Testing of Norris Thermal Technologies
Pilot Scale Torrefier at Big Lagoon, CA

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Outline

1. Testing Background
2. Reactor Temperature Profile
3. Results: Torrefied Biomass Characteristics
4. Conclusions
5. Lessons Learned from Testing
Torrefaction Testing Site

» Old mill in Big Lagoon, CA
» July – August 2015
» Tested with multiple feedstocks
» Feedstocks obtained from nearby forests
Torrefaction Testing Site

» Test Objectives:

» Understand pilot scale unit to inform construction of larger torrefier
» Feedstock tolerance
» Product characterization
» Mass and energy balance
Tests were conducted with various feedstocks at different residence times and reactor temperatures.

<table>
<thead>
<tr>
<th>Species</th>
<th>Douglas Fir</th>
<th>Redwood</th>
<th>Tan Oak</th>
<th>Slash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution Method</td>
<td>Chipped &amp; Screened</td>
<td>Chipped &amp; Screened</td>
<td>Chipped &amp; Screened</td>
<td>Chipped &amp; Screened</td>
</tr>
<tr>
<td>Contaminant</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none added</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>4-9%</td>
<td>10-27%</td>
<td>3-9%</td>
<td>18-32%</td>
</tr>
<tr>
<td>Residence Time (min)</td>
<td>3 - 6</td>
<td>8 - 15</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Target Temp. (°C)</td>
<td>300</td>
<td>400</td>
<td>300</td>
<td>350</td>
</tr>
</tbody>
</table>
Torrefaction Lab Analysis Plan

Key:
- Processing Step
- Measurement
- Calculation

1. In-field
   - 5g
     - Moisture Content
   - >500g
     - Bulk Density

2. -1kg
   - Hydrophobicity

3. -2kg
   - Grindability

4. <100g
   - Size Reduction
     - Ash Content
     - Volatile Matter
     - Fixed Carbon

5. <100g
   - Size & Moisture Reduction
     - Calorific Value (HHV)
Process Instrumentation and Material Flow

» Torrefaction Partner: Norris Thermal Technologies
» Technology: Pilot Scale Pyrolytic Screw
» Screw length: ~160 cm
Reactor Temperatures versus Time

Reactor temperatures vary with time and position.

Test data for slash feedstock at 7% moisture with 6 minute residence time at 350 °C.
Reactor Temperature Profile

Possible air leak through output air lock.
Moisture Content

Product moisture content averaged 1%.

- Slash
- Tanoak
- Redwood
- Douglas Fir

Moisture Content
Water Absorptivity

Product absorptivity averaged 30-50% lower than feedstock

- Slash
- Tanoak
- Redwood
- Douglas Fir

Absorptivity averages:
- Feedstock: 15-20%
- Product: 5-10%
## Energy Density of Torrefied Biomass

Higher heating value of torrefied biomass varies with residence time, reactor temperature, and species.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t</th>
<th>p</th>
<th>Lower Limit 95%</th>
<th>Upper Limit 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir</td>
<td>MJ/kg</td>
<td>7.74</td>
<td>2.04</td>
<td>3.80</td>
<td>0.058%</td>
<td>2.96</td>
<td>12.52</td>
</tr>
<tr>
<td>Tan Oak</td>
<td>MJ/kg</td>
<td>8.45</td>
<td>1.94</td>
<td>4.36</td>
<td>0.012%</td>
<td>3.90</td>
<td>13.00</td>
</tr>
<tr>
<td>Redwood</td>
<td>MJ/kg</td>
<td>9.21</td>
<td>1.87</td>
<td>4.91</td>
<td>0.002%</td>
<td>4.81</td>
<td>13.61</td>
</tr>
<tr>
<td>Slash</td>
<td>MJ/kg</td>
<td>8.46</td>
<td>1.97</td>
<td>4.29</td>
<td>0.015%</td>
<td>3.83</td>
<td>13.10</td>
</tr>
<tr>
<td>Tsky2</td>
<td>(MJ/kg)/K</td>
<td>0.0333</td>
<td>0.0060</td>
<td>5.58</td>
<td>0.0003%</td>
<td>0.0193</td>
<td>0.0474</td>
</tr>
<tr>
<td>Residence Time</td>
<td>(MJ/kg)/min</td>
<td>0.347</td>
<td>0.102</td>
<td>3.39</td>
<td>0.18%</td>
<td>0.107</td>
<td>0.588</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>(MJ/kg)/%</td>
<td>4.22</td>
<td>2.28</td>
<td>1.85</td>
<td>7.32%</td>
<td>-1.13</td>
<td>9.58</td>
</tr>
</tbody>
</table>
**Yield Rate**

Yield rate influenced by reactor temperature and species.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t</th>
<th>p</th>
<th>Lower Limit 95%</th>
<th>Upper Limit 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir</td>
<td>-</td>
<td>1.93</td>
<td>0.17</td>
<td>11.45</td>
<td>4.9E-13</td>
<td>1.54</td>
<td>2.33</td>
</tr>
<tr>
<td>Tan Oak</td>
<td>-</td>
<td>1.82</td>
<td>0.16</td>
<td>11.36</td>
<td>6.1E-13</td>
<td>1.45</td>
<td>2.20</td>
</tr>
<tr>
<td>Redwood</td>
<td>-</td>
<td>1.90</td>
<td>0.16</td>
<td>12.20</td>
<td>9.0E-14</td>
<td>1.53</td>
<td>2.26</td>
</tr>
<tr>
<td>Slash</td>
<td>-</td>
<td>1.88</td>
<td>0.16</td>
<td>11.46</td>
<td>4.8E-13</td>
<td>1.49</td>
<td>2.26</td>
</tr>
<tr>
<td>Tsky2</td>
<td>1/K</td>
<td>-0.0036</td>
<td>0.0005</td>
<td>-7.26</td>
<td>2.5E-08</td>
<td>-0.0048</td>
<td>-0.0024</td>
</tr>
<tr>
<td>Residence Time</td>
<td>1/min</td>
<td>-0.0090</td>
<td>0.0085</td>
<td>-1.06</td>
<td>30%</td>
<td>-0.029</td>
<td>0.011</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>1/%</td>
<td>-0.22</td>
<td>0.19</td>
<td>-1.15</td>
<td>26%</td>
<td>-0.66</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Conclusions

» Pilot system can process 120 kg/day with moisture content up to 25%.
  » New system designed to process 16 ton/day.

» Electrical demand is approximately 1 kWh/kg of feedstock for heating.
  » New system may have lower specific energy demand due to decreased reactor length to throughput ratio.
Lessons Learned

» Torrefier intolerant of larger particles > 1” due to bridging in the hopper.
  » Feeding system is redesigned to widen the range of acceptable feedstocks.

» Air locks leaked excess oxygen into the reactor causing combustion.
  » New system includes improved air locks and automated control to maintain neutral pressure in the reactor.

» Temperature control thermocouple was inadvertently electrically heated.
  » New system insulates the thermocouple from electrical heating.
Acknowledgements

» Aaron Norris, Norris Thermal Technologies
» Chuck Norris, Norris Thermal Technologies
» Charles Chamberlin, Ph.D., Schatz Energy Research Center