolysis very little loss of P but 50% of nitrogen. A large proportion of this is captured if use ceramic filters and/or condense the gases.

3) Virtually no N₂O emitted from burning of syngas if well designed burners used. NOx levels less than 100ppm

4) Need more studies for less sophisticated pyrolysis units

5) State Primary Industries in NSW, SA, Victoria, WA have already engaged with the industry to assess the products for potential hazards and benefits

Note; PAH’s usually only formed at temperature above 550°C.

References; (Bridgewater and Boocock in a number of publications of pyrolysis. Unpublished data from Sydney University, Cleanaway Ltd, Renewed Fuels Pty.)
1) Char produced in fires have a range of properties that are similar to some biochars. Mineral content in these chars ranges from less than 1% to well over 50%.

2) These chars have a range of surface and bulk properties. There are a range of organic compounds that are deposited on the surface and inside pores. Some of these are probably toxic while some promote plant germination and growth (Nelson et al 2009, Ghebrehiwot et al 2009).

3) Research on black carbon particles in soils indicates that all of these different types of biochar are either degraded and/or stabilised through reaction with oxygen, minerals (including clay, silica, pyrite, calcite), cations and anions, roots, soil organic matter, microbes and gases dissolved in water. The rates of reaction are a function of soil type, rainfall patterns, temperature interactions with plants, biota and fauna (Hockaday 2006, Lehmann + Joseph eds. 2009).

4) After fires, regeneration within a given area is variable. Low temp chars seem to promote growth of grasses and some plant species (Nelson et al 2009).
TECHNIQUES USED TO UNDERSTAND MECHANISMS OF BIOCHAR, SOIL, WATER, MICRO-ORGANISM, PLANT INTERACTIONS

To understand complex interactions a wide range of techniques used

Stability: Measuring Labile/Recalcitrant C:

NMR, MIR, TG-MS, Py-GC-MS, hydrogen pyrolysis, LC with NMR-MS or GC-MS, MALDI-TOF, Incubation studies with isotope labelling, other chemical and thermal oxidation methods (Chapter 17 Lehmann and Joseph 2009)

Surface Properties and their Changes with Aging in Soils and Interactions with Plants

XPS, FTIR, Raman, NEXAFS, Nano SIMS, STXM, ESR, Boehm Titration, LC, UV Fluorescence, XRD, SEM, Solid State Cyclic Voltametry, Microprobe, TEM, STM, BET Surface Area Analysis, Leaching/Dissolution Experiments with IC
BIOCHAR WILL REACT WITH SOILS TO FORM ORGANO-MINERAL COMPLEXES

Chicken Litter Biochar

Outside of Terra Preta Particle

Wood Char

Inside of Terra Preta Particle
## IMPORTANT PROPERTIES OF FRESH BIOCHAR FOR CHARACTERISATION

### Yield Increases and Removal of Toxic Substances

1. Mineral content especially Ca (for low pH soils), K, Mg, P and their relative solubility
2. Reactive surfaces that can complex soil organic and mineral matter and toxic substances. These surfaces appear to have
   a) high concentrations of oxygenated functional groups especially carboxylic, phenolic and lactonic.
   b) high concentration of Lewis acid and base sites (N) and radicals for complexation of DOM.
   c) high mineral defect and permanent charges/hydroxylated surfaces
   d) high redox potential
3. High micro/mesopore volume for adsorption of gases and liquids; root penetration and growth of beneficial micro-organisms are promoted by high macropore volume and surface area, and range of char particle sizes (1-5mm)
4. Soluble or easily oxidized surface organic molecules (especially aliphatic) that are produced in low temperature pyrolysis and torrefaction.

Comments; Soil type and other environmental factors play a part in whether a biochar addition will result in an increase in yield. Low temperature wood and high mineral content biochars appear to give the best initial plant response for a wide range of soil types especially poor soils.
1. Amorphous Carbon
2. Mixed Aluminium Oxide (hydroxide) phase deposited on the carbon surface. This could have been deposited in a pore
3. A high carbon phase with significant Fe, Ca and P Concentrations
4. Mixed Mineral/Carbon phase. The nanosized particles of minerals (mainly clay and silica) contain a high content of Al, Si, Fe, O and smaller quantities of P, Mg and Ca. The high carbon calcium phase appears to be binding the mineral particles together. There is a separate Ti,O phase dispersed as nanosized particles.
5. Micropores at interface and in region 4
Bio-chars from $C_3$-vegetation sources ($\delta^{13}C$: -22 to -29 $\%$) were incorporated into soil (Vertisol) from a paddock under $C_4$-vegetation (Mitchell grass with $\delta^{13}C$: -14 $\%$). Then analysing $\delta^{13}C$ of respired CO$_2$ from biochar-amended soils, and through detailed chemical characterisation of decomposing fractions, we are aiming to: document turnover rate of a range of biochars and account for its priming effect on ‘native’ soil C, elucidate stabilisation mechanisms of biochar-C in soil. (BP Singh, NSW DPI)
Increase in Soil Microbial Biomass (Source; BP Singh and K. Kaur)

The effect of biochars on microbial biomass carbon

LSD$_{Time} = 4.5$
LSD$_{Treatment} = 7.8$
Time $\times$ Treatment, NS

Microbial biomass C (mg kg$^{-1}$ soil)

Duration of incubation (days)
Enhancing Properties of Biochars through Addition of Minerals and Micro-organisms

Mycorrhizal colonisation in subterranean clover

WMF = Western Minerals Fertiliser+ Minerals plus micro-organisms

Source; Dr Zakaria Solaiman (2000) The University of Western Australia
Enhancing Properties of Biochars through Addition of Minerals and Biomass

STP= Torrefied Biomass with Clay and Minerals; SBC= wood biochar
Source;(2009) Dr Paul Blackwell Dept. Agriculture of Western Australia
Notes; growth rates are relative; high yield function of field trial method.
Extensive Field Measurements of N2O Emissions (NSW DPI)
LCA to Determine Emissions Reduction

- **Desk-top analysis**: life-cycle greenhouse gas mitigation of biochar
- **Alternative feedstocks**:
  - paper sludge, poultry litter, feedlot manure, greenwaste
- **Two agricultural systems**: canola, broccoli
- **Compared with “business as usual” reference**
- **Calculated for plant processing 50000 tonnes biomass annually**

Source (Professor Annette Cowie NSW DPI/ UNE)
## ECONOMIC ANALYSIS OF 2 YEAR FIELD TRIALS IN NORTHERN NSW

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize 07/08 weight of cobs (t/ha)</th>
<th>Faba bean 2008 dry bean (t/ha)</th>
<th>Maize 08/09 weight of cobs (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry Biochar (10t/ha)</td>
<td>23.7</td>
<td>3.9</td>
<td>23.3</td>
</tr>
<tr>
<td>Papermill Biochar (10t/ha)</td>
<td>25.7</td>
<td>3.9</td>
<td>27.3</td>
</tr>
<tr>
<td>Lime (3t/ha)</td>
<td>22.3</td>
<td>4.6</td>
<td>24.9</td>
</tr>
<tr>
<td>Compost (25t/ha)</td>
<td>19.9</td>
<td>4.4</td>
<td>23.0</td>
</tr>
<tr>
<td>Fertiliser Only</td>
<td>20.5</td>
<td>2.1</td>
<td>19.4</td>
</tr>
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Standard farmer practice 400kg urea 300 single super 100 potash
Soil Carbon increase approximately .5%
### ECONOMIC ANALYSIS OF 2 YEAR FIELD TRIALS IN NORTHERN NSW

#### Treatment: Poultry Litter Biochar (10t/ha) vs farmer practice

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Extra Benefits from Production</th>
<th>Extra Costs of Production</th>
<th>Net Value Incremental Production</th>
<th>Initial cost</th>
<th>Incremental net benefit increase</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$/ ha</td>
<td>$/ ha</td>
<td>$/ ha</td>
<td>$/ ha</td>
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<tr>
<td>Corn 07/08</td>
<td>3,886</td>
<td>1,651</td>
<td>2,235</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faba bean 08</td>
<td>815</td>
<td>87</td>
<td>727</td>
<td>3,250</td>
<td>2,480</td>
</tr>
<tr>
<td>Corn 08/09</td>
<td>4,815</td>
<td>2,046</td>
<td>2,769</td>
<td></td>
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</tr>
</tbody>
</table>

Biochar at $300/t and spreading $25/tonne; Electricity $40/MWh RECs $55/MWh
Source; L Van Zweiten (2009) *Agro-economic valuation of biochar using field-derived data; NSW DPI*
ANALYSIS OF COMBINED ELECTRICITY AND BIOCHAR PLANT

- 4t/hr poultry litter/8000hrs
- 2.3MW/h Electr for 8000hrs
- 38% biochar yield
- 60% C in biochar

Biochar valuation (BCR=1) based on mixed cropping in ferrosol in northern NSW
Source: Van Zweiten (2009) NSW DPI
Possible approaches to accounting for mitigation benefits of biochar

1. Increase in Soil carbon: under cropland and grazing land management (if activity-based approach continues); (CM and GM should be accepted for CDM in next round?).
   Calculate as increase in soil C based on quantity of biochar applied and anticipated stability (ie credit for only stable carbon).
   MRV: record of biochar quantity applied; stability estimated from database of biochar properties related to feedstock and processing conditions. Note the issue of permanence of soil C stock change is largely avoided because biochar is stable in soil.

2. Alternative: Consider pyrolysis as a process that avoids emissions. Calculate credit as quantity of biomass that is stabilised against decomposition.
   MRV: Record of char yield for pyrolysis, stability estimate as above. Demonstration that biochar has been applied to soil.

3. Reduction in N2O: needs more research. May be able to develop models to estimate; could include in FullCAM
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<tr>
<td><strong>SUMMARISING</strong></td>
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<tr>
<td>1.</td>
<td>Understanding of the mechanisms for stabilisation and turnover rate in soils well advanced. Need for more sophisticated research to develop understanding of interactions of Biochar, Soil, Plants and Micro-organisms</td>
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<td>2.</td>
<td>Methods of characterising and measuring biochar properties achieving international agreement</td>
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<tr>
<td>3.</td>
<td>Guidelines are being developed to ensure that biochars are produced from sustainable resources, are fit for purpose and comply with local regulations</td>
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<td>4.</td>
<td>Yield improvements being measured throughout the world. Economic studies emerging but hampered by lack of facility to produce large quantities of biochar for extended field trials</td>
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<td>5.</td>
<td>Techniques to assess greenhouse emissions reduction well advanced</td>
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<td>6.</td>
<td>New methods being developed to enhance specific properties of biochars</td>
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<td>7.</td>
<td>Technology for manufacturing biochar is mature in Japan for certain feedstocks, and ready for commercialisation in Australia, North America and Europe. Limited support for developing industry.</td>
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MOVING FORWARD

1) Need to have virtual center for biochar research which combines the skills of agricultural scientists and engineers, materials scientists and process engineers, chemists, microbiologists, economists and policy makers.

2) Access of emerging industry to skills and analytical equipment of this center. Center should also provide training and extension

3) Long term funding for this center.

4) A facility that allows larger scale production of biochar.

5) Extended field trials that have sufficient finance for detailed measurement of soil, plant and environmental changes.