CORRIM Special Session: Biofuel Environmental Performance

Presented at
Forest Product Society
66th International Convention
June 3, 2012
Washington, DC

Consortium for Research on Renewable Industrial Materials
Research developing life cycle assessments for every stage of processing covering wood products/biofuels and their uses.
Production of Bio-oil from Pyrolysis of Southern Pine Slash: Aspen and SimaPro LCA

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Fast pyrolysis:

Bio-oil is dark brown liquid which is an emulsion comprised of a complex mixture of organic compounds and water.

Fast Pyrolysis

Biomass $\rightarrow\begin{array}{c} 400 - 650 ^\circ C \\ \text{Absence of } O_2 \end{array}$ $\rightarrow$ Syngas + bio-oil vapors $\rightarrow$ Cool and condense $\rightarrow$ Liquid (Bio-oil) $\rightarrow$ Char
Life cycle assessment (LCA):

• Several techno-economic analyses have been performed to estimate the cost of producing fast pyrolysis bio-oil.

• An LCA analysis has not been performed.

Objective

• Perform an LCA analysis for the production of bio-oil with first-thinning loblolly pine slash material as feedstock.
Method and scope:

• The Ringer et al. (2006) developed an ASPEN-Plus® model for a 540 dt/d bio-oil production facility; we modified the scale to 2000 dt/d for an increased feedstock cost of $50 rather than $30 dt.

• Our current LCA analysis utilized the mass and energy balance data from the modified Ringer Aspen model.

• Estimation of the life cycle environmental impacts in the form of emissions, fossil fuel use, resource consumption and global warming impacts were provided by SimaPro 7.
Feedstock properties:

• Fresh slash was obtained from a first-thinning operation that utilized whole tree harvesting in which stems were skidded to a delimber.
• Slash, comprised of limbs and tops, was collected from each of 5 skidder bundles randomly selected during 8 hours of operation; slash from each study bundle was weighed green at the harvest site.
• An average skidder bundle contained 25 stems; slash and tops weighed approximately 50 lb per tree.
Bio-oil Production:

- The slash feedstock was chipped to a particle size of 1-3mm and oven dried to 7% moisture content.

- The MSU auger reactor produced the study bio-oil.
Comparison of pine clear wood and pine slash bio-oils:

<table>
<thead>
<tr>
<th></th>
<th>Slash feed (%)</th>
<th>Pine feed (%)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-oil (%)</td>
<td>49.3</td>
<td>65</td>
<td>-15.7</td>
</tr>
<tr>
<td>Char (%)</td>
<td>28.6</td>
<td>23</td>
<td>+5.6</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1.8</td>
<td>0.4</td>
<td>+1.4</td>
</tr>
<tr>
<td>Gases (%)</td>
<td>14.0</td>
<td>10</td>
<td>+4.0</td>
</tr>
<tr>
<td>Water content</td>
<td>37.4</td>
<td>26.2</td>
<td>+11.2</td>
</tr>
<tr>
<td>Acid value</td>
<td>81.6</td>
<td>98.1</td>
<td>-16.5</td>
</tr>
<tr>
<td>HHV (MJ/kg)</td>
<td>11.9</td>
<td>18.2</td>
<td>-6.3</td>
</tr>
</tbody>
</table>
Comparison of clear pine wood and pine slash bio-oils, cont’d:

• Compared to bio-oil from clear pine wood feedstock the slash feedstock bio-oil:
  
  o Yielded 15.7 percentage points (pp) less
  o Had a water content 11.2 pp higher
  o Had an ash content 1.4 pp higher
    • Lower bio-oil yield and high water content are well known to occur when mineral content is high; the high ash value indicates a high mineral content contributed by the needles and the high ratio of bark-to-clear-wood on small-diameter branch wood.
Comparison of clear pine wood and pine slash bio-oils, cont’d:

• Compared to bio-oil from clear pine wood feedstock the slash feedstock bio-oil:
  
  o Had higher char (+5.6) and gas (+4.0) production.
    ▪ Higher char and gases were also due to the high mineral content of the slash feedstock; the minerals catalyze reactions that produce char and gas at the expense of liquid bio-oil production.
  
  o Had a 6.3 MJ/kg lower HHV.
    ▪ The lower HHV for slash bio-oil was due mainly to the very high water content (37.4%) which was 11.2 pp higher than for bio-oil from clear pine feedstock.
Bio-oil Aspen model unit processes which energy is consumed or generated:

1. **FEED HANDLING & DRYING**: Wood chips @ 50% moisture
2. **PYROLYSIS**: Dried wood chips @ 7.5% moisture
   - Heat from char furnace
3. **QUENCHING**: Bio-oil (unfinished) and syngas
   - Char
   - Ash - Landfill
4. **RECOVERY**: Bio-oil & syngas
   - syngas
   - Wastewater treatment
   - Water to utilities
   - To utilities
5. **CHAR FURNACE**: Char
6. **UTILITIES**: Hot air from cooling the product vapors
7. **RECYCLING**: non-condensable gases
   - To pyrolysis
8. **BURNER / BOILER**: STEAM & POWER PRODUCTION
9. **ELECTRICITY**: BIO-OIL
Cradle-to-grave SimaPro system boundary:

- **Forest operations**

  - **Slash Tree Chipping**

    - **Slash Chips, 50% MC**
    - **Chips, 7.5% MC**

    - **Dryer**

      - **Pyrolysis Reactor**

        - **Quenching**

          - **Recovery**

            - **Char Furnace**

              - **Bio-oil co-fed with coal in industrial boiler**

    - **Bio-oil**

  - **Bio-oil** co-fed with coal in industrial boiler

- **Material flows**
  - Air emissions
  - Water emissions
  - Solid waste (ash)

- **Heat flows**
  - Electricity flows
  - Bio-oil

- **Electricity flows**
LCA methods:

• Life cycle impact assessments (LCIA) were performed with the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI 2).

• Cradle-to-grave impact assessment comparisons were conducted between bio-oil and refined fuel oil (RFO).

• Aspen values for the recovery efficiency of bio-oil from oven-dry wood chips was 49.3%. Other yields for char, ash and syngas were 28.6, 1.8 and 14.0 %, respectively. HHV value was 11.9 MJ/kg.
Cradle-to-grave energy requirement:

- Cradle-to-grave energy requirement for bio-oil and RFO for each life cycle stage
Cradle-to-grave global warming:

- Cradle-to-grave global warming potential for bio-oil and RFO for each life cycle stage:

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<table>
<thead>
<tr>
<th>Stage</th>
<th>Bio-oil</th>
<th>Residual Fuel Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>-0.16</td>
<td>-0.14</td>
</tr>
<tr>
<td>Transport</td>
<td>-0.12</td>
<td></td>
</tr>
<tr>
<td>Fuel Production</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td>Fuel Combustion</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>CO2 Absorption</td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td>Net GWP</td>
<td>-0.04</td>
<td></td>
</tr>
</tbody>
</table>
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Graph showing the global warming potential (kg CO2 eq. / MJ) for bio-oil and residual fuel oil across different life cycle stages.
CO₂ emissions:

- CO₂ emissions calculated from global warming potential for bio-oil and RFO.

![Graph showing CO₂ emissions and GWP calculations.](image)

- Total GWP for Bio-oil: 0.29 kg CO₂ eq./MJ
- Total GWP for Residual Fuel Oil Net: 0.11 kg CO₂ eq./MJ
- GWP net for Bio-oil Net: -0.15 kg CO₂ eq./MJ
- Reduction in GWP: 50%

Reduction in GWP by replacing RFO with slash-derived bio-oil is 50%.
Summary:

• A 2000 dt/d Aspen model was modified to simulate the processes and resultant emissions to produce slash-derived bio-oil.

• LCA for production of bio-oil during pyrolysis was developed with Simapro to analyze resource use and energy consumption inputs and emissions to air, water and land.

• Bio-oil from slash feedstock provided reduced yield, higher water content and an HHV 6.2 MJ/kg lower than for bio-oil from pyrolysis of pine clear wood.

• However, this lower-energy bio-oil from slash feedstock had improved life cycle GHG emissions compared to RFO, resulting in a reduction in GWP of 50%.
Summary, cont’d:

• Slash-derived bio-oil has near carbon neutrality with a net GWP of 0.053 kg CO$_2$ eq./MJ.

• Substitution of slash-derived bio-oil for RFO would reduce CO$_2$ emissions by 0.055 kg CO$_2$ eq./MJ of fuel consumption.
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