Engineering and Economic Considerations of Renewable Energy Production from Forest Residues

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POINTS OF DISCUSSION

1) What are the main factors that affect the cost of feedstock?

2) What is the impact of the main factors across the supply chain?

3) How does freshness of biomass affect sugar yield?

4) How does freshness of biomass affect bulk density?

5) How does freshness of biomass affect comminution costs?

6) How does freshness of biomass affect collection costs?
Forest residues and feedstock preparation

- Biofuel
- Sugars
- Grindings
- Forest Residues
FACTORS AFFECTING COST

- Piece size of residue
- Particle size of grindings
- Capacity of truck
- Collection distance
- Operational settings --> truck-machine interaction
- Fresh or aged
- Amount of sugars
Moisture Content in Biomass Deliveries to Seneca Cogeneration Plant 2013-16

Median Load ~ 37% MC

Seneca, Turs, Sessions, 2016
Harvest Sites near Dexter, Oregon, USA
FRESH AND AGED FOREST HARVEST RESIDUES

MC = 60% Wet Basis
Bark & Needles = 16.7% of Dry Mass

MC = 15% Wet Basis
Bark & Needles = 6.2% of Dry Mass
FRESH HARVESTED BIOMASS

a) 

b)
VALUE DIFFERENCE COMPONENTS AT MILL

▪ From Analytical Test: 26% more residues need to be delivered to provide the same amount of sugar from fresh residues.

▪ The greater the sum of collection + grinding + transportation distance (cost), the greater the cost penalty from the reduced sugar yield
# Value Differences Due to Sugar Content for a $70/ODT Delivery Cost for Fresh and Aged Feedstock

<table>
<thead>
<tr>
<th></th>
<th>Fresh</th>
<th>Aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total polysaccharides, % on feedstock</td>
<td>44.6%</td>
<td>56.3%</td>
</tr>
<tr>
<td>Hydrolysis yield, as polysaccharides to feedstock polysaccharides, %</td>
<td>89.2%</td>
<td>89.2%</td>
</tr>
<tr>
<td>Sugars as polysaccharides, ODT per ODT feedstock, %</td>
<td>39.8%</td>
<td>50.2%</td>
</tr>
<tr>
<td>Sugars as monomers, ODT/ODT, %</td>
<td>35.8%</td>
<td>45.2%</td>
</tr>
<tr>
<td>Assumed delivered cost of feedstock, $/ODT</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Feedstock cost per kg of sugar monomers</td>
<td>0.195</td>
<td>0.155</td>
</tr>
</tbody>
</table>
To Mill

Comminution and Transport

Lowboy

Forest Residues
Piles
## TRANSPORTATION COST

<table>
<thead>
<tr>
<th>Road Surface</th>
<th>Loaded USD h&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>Unloaded USD h&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>Idling USD h&lt;sup&gt;-1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>86.3</td>
<td>77.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Paved</td>
<td>118.4</td>
<td>100.0</td>
<td>50.0</td>
</tr>
</tbody>
</table>

6 x 4 Truck with 130 cy capacity trailer, 45 miles/hr paved (Average), 10 miles/hr gravel
RESIDUE HEIGHT IN TRAILER

14.6 m trailer, 2.5 m wide, dry bulk density = 149 kg/m³

(2.8, 15.4)  
(2.6, 14.1)  
(2.3, 12.8)  
(2.1, 11.6)
Transportation Cost of Fresh and Aged Residues

- **Fresh Residue**
- **Aged Residue**

**Graph Details:**
- **Y-axis:** Transportation cost in USD t⁻¹
- **X-axis:** One-way Distance to the Conversion Facility, km

The graph shows a linear relationship between the transportation cost and the distance to the conversion facility, with the cost increasing as the distance increases.
**COMMINUTION**

**Fresh Biomass (60% MC)**
- Bulk Density = 388.1 kg/m$^3$
- Fuel Consumption = 1.0 L/GT

**Simulation Results**
- 100% Productivity = 69.5 GT/hr
- 100% Productivity = 41.7 ODT/hr
- 66% Productivity = 27.6 ODT/hr

**Aged Biomass (15% MC)**
- Bulk Density = 184.2 kg/m$^3$
- Fuel Consumption = 2.2 L/GT

**Simulation Results**
- 100% Productivity = 49.6 GT/hr
- 100% Productivity = 41.2 ODT/hr
- 80% Productivity = 32.9 ODT/hr

Grinder Utilization for Fresh Biomass Lower Due to Increased Waiting Time due to Greater Number of Trucks Per Hour
COMMINUTION COSTS (750 HP GRINDER + LOADER)

Fresh Biomass

- Operating Cost with Fuel = $357/hr
- Idle Time = $116/hr
- 66% Productivity = 27.6 ODT/hr
- Cost/ODT = $10.0

Aged Biomass

- Operating Cost with Fuel = $406/hr
- Idle Time = $116/hr
- 80% Productivity = 32.9 ODT/hr
- Cost/ODT = $10.6
Greener areas indicate potentially cheaper biomass
System 1: 1-Loader only
System 2: 1-Forwarder & Self-Loading
System 3: 1-Forwarder & 1-Loader
System 4: 2-Forwarders & 1-Loader
## Fresh and Aged Residue Delivery Costs and Sugar Penalty

<table>
<thead>
<tr>
<th>One-Way (km)</th>
<th>Collect ($/ODT)</th>
<th>Grind (Fresh)</th>
<th>Grind (Aged)</th>
<th>Transport (Aged)</th>
<th>Transport (Fresh)</th>
<th>---Cost to Mill-----</th>
<th>Sugar Penalty ($/ODT)</th>
<th>Difference ($/kg)</th>
<th>---Sugar Cost-----</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>13.95</td>
<td>28.44</td>
<td>46.55</td>
<td>60.44</td>
<td>15.71</td>
<td>29.60</td>
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<tr>
<td>40</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>17.83</td>
<td>36.15</td>
<td>50.43</td>
<td>68.15</td>
<td>17.72</td>
<td>35.44</td>
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<tr>
<td>60</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>21.72</td>
<td>44.88</td>
<td>54.32</td>
<td>76.88</td>
<td>19.99</td>
<td>42.55</td>
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<td>80</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>25.10</td>
<td>53.10</td>
<td>57.70</td>
<td>85.10</td>
<td>22.13</td>
<td>49.53</td>
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<tr>
<td>100</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>29.48</td>
<td>61.32</td>
<td>62.08</td>
<td>93.32</td>
<td>24.26</td>
<td>55.50</td>
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<tr>
<td>120</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>33.36</td>
<td>69.54</td>
<td>65.96</td>
<td>101.54</td>
<td>26.40</td>
<td>61.98</td>
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<tr>
<td>140</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>37.24</td>
<td>77.76</td>
<td>69.84</td>
<td>109.76</td>
<td>28.54</td>
<td>68.46</td>
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<tr>
<td>160</td>
<td>22.00</td>
<td>10.60</td>
<td>10.00</td>
<td>41.12</td>
<td>85.98</td>
<td>73.72</td>
<td>117.98</td>
<td>30.67</td>
<td>74.93</td>
</tr>
</tbody>
</table>
DIFFERENCE IN FRESH AND AGED RESIDUE COST INCLUDING COLLECTION+GRINDING+TRANSPORT+SUGAR YIELD PENALTY

Differences in Fresh vs Aged residue, USD t-1

One Way Distance to Conversion Facility, km

[Bar chart showing the increase in cost difference with increasing distance]
SUGAR COST DIFFERENCES BY DISTANCE

Sugar Cost USD $/kg

One Way Distance to Conversion Facility, km

Aged
Fresh
TOTAL ABOVEGROUND NUTRIENTS

Douglas-fir tree, 38 yrs old
dbh=45.6 cm, height =33.5 m, crown length =19.9 m

Mainwaring, Maguire, and Harrison, NARA Annual Meeting, 2015, Spokane, WA
Conclusions from the Engineering and Economic Perspective

- **Mill site**: Aged more valuable due to higher sugar yield
- **Transport**: Aged residues much less expensive
- **Comminution**: Aged slightly more expensive but few differences
- **Operational setting**: Few truck loads less impact on roads
- **Collection**: No difference: Volume limited
- **Environmental**: Needles nutrient content important to left in the field