**BIOCHAR - Agriculture’s Black Gold?**

The Promise of BIOCHAR:

Hal Collins, USDA-ARS
Vegetable and Forage Crops Unit
24106 N. Bunn Rd.
Prosser WA 99350
Biochar

What is Biochar?

- **carbon-rich solid** - a co-product of pyrolysis of biomass.
- **also known as charcoal, biomass derived black carbon, Agrichar, C-Quest™**
- **formed under complete or partial exclusion of oxygen at temperatures between 400 and 1000 °C.**
- **Origins** - has been used for centuries
  - **Cooking, health, water purification, etc**

Active research into soil benefits was renewed by Johannes Lehmann at Cornell University in about 1998 resulting from studies of Terra preta soils of the Amazon.
How is Biochar Made?

- **Major Techniques:**
  - **Slow Pyrolysis**
    - traditional (dirty, low char yields) and modern (clean, high char yields)
  - **Flash Pyrolysis**
    - modern, high pressure, high char yields
  - **Fast Pyrolysis**
    - modern, maximizes bio-oil production, low char yields
  - **Gasification:**
    - modern, maximizes bio-gas production, minimizes bio-oil production, low char yields, highly stable, high ash
  - **Hydrothermal Carbonization**
    - under development, wet feedstock, high pressure, highest “char” yield but quite different composition and probably not as stable as pyrolytic carbons
Pyrolysis/Gasification

The gasification process was originally developed in the 1800s to produce town gas for lighting and cooking. Electricity and natural gas later replaced town gas for these applications, but the gasification process has been utilized for the production of synthetic chemicals and fuels since the 1920s. Source: Wikipedia

Wood gas generators called Gasogene or Gazogène, were used to power motor vehicles in Europe during World War II fuel shortages.
Syngas

$\text{CO}$

$\text{H}_2\text{CH}_4$

Electricity

Transportation fuel

Güssing, 2 MW of electricity and 4 MW of heat, generated from wood chips, since 2003.

Competing Uses:

Gasification

High temp

Facility

Slow Pyrolysis

Low temp

Additional Gasification

Bunker Fuel

Smudge pots

Other?

Feedstocks

Soil Amendment

Syngas

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Soil Amendment
Feedstocks for Biochar Production

Any source of biomass:

- Crop residues (wheat, corn stover, rice husks)
- Nut shells (groundnut, hazelnut, macadamia nut, walnut, chestnut, coconut, peanut hulls)
- Orchard, vineyard pruning's or replacement
- Bagasse from sugar cane production
- Olive or tobacco waste
- Forest debris, wood chips, sawdust, bark, etc
- Animal manure
- Grasses
- Other – sewage sludge, tires, peat, lignite, coal

* Not all organic biomass is suitable for producing biochar

Household, municipal and industrial waste may contain heavy metals or organic pollutants which could cause environmental contamination by land application of the resulting biochar.
Pyrolysis of Ag Residues: USDA-ARS

Corn Stover  Small Grain Straw  Manure

Bio-Oil  BioChar
Pyrolysis of Forest Debris: USDA-FS

- Logging slash
- Thinning slash
- Beetle killed trees
- Portable pyrolysis unit

JF Biocarbon Systems INC, Canada
Structure of Biochar

Pine Wood Char

Oak Wood Char

Manure

Corn Cob Char
• The properties of biochar greatly depend upon the production procedure. Temperature effects on C recovery, CEC, pH and surface area. 
  
Soil Applications: Biochar

Richard Haard
Four Corner Nurseries
Bellingham, WA

Potting soil mixes

Brazil
What we know: Terra Preta

Terra preta do indio or the “black earth of the Amazons”

- fine dark loamy soil
  - up to 9% carbon, (adjacent soil 0.5% C)
  - high nutrient content and high fertility
  - 3 times the phosphorous and nitrogen

Developed over thousands of years by human habitation correspond to ancient settlements

- results from long-term mulching of charcoal production from hearths and bone fragments with soil application of food wastes and animal manures

- persistents in soil, recalcitrant, resistant to decomposition.

- forest fires and slash-and-burn contribute very low amounts of charcoal-C (~3%)
  “Slash and Char”

Comparisons of Terra Preta to Adjacent Soils show crop yield increases of 2-3 fold.

Yields typically increase with applications to 65 T/ha.

Increases result from improvements in:
- Nutrient availability (N, P, S, etc.) - Storage
- increased CEC
- increased soil pH
- Changes in physical properties
  - water retention
  - reduced soil density
  - increased porosity/aeration

Impact on Temperate soils?
“Although managing SOM is usually not a priority in farm decision making, practices that improve SOM contribute more than any other resource to a farm's long-term productivity.”
Benefits of Soil Organic Matter:

- Reservoir of plant nutrients
- “Food” for soil biota
- Soil Physical properties
  - Reduces soil density
  - Essential for aggregate formation
  - Improves air/water infiltration
  - Improves water storage
- Improves soil “Tilth”
- Reduces soil erosion
Soil Organic Matter

Organic matter is 1-8% of total soil mass.
Soil organic matter is composed of:

- Organic matter is the vast array of carbon compounds in soil.
- Originally created by plants, microbes, and other organisms,
- Plant materials consist of simple sugars, cellulose, hemicellulose and lignin – contain also proteins and amino sugars

Decay Process – solution, fragmentation, decay and humification.

Humification: Chemical process, condensation with N compounds and lignin.
The downward spiral of soil degradation.

Adapted From Topp et al., 1995
Carbon Farming vs. Farming for Carbon?

1930's
Most organic matter losses in soil occurred in the first decade or two after land was cultivated. Native levels of organic matter may not be possible under agriculture, farmers can increase the amount of active organic matter by reducing tillage and increasing organic inputs.
How can biochar help mitigate CO₂ Imbalance?

- Create stable C pool using biochar in soil
- Use energy from pyrolysis to offset fossil C emissions
- Avoid emissions of N₂O and CH₄
- Increase net primary productivity of sub-optimal land
- Boundary conditions for biochar contribution shown to right
  - Maximum levels are not sustainable
  - Biochar cannot solve climate change alone
Laboratory, Greenhouse and Field Studies

- **Produced chars from:**
  - Switchgrass
  - Digested Fiber
  - Softwood bark
  - Softwood pellets

- **Chars produced at four temperatures:**
  - 350, 425, 500 and 600 °C

- **Five soil Types:**
  - Quincy Sand, Naff SiL, Palouse SiL, Thatuna SiL and Hale SiL

- **Four rates of application:**
  - 0, 10, 20 and 40 Mg ha^{-1}
Biochar/Soil Analyses

- **Laboratory incubations**
- **Soil properties evaluated**
  - soil pH (49 d)  
  - CEC (49 d)  
  - water retention curves (0 and 0.1 Mpa)  
  - $\Delta$ nutrient content (N,P,K,S, micro-macro)  
  - C mineralization potentials (+200d)  
  - N mineralization potentials (49 d)  
  - C sequestration (Three pool model)

$$C_t = C_a e^{-ka} + C_s e^{-ks} + C_r e^{-kr}$$

where; $C_a$, $k_a$=Active pool; $C_s$, $k_s$=Slow pool; $C_r$, $k_r$=Resistant pool.
Pyrolysis unit built by Washington State University

Batch Pyrolysis Reactor

Output - 1 kg h⁻¹
Barrel Retort
Summary of Char Production

• Biochar yield decreased as pyrolysis temperature increased from 350 to 600 °C
  Yield of char was 30-45%

• Herbaceous feedstocks (DF and SG) lost 41 – 50% of their initial total C

• Woody feedstocks (SWP and SB) lost 40 – 45% of their initial total C.

• For each 100 °C rise in pyrolysis temperature C concentration of the resulting char increased an average of 41 g C kg⁻¹ among feedstocks.

• As pyrolysis temperature increased from 350 to 600 °C, feedstocks lost 60 - 70% of total N.
**Biochar Characteristics**

**Figure 4.1.** Relationship between pyrolysis temperature and the C concentration of the resulting biochar.

**Yield of char was 30-45%**

**Figure 4.2.** Influence of pyrolysis temperature on the pH of a variety of biochars.
## Change in Soil C and N with BioChar

### ‡Soil + Biochar Characteristics

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Biochar</th>
<th>Rate t/acre</th>
<th>C</th>
<th>N</th>
<th>S</th>
<th>C:N</th>
<th>C:S</th>
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<td>Quincy</td>
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<td>0.23</td>
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<td>0.014</td>
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<td>1.79</td>
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<td>1.12</td>
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<td></td>
<td></td>
<td>20</td>
<td>1.60</td>
<td>0.02</td>
<td>0.026</td>
<td>86</td>
<td>62</td>
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</tbody>
</table>

### 400-600% increase in soil-C and N with a 20 T/acre amendment
C Sequestration Potential of Biochar

Figure 1. Schematics for biomass or bio-char remaining after charring and decomposition in soil. from Lehmann et al., 2006. Mitigation Adap. Strat. Glob. Change 11: 403–427.
How Long will Biochar Persist ???

Mechanisms of Biochar Decay:

- Mineralization  Biological decomposition (<2%)
  - type of biochar; production temperature
- Co-metabolism and priming (possible but limited)
- Abiotic processes – Oxidation / hydrolysis
- Physical processes – Freeze / thaw

Estimates of persistence based on the study of natural biochar/charcoal in soils show:

- Terra Preta – Amazon Dark earths – 500 to 7000 yrs
- Based on annual char inputs from fires:
  - Northern Australian woodlands - 1300 to 2600 yrs
  - Western Vancouver – 3300 yrs
What to do . . .

- Eliminate the C-positive, accentuate the C-negative!
- Minimize fossil fuel inputs
  - Improve energy efficiency
  - Point-source capture/sequestration of CO$_2$
  - Replace with biofuels, nuclear (???$$$
- Maximize terrestrial sink (diffuse capture/sequestration)
  - Afforestation
  - Low-input and perennial cropping systems
- Implement C-negative energy technologies
  - Biomass combustion with CO$_2$ sequestration
  - Biomass pyrolysis with biochar production/CO$_2$ sequestration
Where does Biochar Fit?

- Offers a flexible blend of biofuel energy, soil fertility enhancement, and [climate] (CO$_2$) change mitigation
- Limited by biomass availability and, eventually, land disposal area
- How much biomass can be made available for biochar production vs. other uses?
- Crop-derived biofuels cannot supply all the world’s energy needs
  - Maximum estimates suggest 50% of current, 33% of future
  - Biodiversity (HANPP)?
  - N$_2$O?
- Perhaps best use of harvested biomass is to make biochar to draw down atmospheric C levels and enhance soil productivity, with energy production as a bonus (but not the driving force).
- This will require government incentives (C credits/taxes?) and a change in the way we value cropped biofuels
Long-term Supply of feedstocks: Biochar?

• Forest Resources
  - logging debris – 67 M dry T y⁻¹
    60% recovery
    Converted to biochar = 10 M T Carbon
  - forest thinning – 60 M dry T y⁻¹
    at most 30% collected 18 MT
    Converted to biochar = 4.5 M T Carbon
  - Primary wood processing mills – 91 M dry T y⁻¹
    bark, saw mill slabs, edgings, sawdust, etc.
    < 2 million dry tons available
    Converted to biochar = 0.4 M T Carbon
  - Secondary wood processing mills – 16 M dry T y⁻¹
    millwork, containers, pallets, etc.
    recovered from urban MSW

DOE Billion Ton Report, 2005
Long-term Supply:

- **Available Urban Wood residues 63 M dry T y\(^{-1}\)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Generated</th>
<th>Recovered/Un-useable</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>11.6</td>
<td>3.0</td>
<td>8.6</td>
</tr>
<tr>
<td>Demolition</td>
<td>27.7</td>
<td>16.1</td>
<td>11.7</td>
</tr>
<tr>
<td>Woody yard</td>
<td>9.8</td>
<td>8.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Wood (MSW)</td>
<td>13.2</td>
<td>7.3</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62.3</strong></td>
<td><strong>34.4</strong></td>
<td><strong>28.0</strong></td>
</tr>
</tbody>
</table>

Expected to increase 30%.

**Converted to biochar = 7 M T Carbon**

- **Total Forest resources available for biochar production**
  ~ 88 M dry T y\(^{-1}\) of 296 M dry T y\(^{-1}\) inventoried. (30%)

**Total biochar produced = 22 M T Carbon y\(^{-1}\)**

Land Application @ 10 T acre\(^{-1}\) = 2.2 million acres
Long-term Supply:

- **Crop residues** (corn stover, small grain residues)
  - DOE estimated 428 M dry T of residues. (2006)
  - 28% (120 M dry T) will be available for conversion
  - ignore ethanol industry, convert by pyrolysis

  Converted to biochar = 27 M T Carbon

- **Dedicated crops** (perennial, switchgrass, poplars, etc.)
  - DOE reports potential production for 377 M dry T
  - Yields range from 5-10 T acre⁻¹
  - Acreage needed: 38 - 75 M acres
  - ignore ethanol industry, convert by pyrolysis

  Converted to biochar = 85 M T Carbon

Total biochar produced = 112 M T Carbon y⁻¹
Land Application @ 10 T acre⁻¹ = 11.2 million acres
Washington State

**Forest Resources**
- logging debris – 1.9 M T y\(^{-1}\)
- forest thinning – 0.5 M T y\(^{-1}\)
- mill residues – 5.2 M T y\(^{-1}\) @10% = 0.5 M T y\(^{-1}\)
- urban wood – 0.8 M T y\(^{-1}\)
  - 3.7 M T y\(^{-1}\)

Converted to biochar = 0.8 M T Carbon

**Crop Residues** – 2.2 M T y\(^{-1}\) @ 20% = 0.4 M T y\(^{-1}\)

Converted to biochar = 0.1 M T Carbon

Total biochar produced = 0.9 M T Carbon y\(^{-1}\)

Land Application @ 10 T acre\(^{-1}\) = 90,000 acres

WA State, Biomass Inventory and Bioenergy Assessment, 2005
Yield was not significantly different in 2007

<table>
<thead>
<tr>
<th></th>
<th>Grain (bu/Ac)</th>
<th>Stover (ton/Ac)</th>
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</thead>
<tbody>
<tr>
<td>With biochar</td>
<td>223</td>
<td>5.67</td>
</tr>
<tr>
<td>No biochar</td>
<td>217</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Biochar applied fall of 2006
USDA-ARS Biochar/Pyrolysis Initiative: Field Trials

Dynamotive CQuest™

USDA-ARS Biochar/Pyrolysis Initiative: Field Trials

Dynamotive CQuest™

USDA-ARS Biochar/Pyrolysis Initiative: Field Trials

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USDA-ARS Biochar/Pyrolysis Initiative: Field Trials

Dynamotive CQuest™
29% of all C fixed by photosynthesis aboveground (ca. 10.2 GtC/yr) is currently used by humans!

Of this 1.5 GtC/yr is unused crop residues, manures, etc.

An additional 1.8 GtC/yr is not fixed due to prior human activities (e.g., land degradation) and current land use

Current fossil-C emissions are ca. 8 GtC/yr

Increased productivity and expanded use of residues from biochar production could have a significant impact on global C budget

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**Table 1. Global carbon flows related to the human appropriation of net primary production (HANPP) around the year 2000**

<table>
<thead>
<tr>
<th>NPP-related carbon flows</th>
<th>Total NPP</th>
<th>%</th>
<th>Aboveground NPP</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential vegetation (NPP₀)</td>
<td>65.51</td>
<td>100.0</td>
<td>35.38</td>
<td>100.0</td>
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<tr>
<td>Actual vegetation (NPPₚₑₑ)</td>
<td>59.22</td>
<td>90.4</td>
<td>33.54</td>
<td>94.8</td>
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<tr>
<td>Human-induced alteration of NPP</td>
<td>6.29</td>
<td>9.6</td>
<td>1.84</td>
<td>5.2</td>
</tr>
<tr>
<td>NPP (ANPPₚₑₑ)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human harvest (NPPₑ)</td>
<td>8.18</td>
<td>12.5</td>
<td>7.22</td>
<td>20.4</td>
</tr>
<tr>
<td>Human-induced fires</td>
<td>1.14</td>
<td>1.7</td>
<td>1.14</td>
<td>3.2</td>
</tr>
<tr>
<td>Remaining in ecosystem (NPPₐ)</td>
<td>49.90</td>
<td>76.2</td>
<td>25.18</td>
<td>71.2</td>
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<tr>
<td>HANPPₚₑₑ total</td>
<td>15.60</td>
<td>23.8</td>
<td>10.20</td>
<td>28.8</td>
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<tr>
<td>Backflows to nature*</td>
<td>2.46</td>
<td>3.7</td>
<td>1.50</td>
<td>4.2</td>
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Haberl et al., PNAS 2007

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Questions?

hal.collins@ars.usda.gov