Black Diamond, Black Char, (new) Black Gold
Technical Area 1: **Feedstocks Development**

1. Evaluate existing and new systems of harvesting, processing, and transporting forest biomass feedstock from the forest to biomass conversion facilities
2. Develop enhanced system logistics
3. Develop new trucking and processing equipment
4. Produce next-generation landscape-level spatial feedstock supply models
Technical Area 2: Biofuels/Bio-based Products Development

1. Research, develop and improve the performance of a modular biomass gasification system (Tucker unit)
2. Evaluate the suitability of biochar outputs for the production of activated carbon
3. Develop and test pelletizing processes that can be used to improve the transport and storage characteristics of the carbon output, as well as its suitability for filtering and soil amendment applications.
4. Research and develop equipment and methods of spreading biochar on forest and agricultural sites.
Technical Area 3: **Biofuels Development Analysis**

1. Evaluate net life cycle greenhouse gas emissions and energy balance of Tucker System products (LCA)
2. Evaluate the impacts for forest biomass utilization
3. Develop financial models for biomass on economic conditions in the US West
4. Develop an economic synthesis of modular gasification at forest industry facilities
Our part:
Life-cycle analysis

Evaluate net life cycle greenhouse gas emissions and energy balance of Tucker System products using consequential life cycle assessment syngas for heat and electricity and biochar for activated carbon for filtering applications.
Life-cycle Inventory Analysis of Bio-products from a Modular Advanced Biomass Pyrolysis System

Hongmei Gu
Rick Bergman

USDA Forest Service
Forest Products Laboratory
Madison, WI

March 10, 2014
Illinois Biochar Group Spring meeting
LCA calculates all kinds of environmental impacts (Carbon footprint, energy, water, acidity, toxicity, etc.) for a product or service across the entire life cycle – from raw material extraction, to product making, to distribution, use, and end of life.
CARBON SEQUESTRATION BY BIOCHAR

- One metric ton of oven dry building timber stores roughly 510 kg of carbon, corresponding to 1.8 metric ton of CO2;
- One metric ton of biochar stores roughly 880 kg of carbon, corresponding to 3.2 metric ton of CO2;
SYSTEM CHAIN

- **Up Stream**: forest management, extraction, chip production
- **Tucker (TEA) system - pyrolysis**
- **Down Stream**: syngas to electricity, biochar to activated carbon
GOAL OF PROJECT LCA

Conduct comparative LCA for the following:

1. Activated carbon from coal or biochar
2. Electricity from fossil fuels or syngas

Determine the following:

• Mass and energy balance of biomass pyrolysis
• Net GHG balance of bio-based products
• Major environmental impacts
Process flow diagram for Tucker system

- Mill residues
  - Air lock
  - Feed stock
- Tar/water sludge
- Mable active section
  - Propane
  - Low Btu syngas
  - Medium-Btu syngas
- Tar condenser
- Residue heat
- Misting Chamber
- Compressor
- Gas storage tank
- flare
- Ethyl passive section
  - Flue gas
  - Biochar
  - syngas
  - char
**MASS AND ENERGY BALANCE**

Initial analysis -- Functional unit is 263 kg (580 lb) of pine/fir chip

<table>
<thead>
<tr>
<th>Source</th>
<th>Mass (kg)</th>
<th>Energy (MJ/kg)</th>
<th>Total Energy (MJ)</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td>263</td>
<td>18.4 (1)</td>
<td>4,848</td>
<td>72.0%</td>
</tr>
<tr>
<td>Propane</td>
<td>36.4</td>
<td>51.8 (2)</td>
<td>1,885</td>
<td>28.0%</td>
</tr>
<tr>
<td><strong>Total Thermal</strong></td>
<td></td>
<td></td>
<td><strong>6,732</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

**Parasitic**

| Electricity     | 2.87 kWh  | 3.6 MJ/kWh (2) | 10.3 MJ          |

(1) As measured from wood chips with 8.19% moisture (wt)
(2) Propane and electricity unit energy HHV values are taken from Franklin Database.
## MASS AND ENERGY BALANCE

Initial analysis – Functional unit is 263 kg (580 lb) of pine/fir chip

<table>
<thead>
<tr>
<th>Source</th>
<th>Mass (kg)</th>
<th>Mass (%)</th>
<th>Energy (MJ/kg)</th>
<th>Total Energy (MJ)</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syngas</td>
<td>172</td>
<td>65.4</td>
<td>17.96(^{(3)})</td>
<td>3,091</td>
<td>64.1</td>
</tr>
<tr>
<td>Tar, oil/water</td>
<td>54.3</td>
<td>20.6</td>
<td>10.54</td>
<td>572</td>
<td>11.9</td>
</tr>
<tr>
<td>Biochar</td>
<td>36.4</td>
<td>13.8</td>
<td>31.74</td>
<td>1,156</td>
<td>24.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>263</strong></td>
<td><strong>100</strong></td>
<td><strong>4,819</strong></td>
<td></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

\(^{(3)}\) unit energy value for biochar and tar oil/water were obtained from the proximate analysis and syngas unit energy value obtained from ASTM-D1945/3588 standard tests.
• Zaimes and others (2013) reported EROI for miscanthus and switchgrass to convert into biofuel for bioelectricity at 2.5 to 4.5 MJ/MJ;
• Gaunt and Lehmann (2008) showed a net energy gain for a slow pyrolysis-based bioenergy system for biochar and energy production of 2–9 MJ/MJ;
• Patzek (2005) and Metzger (2006) reported net energy gain for ethanol from corn at about 0.7 – 2.2 MJ/MJ
• Steele and others (2012) reported an EROI of 2 MJ/MJ for cradle-to-grave production and use of bio-oil derived from southern pine whole tree chips
Most fossil CO$_2$ and water emission are from burning propane and transporting the chips from Montana to North Carolina. Electricity use of Tucker unit operation is minor.

<table>
<thead>
<tr>
<th>Substances</th>
<th>Unit</th>
<th>Quantity</th>
<th>Percent, by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air emission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>g</td>
<td>2.14</td>
<td>0.3%</td>
</tr>
<tr>
<td>Carbon dioxide, biogenic</td>
<td>g</td>
<td>0.43</td>
<td>0.1%</td>
</tr>
<tr>
<td><strong>Carbon dioxide, fossil</strong></td>
<td>g</td>
<td><strong>709</strong></td>
<td><strong>98.4%</strong></td>
</tr>
<tr>
<td>Methane</td>
<td>g</td>
<td>2.01</td>
<td>0.3%</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>g</td>
<td>3.32</td>
<td>0.5%</td>
</tr>
<tr>
<td>Water emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids, unspecified</td>
<td>g</td>
<td>43.54</td>
<td>46.7%</td>
</tr>
<tr>
<td>Chloride</td>
<td>g</td>
<td>34.17</td>
<td>36.7%</td>
</tr>
</tbody>
</table>
CONCLUSION – TUCKER UNIT LCI

• Cumulative energy consumed - 12.1 MJ/OD kg chips
  – Generated from primary energy
  – Includes indirect energy used to make fossil fuel energy products

• Fossil Energy Replacement Ratio (FERR) is 2.54,
  – On the low end of other bioenergy systems
  – Does not include upstream and downstream processes

• Most air and water emission are from propane and diesel
  – Co-locating unit
    ▪ Substantially lower diesel fuel use (i.e. GHG emissions)
    ▪ Lower cumulative energy/increase FERR
FUTURE BIOCHAR WORK

- Tucker unit has been upgraded
  - Selling electricity on grid (Renewable Energy Credits (3x))
  - Fixed carbon of biochar has less variability
- Making activated carbon from new biochar
  - Steam activation – rotary calciner (Alston?)
  - Plan to re-characterize
  - Find environmental impacts (LCA)
  - Use for filter applications
ACKNOWLEDGEMENT

United States Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) Biomass Research and Development Initiative (BRDI) award no. 2011-10006-30357 is gratefully acknowledged. BRDI is a joint effort between the USDA and the U.S. Department of Energy (DOE)
QUESTIONS?

Hongmei Gu
hongmeigu@fs.fed.us
(608) 231-9589

Rick Bergman
rbergman@fs.fed.us
(608)231-9477

Using life-cycle analysis to estimate environmental consequences of products made from biomass pyrolysis and fossil fuels