Techno-economic Analysis of Biochar Production Using Portable Systems

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Forest Products Laboratory and Research Priorities

- Advanced Composites
- Advanced Structures
- Forest Biorefinery
- Nanotechnology
- Woody Biomass
- Life cycle assessment and techno-economic analysis of forest based products
- Supply chain modeling, simulation and optimization

- Founded in 1910 by the U.S. Forest Service and located in Madison, WI
- The Nation’s source for unbiased wood research and technical information
- A long history of cooperative research and public service
Biochar market: Present and Future

Biochar companies in 2015
Source: International Biochar Initiative (IBI)

- Biochar companies rose from 200 in 2014 to 326 companies in 2015
- $3.1 billion by 2025 with a CAGR of 13.2% (www.grandviewresearch.com)
- US biochar production - 94,000 tonnes in 2014 to 285,000 tonnes by 2025.
- ~35 US policies that support biochar production (15 are commercial financial incentives)
- Biochar price in the US varies between ($1360-3864/ton)
Background: Why biochar?

Piling residues: $150-200/hectare

Site preparation: $750-2000/hectare

Air quality issues, Wild fires

Scattered residues

Piled residues

(81-116 million dry tons of forest biomass)

- Require higher quality feedstock (less contamination, low moisture content, uniform-size, etc.)
- Large plant (high capital investment & risks, Higher logistics cost, Uncertainties)

Biochar

Solid biofuels

Liquid biofuels

Heat and electricity
Objectives

- To analyze the economic feasibilities [i.e., estimate minimum selling price (MSP)] of portable biochar production systems at near-forest (remote sites) and in-town locations.

- To perform sensitivity analyses to identify critical factors affecting economic performances of portable systems and suggest improvements.
Biochar production using portable systems

Forest residues → Oregon kiln (Wilson Biochar Associate) → Air curtain burner → Biochar Solution Inc. (BSI) → Woodchips/ground residues
BSI portable system

- Watershed boundary
- Individual Parcels
- Remote Bio-Conversion Site (BCT)
- Low speed road network to center of watershed – max travel time 1 hour

To facility (in town) – max 2 hour and 4 hour travel times
Oregon kiln and Air burners
portable systems

Oregon kiln

In forest operations
(felling, yarding, loading/hauling biomass)

Sorting boles, branches, and tops

Processing site

Further processing using chainsaws

Biomass

Water

Diesel

Propane

Biochar production with Oregon kiln

Biochar

Ash

Emissions

Air curtain burners

In forest operations
(felling, yarding, loading/hauling biomass)

Processing site

Biomass

Loading

Water

Diesel

Propane

Biochar production with Air burner

Biochar

Ash

Emissions
# Feedstocks specifications and system throughput

<table>
<thead>
<tr>
<th>Species</th>
<th>Contaminant</th>
<th>Commination method</th>
<th>Moisture content (wet basis)</th>
<th>Portable system</th>
<th>Throughput (*kg/hr/unit) or **kg/batch/unit</th>
<th>Biochar yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conifer</td>
<td>None</td>
<td>Ground</td>
<td>16.93%</td>
<td>BSI</td>
<td>*386</td>
<td>14.8%</td>
</tr>
<tr>
<td>Conifer</td>
<td>9% soil</td>
<td>Ground</td>
<td>14.91%</td>
<td>BSI</td>
<td>*341</td>
<td>11.7%</td>
</tr>
<tr>
<td>Conifer</td>
<td>none</td>
<td>Chip, medium</td>
<td>25.18%</td>
<td>BSI</td>
<td>*351</td>
<td>10.5%</td>
</tr>
<tr>
<td>Conifer</td>
<td>none</td>
<td>Chip, small</td>
<td>20.66%</td>
<td>BSI</td>
<td>*268</td>
<td>14.4%</td>
</tr>
<tr>
<td>Conifer</td>
<td>2/3 bole, 1/3 tops</td>
<td>Ground</td>
<td>16.20%</td>
<td>BSI</td>
<td>*434</td>
<td>13.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td>Oregon kiln</td>
<td>**45</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td>Air curtain burner</td>
<td>*10,000</td>
<td>20%</td>
</tr>
</tbody>
</table>

* = Kiln, ** = Air curtain burner

April 27, 2019
Critical assumptions for economic model

- No grants and subsidies included in this study
- Forest residues at no-cost
- 8 hours/day x 100 days of operations in a year (But BSI system with drying unit can work all year with addition of feedstocks drying units)
- BSI system can be used to produce biochar at the near-forest and in-town locations
- Oregon kiln and Air curtain burner used in-forest locations
- 2 BSI units or 12 Oregon kilns or 1 Air curtain burner for the base case
- 10 years economic life of the project
- 15% Required Returns on Invested Capital (ROIC), 2% inflation for cost and revenue, 6% loan interest rate, loan (40% of total capital investment), etc.
- 40% income tax
### Input data:
#### Capital costs

<table>
<thead>
<tr>
<th>No of units</th>
<th>Equipment</th>
<th>Description</th>
<th>Purchase price($)</th>
<th>Economic life (year)</th>
<th>Salvage Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tractor</td>
<td>Front-end loader</td>
<td>15,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Dryers</td>
<td>Beltomatic 123B</td>
<td>45,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Biochar machines</td>
<td>Biochar Solutions, 0.5 Tonnes/hr</td>
<td>340,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Gasifier-Gensets</td>
<td>20 kW, PP20GT gasifier</td>
<td>35,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>Diesel-Genset</td>
<td>Diesel generator, 40 kW</td>
<td>40,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td><strong>BSI, Total</strong></td>
<td></td>
<td><strong>$955,000</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Kiln</td>
<td>Oregon kiln</td>
<td>850</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Shovel</td>
<td></td>
<td>50</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Chain saw</td>
<td></td>
<td>500</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Propane torch</td>
<td></td>
<td>300</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Skidder</td>
<td>CAT-70hp</td>
<td>32,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td><strong>Oregon Kiln, Total</strong></td>
<td></td>
<td><strong>$78,100</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Air curtain burner</td>
<td>S-327</td>
<td>169,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>Loader</td>
<td>John Deere 2954D</td>
<td>433,000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td><strong>Air burner, Total</strong></td>
<td></td>
<td><strong>$602,000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Input data:
### Operational costs

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Units</th>
<th>BSI</th>
<th>Oregon Kiln</th>
<th>Air Burner</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstocks</td>
<td>$/tonne</td>
<td>10-30</td>
<td>-</td>
<td>-</td>
<td>Chipping/grinding and transportation for BSI system</td>
</tr>
<tr>
<td>Relocations</td>
<td>$/site</td>
<td>11,300</td>
<td>500</td>
<td>1000</td>
<td>Assuming two relocations in a year</td>
</tr>
<tr>
<td>Repair and maintenance</td>
<td>% capital cost</td>
<td>20%</td>
<td>10%</td>
<td>10%</td>
<td>Straight line depreciation</td>
</tr>
<tr>
<td>Consumable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>l/hr</td>
<td>0.54</td>
<td>2.03</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td>batch</td>
<td>batch</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>$/dry tonne</td>
<td>124.1</td>
<td>-</td>
<td>-</td>
<td>Transport: Remote locations to consumers in town</td>
</tr>
<tr>
<td>Finished good transportation</td>
<td>$/dry tonne</td>
<td>52.0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Technician:</td>
<td>$50.5/hr</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>Includes 35% fringe benefits</td>
</tr>
<tr>
<td>Loader operator:</td>
<td>$22.5/hr</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Non-skilled labor:</td>
<td>$16.8/hr</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Results: Remote site/Near-forest locations: Cost components and MSP of biochar produced using BSI system

Feedstocks used to make biochar in BSI system:
- Diesel Genset Ground, Clean
- Diesel Genset Ground, 9% soil
- Diesel Genset Ground, (2/3 bole and 1/3 tops)
- Diesel Genset Chipped-Small, clean
- Diesel Genset Chipped-medium, clean

Cost components:
- Product transport
- Repair and maintenance
- Fixed operating cost
- Product packaging
- Labor
- Capital assets
- Consumables
- Feedstocks and handling

MSP (Minimum Selling Price)
Results: Remote site Vs In-town locations (2-hrs and 4-hrs):
Biochar production with BSI system, including power from grid

BSI, Ground, (2/3 bole and 1/3 tops)
BSI, Chipped-Small, clean
Results: Comparison of biochar MSPs between portable systems at the remote sites (100 days/year working)

BSI system
MSP=$3060/tonne

Oregon Kiln
MSP=$1590/tonne

Air curtain burners
MSP=$1361/tonne

- Capital assets
- Labor
- Fixed operating cost
- Repair and maintenance
- Feedstocks and handling
- Consumables
**Impacts of drying feedstocks and technological improvements on financial performances of BSI system**

- Drying units was added to the BSI system (higher feedstocks moisture content and wide operations days, i.e., 300 days/year).
- Double augur added to BSI improved the throughput (22%) and biochar yield (21%).

<table>
<thead>
<tr>
<th></th>
<th>Before-finance &amp; tax</th>
<th>Before-tax</th>
<th>After-tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP (Minimum Selling Price)</td>
<td>1,244</td>
<td>1,137</td>
<td>1,163</td>
</tr>
<tr>
<td>Real IRR*</td>
<td>14.2%</td>
<td>17.5%</td>
<td>13.0%</td>
</tr>
<tr>
<td>Nominal IRR</td>
<td>16.5%</td>
<td>19.8%</td>
<td>15.3%</td>
</tr>
<tr>
<td>Break-even delivered feedstock cost ($/green tonne)</td>
<td>10.3</td>
<td>21.0</td>
<td>18.3</td>
</tr>
<tr>
<td>Medium-term operating B-E avg. product value ($/tonne)</td>
<td>860.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Short-term operating B-E avg. product value ($/tonne)</td>
<td>714.6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
BSI: Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Base case</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass cost</td>
<td>$/tonne</td>
<td>10</td>
<td>10-50</td>
</tr>
<tr>
<td>Economic life</td>
<td>Year</td>
<td>10</td>
<td>5-15</td>
</tr>
<tr>
<td>Operating hours</td>
<td>hrs/day</td>
<td>16</td>
<td>8-24</td>
</tr>
<tr>
<td>Biochar units</td>
<td>units/site</td>
<td>2</td>
<td>1-5</td>
</tr>
<tr>
<td>Product yield</td>
<td>%</td>
<td>16%</td>
<td>10%-24%</td>
</tr>
<tr>
<td>Throughput</td>
<td>kg/hr/unit</td>
<td>390</td>
<td>270 -520</td>
</tr>
<tr>
<td>Capital cost</td>
<td>M$</td>
<td>0.95</td>
<td>0.65 - 1.21</td>
</tr>
<tr>
<td>Operating cost</td>
<td>M$/year</td>
<td>0.56</td>
<td>0.4-0.73</td>
</tr>
</tbody>
</table>

BC: Base case MSP
S1: Biochar yield (16 → 22%)
S2: BSI units at site (2 → 4)
S3: Operating hours (16 → 24)
S4: Economic life (10 → 15) yr
S5: Throughput (390 → 470) kg/hr
S6: Capital cost (20% reduction)
S7: Operating cost (20% reduction)
Conclusions and future research

- A portable system at the near-forest setup can be a potential option to produce biochar from forest biomass.

- Estimated Minimum selling prices (MSPs) were $1060, $1590, and $1361/ dry metric tonne biochar for the BSI, Oregon kiln and Air curtain burner respectively.

- Major cost components are capital investment and labor.

- Biochar MSPs can be reduced by more than half with efficient portable systems and lowering their costs.

- Further, Biochar MSPs could possibly reduced with current government incentives and credits but this requires further research.
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