Rotary-shear Production of Flowable Uniform Feedstocks for Thermochemical Conversion to Renewable Diesel: Technoeconomic Analysis and Experience with First Commercial Scale System

David N. Lanning, Neal A. Yancey, Damon S. Hartley, James H. Dooley
Introduction

• Rotary Shears and Crumbles
  – Precision feedstocks for conversion to biofuels, biochemicals, and bioproducts
  – Biomass in, biomass out - making small particles
  – Veneer, wood chips, and herbaceous biomass
What is Crumbles® Feedstock?

• Physical properties are optimizeable for specific conversion processes
  – Length
  – Thickness
  – Moisture
  – Uniformity of size
  – Flowability

• Particle size converges on cutter thickness
Why Crumbles?

- Tolerant of high moisture
- Narrow particle size distribution
- Lower fines production
- Higher flowability - low aspect ratio
- Quieter than hammer mills and grinders
- Low / no dust production
Test Method

• Biomass Logistics Model (BLM)
  – Engineering performance databases of equipment
  – Spatially explicit labor cost datasets
  – Local tax and regulation data
  – Simulates flow of biomass through entire supply chain while tracking characteristic changes
    • MC, dry matter, ash, bulk density, etc
Modeling Scenarios

- Crumbler data collected at PPI, Rockwood, TN
- Hammermill and dryer data collected at INL’s PDU
- Data scaled to 800,000 dry short tons per year reactor ready feedstock (95 short tons per hour)
- Each pathway starts with pulp quality hardwood chips
- Processed 16.5 tons through Crumbler
- 4 super sacks crumbles shipped to INL for drying
- 4 super sacks chips shipped to INL for hammer mill processing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Chips</td>
<td>$37.00 / dry ton</td>
</tr>
<tr>
<td>Electricity</td>
<td>$0.071 / kWh</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>$5.39 / MMBtu</td>
</tr>
<tr>
<td>Off-Road Diesel Cost</td>
<td>$3.29 / gal</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>8%</td>
</tr>
</tbody>
</table>
Modeling Scenarios - Pathways

**Traditional Hammer mill**

1. Wood Chips
   - 40% MC, 2” Particle Size
2. Rotary Dryer
3. Dried Chips
   - 6% MC, 2” Particle Size
4. Hammermill
5. Screen
6. Hammer milled Chips
   - 6% MC, ¼” Particle Size
7. Covered Storage
8. Recirculate Overs
9. Lost Fines

**Crumbler® Rotary Shear**

1. Wood Chips
   - 40% MC, 2” Particle Size
2. Crumbler® Rotary Shear
3. Screen
4. Dryer
5. Dried Crumbles
   - 6% MC, 1/4” Particle Size
6. Covered Storage
7. Recirculate Overs
8. Lost Fines
Results

Particle size distribution
## Results

<table>
<thead>
<tr>
<th>Milling Energy kWh/dry ton</th>
<th>Drying Energy kWh/dry ton</th>
<th>Air Handling / Dust Collection kWh/dry ton</th>
<th>Total Energy Consumed kWh/dry ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crumbler Rotary Shear</td>
<td>18.4</td>
<td>1220</td>
<td>1238</td>
</tr>
<tr>
<td>Hammer mill</td>
<td>11.2</td>
<td>2314</td>
<td>2330</td>
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</tbody>
</table>

Energy summary for hammer milled hardwood chips

<table>
<thead>
<tr>
<th>Recirculated</th>
<th>Lost Fines</th>
<th>Accepts</th>
<th>Particle Size</th>
<th>Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crumbler Rotary Shear</td>
<td>17.6%</td>
<td>1.1%</td>
<td>81.3%</td>
<td>5.0</td>
</tr>
<tr>
<td>Hammer mill</td>
<td>0%</td>
<td>35%</td>
<td>65%</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Energy summary for Crumbler rotary shear milled hardwood chips
### Results

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Ownership Cost ($/dry ton)</th>
<th>Operating Cost ($/dry ton)</th>
<th>Lost Material Cost ($/dry ton)</th>
<th>Total Cost ($/dry ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryer</td>
<td>$1.31</td>
<td>$45.39</td>
<td>$0.00</td>
<td>$46.70</td>
</tr>
<tr>
<td>Hammer mill</td>
<td>$0.89</td>
<td>$3.71</td>
<td>$46.17</td>
<td>$50.77</td>
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<tr>
<td>Conveyors</td>
<td>$0.05</td>
<td>$0.04</td>
<td>$0.00</td>
<td>$0.09</td>
</tr>
<tr>
<td>Dust Collection</td>
<td>$0.18</td>
<td>$0.66</td>
<td>$0.00</td>
<td>$0.84</td>
</tr>
<tr>
<td>Total</td>
<td>$2.64</td>
<td>$49.80</td>
<td>$46.17</td>
<td>$98.40</td>
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</tbody>
</table>

Cost summary for hammer milled hardwood chips

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Ownership Cost ($/dry ton)</th>
<th>Operating Cost ($/dry ton)</th>
<th>Lost Material Cost ($/dry ton)</th>
<th>Total Cost ($/dry ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary Shear</td>
<td>$2.50</td>
<td>$3.32</td>
<td>$0.67</td>
<td>$6.49</td>
</tr>
<tr>
<td>Dryer</td>
<td>$1.31</td>
<td>$24.40</td>
<td>$0.00</td>
<td>$25.71</td>
</tr>
<tr>
<td>Conveyors</td>
<td>$0.05</td>
<td>$0.04</td>
<td>$0.00</td>
<td>$0.09</td>
</tr>
<tr>
<td>Dust Collection</td>
<td>$0.16</td>
<td>$0.65</td>
<td>$0.00</td>
<td>$0.81</td>
</tr>
<tr>
<td>Total</td>
<td>$4.02</td>
<td>$28.41</td>
<td>$0.67</td>
<td>$33.10</td>
</tr>
</tbody>
</table>

Cost summary for Crumbler rotary shear milled hardwood chips
Summary

• Size reduction before drying = significant drying energy savings
• Rotary shear produces more uniform particles
• Rotary shear produces more lower aspect ratio particles
• Cost savings as tested $65.30 / dry short ton for rotary shear
• Potential biorefinery savings of $52.24 million per year
Acknowledgments

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Thank You

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