Biochar, soil, pyrolysis, carbon, and more

K. Thomas Klasson, Research Leader
U.S. Department of Agriculture,
Agricultural Research Service,
New Orleans, LA 70124
How much are we publishing?

Since the first article was published in 2000 using the word “biochar,” the term has seen exponential increase in its use with a doubling rate of 1.3 years.
USDA-ARS has a variety of activities that contributes to the number of manuscripts published. Not only do we work on **pyrolysis methods**, we also have a strong **characterization** program and **implementation** focus.
Surprisingly many books on the topic
Biochar from the Straw-Stalk of Rapeseed Plant

Filiz Karaosmanoğlu,* † Aslı İşığıür Ergüdenler, and Aydin Sever †

Department of Chemical Engineering, Istanbul Technical University, Maslak-Istanbul 80626, Turkey

Received June 8, 1999. Revised Manuscript Received November 1, 1999

Agricultural residues are an important and inexpensive bioresource for energy production. In this study the slow pyrolysis technique has been applied to the straw and stalk of rapeseed plant, and the effects of temperature and heating rate on the yields and characteristics of the solid products (biochars) have been investigated. Experiments were performed in a tubular reactor under nitrogen atmosphere at constant heating rate (5 °C min⁻¹) and varying temperatures (400–900 °C) and at constant temperature (800 °C) and varying heating rates (5, 10, 15, °C min⁻¹). The biochars obtained are carbon rich, reactive, and relatively pollution-free potential solid biofuels.
The first publications on “biochar”

2001

2003

A biochar from casein and its properties

B. Purevsuren, B. Avid
Institute of Chemistry and Chemical Technology, Mongolian Academy of Sciences, Ulaanbaatar-51, Mongolia
E-mail: b_avid@yahoo.co.uk

B. Tesche
Max-Planck-Institut für Kohlenforschung, Elektronenmikroskopie Kaiser-Wilhelm-Platz 1, Mülheim an der Ruhr, 45470 Germany

Y. Davaajav
Institute of Chemistry and Chemical Technology, Mongolian Academy of Sciences, Ulaanbaatar-51, Mongolia

A biochar was prepared by pyrolysis of casein. A helium and mercury porosimeter were used to measure the true and apparent densities of the chars respectively, elemental and IR analysis were used to characterize the chemical composition of char. A SEM was used to observe the char surfaces in order to verify the presence of porosity. The biochar has 9.02% of nitrogen, content of porosity is 20%. The experimental results show that it is possible to prepare chars with relatively high porosity from casein for the further preparation of activated carbon. © 2003 Kluwer Academic Publishers

Keywords: biochar, casein, pitch, pyrolysis
The first publications on “biochar”

An Activated Carbon Product Prepared from Milo (Sorghum Vulgare) Grain for Use in Hazardous Waste Gasification by ChemChar Co-current Flow Gasification

Harshavardhan Bapat and Stanley E. Manahan*  
Department of Chemistry  
123 Chemistry Building  
University of Missouri-Columbia  
Columbia, MO 65211 USA

David W. Larsen  
Department of Chemistry  
University of Missouri-St. Louis  
8001 Natural Bridge Road  
St. Louis, Missouri 63121

(Received in Germany 12 August 1998; accepted 15 October 1998)

Abstract

An activated carbon was prepared by pyrolysis of sorghum grain (Sorghum vulgare) for use in the gasification of hazardous wastes and for sequestering metal bearing wastes. This is the most common variety of sorghum grown in the United States, with about 90% of the nation’s production coming from Texas, Kansas, Nebraska and Missouri. Milo produces a very hard spherical kernel 2-4 mm in diameter which has the properties needed to make a char and activated carbon useful for waste treatment. This paper describes the preparation and characterization of a low ash, low sulfur content, macroporous, moderately activated char made by the pyrolysis followed by gasification of milo grain. This material, called Milo Biochar, was tested as a waste carrier medium and fuel in the ChemChar waste gasification of selected organic compounds and wastes containing selected heavy metals.
Quantitative solid-state $^{13}$C n.m.r. measurements on cokes, chars and coal tar pitch fractions

M. Mercedes Maroto-Valer, John M. Andrésen, J. Dilcio Rocha and Colin E. Snape

University of Strathclyde, Department of Pure & Applied Chemistry, Thomas Graham Building, Glasgow, UK.

(Received 25th February 1996; Revised 1st May 1996; Accepted 2nd June 1996)

Table 1 Elemental analysis and ash content of samples investigated

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temp. (°C)</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>(O + S)$^a$</th>
<th>H/C</th>
<th>Ash (wt% db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>--</td>
<td>87.8</td>
<td>4.4</td>
<td>1.7</td>
<td>6.1</td>
<td>0.60</td>
<td>8.7</td>
</tr>
<tr>
<td>PCC-1</td>
<td>440</td>
<td>88.2</td>
<td>4.0</td>
<td>1.6</td>
<td>6.2</td>
<td>0.54</td>
<td>8.8</td>
</tr>
<tr>
<td>PCC-2</td>
<td>497</td>
<td>89.7</td>
<td>3.2</td>
<td>1.4</td>
<td>5.7</td>
<td>0.43</td>
<td>9.2</td>
</tr>
<tr>
<td>Bio-char</td>
<td>450</td>
<td>81.0</td>
<td>3.1</td>
<td>0.3</td>
<td>15.6</td>
<td>0.46</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>CT-TI</td>
<td>--</td>
<td>92.1</td>
<td>2.7</td>
<td>0.9</td>
<td>4.3</td>
<td>0.35</td>
<td>n.d.$^b$</td>
</tr>
<tr>
<td>CTP-TI</td>
<td>370</td>
<td>92.9</td>
<td>3.4</td>
<td>1.0</td>
<td>2.7</td>
<td>0.44</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

$^a$ Estimated by difference
$^b$ Not determined
POWER-PRODUCTION OPTIONS FROM BIOMASS: THE VISION OF A SOUTHERN EUROPEAN UTILITY

G. Trebbi

ENEL S.p.A., Thermal and Nuclear Research Centre, Via Andrea Pisano 120, 56100 Pisa, Italy

Abstract

In the medium term, vegetable energy crops are expected to play a significant role in an environmentally friendly energy system. The technical progress of technologies to convert biomass into usable energy will be essential in order to meet the energy needs of the world. In the framework of the European Communities (CEC), ENEL, the Italian electricity utility, is contributing to the development and field tests of these technologies, in order to diversify the energy sources and mitigate the dependence on imported fuels. The activities promoted by ENEL, together with those carried out by the European Communities (CEC), are intended to foster the development of the biomass energy market and to ensure a rapid and cost-effective supply of energy from biomass.

Key words: Energy crops, biomass, energy sources, utilization, available resources.

26

(typical values about 20%) and high investment (around USD 2500/kWe). Their use is only appropriate when low-price agricultural or forestry residues are available and/or the electricity selling prices are particularly high. A more interesting option would be combustion in large power stations with a capacity of more than 50 MW, with higher efficiencies ($\eta = 35-40\%$) and lower specific investments. In this area, new fluidized-bed boilers are gradually substituting the old grate-combustion systems equipped with different kinds of fuel distributor; the steam conditions are also increased to improve the efficiency.

ENEL activities in this field are limited to the evaluation of the pneumatic transport of biomass powder to burners and to the preparation and testing of slurries obtained from powders or biochar mixed with water and/or bio-oil. Before inlet in the combustion chamber (regenerative cycle) or to produce steam that can be injected into the same GT (STIG cycle) or used to generate electricity through a steam turbine (combined cycle).

Preliminary firing tests indicated that the direct combustion of biomass powder is difficult owing to alkali evaporation and the subsequent condensation: heavy deposits were encountered downstream of the combustion camber. A possible solution to avoid this problem would be the introduction of an indirect combustor (slagging combustors or fluidized-bed combustors) fed by the exhaust from the turbine. When using sugar cane and sweet sorghum, this scheme could be modified by introducing a topper combustor (Fig. 1): the ethanol obtained by juice fermentation and the bagasse are burnt in the topper and bottom combustors, respectively.
Bio-Char Inc., 1984-2002

United States Patent

Kerr

[54] INCINERATOR DISCHARGE SYSTEMS

[75] Inventor: Clifford G. Kerr, Mississauga, Canada

[73] Assignee: Ancliff Equities Inc., Streetsville, Canada

[21] Appl. No.: 2,584

[22] Filed: Jan. 12, 1987

[51] Int. Cl. ......................... F23G 5/08; F23G 5/12; F23G 5/44

[52] U.S. Cl. .......................... 110/259; 110/165 R

[58] Field of Search ............. 110/259, 165, 168, 169, 110/210

[56] References Cited

U.S. PATENT DOCUMENTS

3,046,915 7/1962 Ledin ......................... 110/259 X


[45] Date of Patent: Feb. 9, 1988

Primary Examiner—Edward G. Favors
Attorney, Agent, or Firm—Fetherstonhaugh & Co.

[57] ABSTRACT

A processor for processing the residue which is discharged from an incinerator comprises a receiver for receiving the residue and a discharge enclosure through which the processed residue is discharged. The processor is used in association with an incinerator which may be a batch incinerator of any conventional construction.

The reference numeral 10 refers generally to a processor constructed in accordance with an embodiment of the present invention. The processor 10 is used in association with an incinerator 12 which may be a batch incinerator of any conventional construction. A suitable incinerator presently manufactured by Bio-Char Inc. is located at Churchill Blvd., Mississauga, Ontario, and is identified as Bio-Char Model 4, Pryolysis Incinerator.
What happened to Bio-Char Inc.?  

---

Ontario
Superior Court of Justice

Between:

The Corporation of the Town of Ajax

- and -

2047330 Ontario Limited and Gordon Kerr

Plaintiff

- and -

Defendants

13. The Plaintiff pleads that it did enter into a site plan agreement with Bio-Char, as contemplated, dated April 1, 1985 and a site plan was approved on June 6, 1985.

15. The Plaintiff pleads that Bio-Char subsequently changed its name to Ajax Energy Corporation and the change was registered on April 11, 2002.


35. The Plaintiff pleads that 2047330 Ontario Limited was incorporated on May 25, 2004.
What happened to Bio-Char Inc.?

Moral of the story: Don’t try to sell BIOCHAR in Ajax
Advantages & Opportunities for Biochar

• Advantages
  - Good information about raw materials
  - Easy concept to accept
  - On the radar and in the news
  - Classification progress

• Opportunities
  - Stability
  - High cost and low value of carbon
  - Sustainability

• Benefits
“The purpose of this report is to determine whether the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30 percent or more of the country’s present petroleum consumption – the goal set by the Advisory Committee in their vision for biomass technologies. **Accomplishing this goal would require approximately 1 billion dry tons of biomass feedstock per year.**”
“In addition to updating the 2005 study, this report attempts to address a number of its shortcomings. Specifically, the update provides:

- A spatial, county-by-county inventory of primary feedstocks
- Price and available quantities (e.g., supply curves) for the individual feedstocks
- A more rigorous treatment and modeling of resource sustainability.”
Advantage – Bioenergy KDF database

Champagne, IL
Population: 179,669
Sq.mi.: 999
Forest res.: 233
Crop res.: 607,233
Manure: 390
Urban wood res.: 19,288
Sec. mill res.: 290
“PERSONALLY, I have realized by using charcoal that it helps to keep the surface of the putting greens in a good porous condition so that when the player makes a good shot to the putting green the ball will bite well and not bounce off the green. We often create this condition by the use of charcoal, especially where silt and clay loams predominate. During the playing season, should it be a dry one, charcoal helps to prevent the surface of the soil from baking and cracking open, thus preventing the nitrogen gases from escaping out of the soil. After a heavy rain or watering charcoal expands, thus allowing more water to enter into the subsoil. Charcoal also helps to make the surface of the putting greens firm and porous. For illustration (and don’t think this is a fish story), a year ago in the early part of the month of May our clubhouse was destroyed by fire. I had a large practice green situated close to the clubhouse. A huge fire engine drove across the middle of the green and it did not destroy a square inch of sod. I have counted at least twenty women with high heeled shoes walk across this green and they never leave any evil effects. I have never raised a divot on any of our short holes in two years and never have had a single complaint. The chief cause of maintaining a good firm surface I attribute to the liberal amount of charcoal in my putting greens.”
On August 13, 2005, American archaeologist James Petersen, Brazilian archaeologist Eduardo Neves, and two colleagues pulled up to a restaurant on a jungle road near Iranduba in the Brazilian Amazon to have a beer. At about 6:45 p.m., two young men, one brandishing a .38 revolver, entered the restaurant and demanded the patrons’ money. The archaeologists turned over their money and the bandits started to leave. Then, almost as an afterthought, one of them shot Petersen in the stomach. Neves and the others raced Petersen to the hospital, but their friend bled to death before they could reach help.

State and municipal police reacted quickly to the news, cordoning off roads, and brought suspects to the restaurant for identification. Within 24 hours the police had arrested the two armed bandits and the driver and learned there were two others involved. The crime was front-page news in Manaus, the capital of the state, a city of more than a million about an hour north of the study site, across the Rio Negro. After a 21-day manhunt through the jungle, the remaining two fugitives were captured, and when the state police brought them in, the Iranduba chief of police, Normando Barbosa, says, “there were hundreds of people lined up on the road that wanted to lynch the killers.”

Black Is the New Green

In a deft act of ecological justice, Johannes Lehmann wants to borrow an 8,000-year-old technology to interrupt the natural carbon cycle and return some of the infamous black stuff to the soil.

With wind solutions can be hard to come by, But if Cornell University soil scientist Johannes Lehmann is right, there may be a way to lower our emission of heat-trapping greenhouse gases, save millions of people’s lives, and significantly boost the productivity of the world’s farms— all at the same time. And, most remarkably, this strategy is based on a deceptively simple technology invented 8,000 years ago.

Lehmann’s idea starts with organic leftovers that people normally burn or leave to rot—forest brush, corn husks, nutshells, and even chicken manure. When this stuff decays or goes up in smoke, it releases vast amounts of heat-trapping carbon into the atmosphere. Lehmann’s plan is to short-circuit this carbon cycle by creating a material called biochar. Making biochar involves heating this organic matter without oxygen in a process called pyrolysis. It can be carried out in a small household stove, or it can be an industrial operation. Either way, the pyrolysis doesn’t produce carbon dioxide as ordinary, oxygen-fueled fire does. Instead, the carbon gets locked up in black chunks of charcoal-like material.
Biochar: Examination of an Emerging Concept to Mitigate Climate Change

Kelsi S. Bracmort
Analyst in Agricultural Conservation and Natural Resources Policy

February 3, 2009

Biochar is produced by the pyrolysis of organic waste materials, such as wood, crop residues, and manure. When applied to soils, biochar can improve soil fertility, increase water retention, and enhance the soil’s ability to store carbon. These beneficial effects can help mitigate climate change by reducing greenhouse gas emissions.

Carbon dioxide emissions from burning fossil fuels are a major contributor to climate change. By capturing and storing carbon in biochar, it is possible to reduce the amount of carbon dioxide that enters the atmosphere.

While the use of biochar is still in its early stages, it has the potential to be a powerful tool in the fight against climate change. Further research is needed to fully understand the potential benefits and limitations of biochar, but the early results are promising.

If the potential of biochar is realized, it could have important implications for agriculture and the environment. It could help farmers reduce their greenhouse gas emissions, improve soil health, and increase crop yields. Additionally, it could contribute to the global effort to reduce carbon dioxide emissions and combat the effects of climate change.
Advantage – Biochar classification/analysis

Total C, H, O
- High (>80%), Medium (60-80%), Low (20-60%) C

Labile (and stable C)
- Dissolves in water, decomposes at 350°C, decomposes at 950°C

Element other than C, H, O
- S and N from ultimate analysis, metals from ash dissolution

Surface area and pore-size distribution
- Macropore/Micropore ratio

Cation-exchange capacity
- Alternate absorption of ammonium and potassium

Schenkel and Shexue review - implications on char production and biochar


Hugh McLaughlin, PhD, PE[1] and Frank E. Spivey
### Feedstock

Biomass and diluents (<10%). <2% contaminants. No municipal solid waste or hazardous waste.

**Test Category A - Basic Utility Properties (required)**

- Particle size, moisture

**Test Category B - Toxicant Reporting (required)**

- Germination Inhibition Assay
- Polycyclic Aromatic Hydrocarbons (PAHs)

**Test Category C - Advanced Analysis and Enhanced Soil Properties (optional)**

- Mineral N (ammonium and nitrate)
- Total P&K
- Available P
- Volatile Matter
- Total Surface Area
- External Surface Area

### Ingredients

- **GOD GROW BIOCHAR**
  - MATERIAL TYPE: Biochar made from declared feedstock
  - COUNTRY OF ORIGIN: Australia
  - COUNTRY OF USE: Australia
  - FEEDSTOCK COUNTRY OF ORIGIN: Australia
  - FEEDSTOCK TYPE: Processed Feedstock
  - FEEDSTOCK COMPOSITION DECLARATION: Poultry manure - 83%, wood chip bedding - 17%

<table>
<thead>
<tr>
<th>Test Category A</th>
<th>BIOCHAR BASIC UTILITY PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (at time of analysis)</td>
<td>20% - DECLARATION</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>42% - CLASS 2 BIOCHAR</td>
</tr>
<tr>
<td>H:Corg</td>
<td>0.6 - PASS</td>
</tr>
<tr>
<td>Total Ash</td>
<td>40% - DECLARATION</td>
</tr>
<tr>
<td>Total N</td>
<td>5.4% - DECLARATION</td>
</tr>
<tr>
<td>pH</td>
<td>7.5 - DECLARATION</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>7.3 dS/m - DECLARATION</td>
</tr>
<tr>
<td>Liming</td>
<td>23% CaCO₃</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>5% &lt;420µm; 35% 420-2,380 µm; 45% 2,380-4,760 µm; 15% &gt;4,760 µm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Category C</th>
<th>BIOCHAR ADVANCED ANALYSIS AND SOIL ENHANCEMENT PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dioxin/Furan (PCDD/Fs)</td>
<td>0.02 ng/kg 1-TEQ - PASS</td>
</tr>
<tr>
<td>Polychlorinated Biphenyls (PCBs)</td>
<td>0.2 mg/kg - PASS</td>
</tr>
<tr>
<td>Arsenic</td>
<td>10 mg/kg - PASS</td>
</tr>
<tr>
<td>Cadmium</td>
<td>1.2 mg/kg - PASS</td>
</tr>
<tr>
<td>Chromium</td>
<td>60 mg/kg - PASS</td>
</tr>
<tr>
<td>Cobalt</td>
<td>14 mg/kg - PASS</td>
</tr>
<tr>
<td>Copper</td>
<td>143 mg/kg - PASS</td>
</tr>
<tr>
<td>Lead</td>
<td>125 mg/kg - PASS</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.5 mg/kg - PASS</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>5 mg/kg - PASS</td>
</tr>
<tr>
<td>Nickel</td>
<td>25 mg/kg - PASS</td>
</tr>
<tr>
<td>Selenium</td>
<td>10 mg/kg - PASS</td>
</tr>
<tr>
<td>Zinc</td>
<td>320 mg/kg - PASS</td>
</tr>
<tr>
<td>Boron</td>
<td>20 mg/kg - DECLARATION</td>
</tr>
<tr>
<td>Chlorine</td>
<td>90 mg/kg - DECLARATION</td>
</tr>
<tr>
<td>Sodium</td>
<td>140 mg/kg - DECLARATION</td>
</tr>
</tbody>
</table>

**Net Weight**

- Net Weight – 25 lbs (11.33kg)

**Name and Address of Manufacturer**

- Good Grow Biochar Company
- 123 County Route 1
- Centerville, Any State, USA

---

*Please see attached MSDS documentation for appropriate shipping, handling, and storage procedures.*
Advantage – Long term stability is certain
Labile (and stabile C)
Dissolves in water, decomposes at 350°C, decomposes at 950°C

\[ C_t = C_{labile} e^{-k_{labile} t} + C_{stabile} e^{-k_{stabile} t} \]

McShields Biochar Characterization Procedure
(1) Dry at 200°C, (2) pyrolysis at 450°C, (3) ash part of (2) at 550°C
(2)-(1) is mobile matter and (2)-(3) is resident matter
Determine C & N on (1) and (2). Assume Total – C = OH

Mobile is mobile, resident is stable
Test Category A - Basic Utility Properties (required)
\( C_{inorg}, C_{org} (C_{tot} - C_{inorg}), H, N, \text{ash}, (H:C_{org}) \)

\[ H:C_{org} < 0.7 \]
Opportunity – Predicting stability

94 biochars with varied fixed carbon, volatile matter, and ash content

H:C\text{org} and O:C\text{org} correlated very well with ash-free volatile matter

VM>80\%_{afb} = no C sequestration value
VM<80\%_{afb} \& O:C\text{org} >0.2 or H:C\text{org} >0.4 = moderate C sequestration
VM<80\%_{afb} \& O:C\text{org} <0.2 or H:C\text{org} <0.4 = high C sequestration

No indication of what “moderate” or “high” C sequestration was
Opportunity – Predicting stability

Edinburgh Stability Tool
Oxidation with H\textsubscript{2}O\textsubscript{2} at 80°C predicts labile C that will degrade in 50-250 years
The stable C correlated well with Fixed C and O:C
Cost of biochar

$4,440/ton

$21,730/ton

Biochar Enhanced Soil Amendment (1/2 Cu. Ft.)
by Biochar Enhanced Soil Amendment (1/2 Cu. Ft.)

Biochar UHP -(Ultra High Porosity)- 5 Gallons
by Charfecta

In stock.
Processing takes an additional 4 to 5 days for orders from this seller.
Ships from and sold by Charfecta.

Price: $113.33

- Enhanced plant growth
- Reduced fertilizer requirement
- Reduced leaching of nutrients
- Stored carbon in a long term stable sink
- Improved soil water handling characteristics
  - Provides a natural carbon source, minimizes nutrient leaching
  - Reduces soil acidity
  - Use in your garden, lawn or landscape projects, or add to houseplants
  - That's it!

Thank you for choosing carbon negative soils. We appreciate your continued support and please let us know if we can do anything to improve your experience.
Opportunity – Reduce the cost of biochar

<table>
<thead>
<tr>
<th>Crop</th>
<th>M acres</th>
<th>$/acre</th>
<th>Biomass $/acre</th>
<th>Recovery (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>87.4</td>
<td>1,081</td>
<td>2,228</td>
<td>7</td>
</tr>
<tr>
<td>Soybeans</td>
<td>76.1</td>
<td>658</td>
<td>2,228</td>
<td>11</td>
</tr>
<tr>
<td>Hay</td>
<td>56.3</td>
<td>376</td>
<td>2,228</td>
<td>20</td>
</tr>
<tr>
<td>Wheat</td>
<td>49.0</td>
<td>365</td>
<td>2,228</td>
<td>21</td>
</tr>
<tr>
<td>Cotton</td>
<td>9.4</td>
<td>858</td>
<td>2,228</td>
<td>9</td>
</tr>
<tr>
<td>Grain sorghum</td>
<td>5.0</td>
<td>410</td>
<td>2,228</td>
<td>18</td>
</tr>
<tr>
<td>Barley</td>
<td>3.2</td>
<td>445</td>
<td>2,228</td>
<td>17</td>
</tr>
<tr>
<td>Sunflower</td>
<td>1.8</td>
<td>474</td>
<td>2,228</td>
<td>16</td>
</tr>
<tr>
<td>Canola</td>
<td>1.7</td>
<td>399</td>
<td>2,228</td>
<td>19</td>
</tr>
</tbody>
</table>

CO₂ Credit
2.75 ton CO₂e/ton char
$4/ton CO₂e
Detail cost analysis

**Fast** pyrolysis require $58/ton CO$_2$e
**Slow** pyrolysis require $71/ton CO$_2$e
(base case $4/ton CO$_2$e)
Low value of carbon (credit)

**Fast** pyrolysis require $58/ton CO$_2$e to be profitable

**Slow** pyrolysis require $71/ton CO$_2$e to be profitable

(base case $4/ton CO$_2$e)

Dropped to $0.10/ton CO$_2$e from forecast $18/ton CO$_2$e

$4.80/ton CO$_2$e
Opportunity – Sustainability

<table>
<thead>
<tr>
<th>Crop</th>
<th>Ton residue/acre</th>
<th>Ton SP Char/acre</th>
<th>Ton FP Char/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>23.3</td>
<td>8.1</td>
<td>1.05</td>
</tr>
<tr>
<td>Soybeans</td>
<td>0.3</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Wheat</td>
<td>10.8</td>
<td>3.8</td>
<td>0.49</td>
</tr>
<tr>
<td>Cotton</td>
<td>1.7</td>
<td>0.6</td>
<td>0.08</td>
</tr>
<tr>
<td>Grain sorghum</td>
<td>10.1</td>
<td>3.5</td>
<td>0.45</td>
</tr>
<tr>
<td>Barley</td>
<td>13.2</td>
<td>4.6</td>
<td>0.59</td>
</tr>
</tbody>
</table>

**Biochar**
- 35% yield for Slow P
- 4.5% yield for Fast P

**Application Rates (8”)**
- 6.5 ton/acre = 0.5%
- 13 ton/acre = 1%
Plants thrive in powdered charcoal, and may be brought to blossom and bear fruit if exposed to the influence of the rain and the atmosphere; the charcoal may be previously heated to redness. Charcoal is the most "indifferent" and most unchangeable substance known; it may be kept for centuries without change, and is therefore, not subject to decomposition. The only substances it can yield to plants are some salts, which it contains, amongst which is silicate of potash.