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.
Bioethanol from Lignocellulosic Feedstocks: A Life Cycle Assessment of the Thermochemical Conversion Pathway

Jesse Daystar
PhD Candidate
Department of Forest Biomaterials
North Carolina State University
Forest Products Society International Convention
June 3, 2012- Washington DC

Other Contributors:
Carter Reeb, Trevor Treasure, Hasan Jameel, Mike Jett, Daniel Saloni and Steve Kelley

Principal Investigators:
Richard Venditti and Ronalds Gonzalez
Policy forces driving adoption of biofuels

Convergence of forces will accelerate biofuels adoption
~ 70 billion gallons of biofuels worldwide by 2020.
(~10% penetration)
Renewable fuel mandates

*Economic Incentives*

- Energy Independence and Security Act 2007
  - Reduce oil imports by $41.5 billion
  - Additional security benefits of $2.6 billion
  - Increase net farm income by $13 billion
## Renewable Fuel Standards

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>GHG Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable fuel</td>
<td>20%</td>
</tr>
<tr>
<td>Advanced biofuel</td>
<td>50%</td>
</tr>
<tr>
<td>Biomass-based diesel</td>
<td>50%</td>
</tr>
<tr>
<td>Cellulosic biofuel</td>
<td>60%</td>
</tr>
</tbody>
</table>

Lifecycle GHG Thresholds Specified in EISA (percent reduction from 2005 baseline)

Bioethanol Target: 6%
Renewable Fuel Standards

• Reduce GHG emissions by 138 million metric tons when fully implemented in 2022

• Equivalent of removing 27 million cars off the road

• Reduce dependence on fossil fuels

| Lifecycle GHG Thresholds Specified in EISA (percent reduction from 2005 baseline) |
|----------------------------------------|--------|
| Renewable fuel                        | 20%    |
| Advanced biofuel                      | 50%    |
| Biomass-based diesel                  | 50%    |
| Cellulosic biofuel                    | 60%    |
## EISA Renewable Fuel Volume Requirements (billion gallons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cellulosic biofuel requirement</th>
<th>Biomass-based diesel requirement</th>
<th>Advanced biofuel requirement</th>
<th>Total renewable fuel requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>9.0</td>
</tr>
<tr>
<td>2009</td>
<td>n/a</td>
<td>0.5</td>
<td>0.6</td>
<td>11.1</td>
</tr>
<tr>
<td>2010</td>
<td>0.1</td>
<td>0.65</td>
<td>0.95</td>
<td>12.95</td>
</tr>
<tr>
<td>2011</td>
<td>0.25</td>
<td>0.80</td>
<td>1.35</td>
<td>13.95</td>
</tr>
<tr>
<td>2012</td>
<td>0.5</td>
<td>1.0</td>
<td>2.0</td>
<td>15.2</td>
</tr>
<tr>
<td>2013</td>
<td>1.0</td>
<td>a</td>
<td>2.75</td>
<td>16.55</td>
</tr>
<tr>
<td>2014</td>
<td>1.75</td>
<td>a</td>
<td>3.75</td>
<td>18.15</td>
</tr>
<tr>
<td>2015</td>
<td>3.0</td>
<td>a</td>
<td>5.5</td>
<td>20.5</td>
</tr>
<tr>
<td>2016</td>
<td>4.25</td>
<td>a</td>
<td>7.25</td>
<td>22.25</td>
</tr>
<tr>
<td>2017</td>
<td>5.5</td>
<td>a</td>
<td>9.0</td>
<td>24.0</td>
</tr>
<tr>
<td>2018</td>
<td>7.0</td>
<td>a</td>
<td>11.0</td>
<td>26.0</td>
</tr>
<tr>
<td>2019</td>
<td>8.5</td>
<td>a</td>
<td>13.0</td>
<td>28.0</td>
</tr>
<tr>
<td>2020</td>
<td>10.5</td>
<td>a</td>
<td>15.0</td>
<td>30.0</td>
</tr>
<tr>
<td>2021</td>
<td>13.5</td>
<td>a</td>
<td>18.0</td>
<td>33.0</td>
</tr>
<tr>
<td>2022</td>
<td>16.0</td>
<td>a</td>
<td>21.0</td>
<td>36.0</td>
</tr>
<tr>
<td>2023†</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>b</td>
</tr>
</tbody>
</table>

*a To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.
*b To be determined by EPA through a future rulemaking.
Renewable Feedstocks

- EPA Acceptable Feedstocks for biofuels
- Non-agricultural
  - *Planted trees*
  - Slash/Pre-commercial biomass waste
  - Animal waste
- Agricultural
  - Planted crops
  - Crop residues
Why Biofuels?

- **Biomass Growth**
- **Harvesting**
- **Storage**
- **Transportation**
- **Combustion**
- **Fuel Production**

**Biofuels Carbon Cycle**

- CO\(_2\)

NC State University
Supply Chain Analysis

-0.09 Other fixed costs
-0.21 Overhead
-0.17 Maintenance
-0.55 Depreciation
-0.05 Chemicals
-0.07 Labor
-0.62 Biomass

Biomass 35.2%
Depreciation 31.3%
Labor 4.0%
Chemicals 2.7%
Maintenance 9.7%
Overhead 11.8%
Other fixed costs 5.3%

Costs and revenues (US$ per gallon ethanol)

Ethanol subsidy 1.01
Ethanol price 2.08

2. Ethanol production costs (US$ per gallon ethanol) and cost share (%), using loblolly pine as feedstock. 1 gal = 3.7854 l.
Outline

• Introduction
• General LCA Modeling Approach
• Life Cycle Assessment
  – Biomass Feedstock Production (cradle-to-gate)
  – Bioethanol from Thermochemical Conversion (gate-to-gate)
  – Bioethanol production and use: (cradle-to-grave)
• Summary
• Future Work
• Acknowledgements
Objectives:
Life Cycle Assessment

• Feedstock production
  – Identify feedstock production scenarios with lowest environmental impact, GHG emissions
  – Evaluate the impacts of land use change

• Thermochemical conversion process (TC): mixed alcohol production
  – Determine optimal feedstock and conversion technology pairing
  – Identify conversion process and feedstocks scenarios producing least environmental impacts

• Fuel delivery and combustion
  – Quantify fuel combustion emissions based on 1 MJ fuel

• Determine environmental impacts of biofuel (TC) production and use compared to gasoline (cradle-to-grave)
Life Cycle Assessment Modeling Structure

Thermochemical Ethanol Production Process Simulation

U.S. Life Cycle Inventory Database

Full Cradle-to-Grave LCA
Methods: Life Cycle Assessment
Cradle-to-Mill Gate

• Emissions inventory analysis (SimaPro)
  – Feedstock models
  – NREL (U.S. LCI) data used when possible
  – IPCC & FICAT used to model land use change impacts

• Impact assessment (SimaPro)
  – TRACI impact assessment method
  – Updated to 2007 GHG equivalents
Outline

• Introduction
• General LCA Modeling Approach
• Life Cycle Assessment
  – Biomass Feedstock Production (cradle-to-gate)
  – Bioethanol from Thermochemical Conversion (gate-to-gate)
  – Bioethanol production and use: (cradle-to-grave)
• Summary
• Future Work
• Acknowledgements
System Boundaries:
Loblolly Pine & Eucalyptus

- Plantation Establishment
- Maintenance
- Harvesting
- Transportation
- Biorefinery Gate
- Biomass Production

Inputs:
- Fertilizer
- Herbicide
- Diesel
- CO₂

Outputs:
- Processing
System Boundaries: Forest Residues & Unmanaged Hardwood
System Boundaries: Switchgrass & Sweet Sorghum
# Biomass Production

## Input Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Loblolly Pine</th>
<th>Eucalyptus</th>
<th>Unmanaged Hardwood</th>
<th>Switchgrass</th>
<th>Sweet sorghum</th>
<th>Forest residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity (dry tonne ha(^{-1}) year(^{-1}))</td>
<td>12.80</td>
<td>13.50</td>
<td>2.24</td>
<td>13.50</td>
<td>11.77</td>
<td>0.76</td>
</tr>
<tr>
<td>Rotation length (years)</td>
<td>12</td>
<td>4</td>
<td>50</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Harvesting window</td>
<td>Year round</td>
<td>Year round</td>
<td>Year round</td>
<td>Three months</td>
<td>Three months</td>
<td>Year round</td>
</tr>
<tr>
<td>Moisture content</td>
<td>45%</td>
<td>45%</td>
<td>45%</td>
<td>16%</td>
<td>74%</td>
<td>45%</td>
</tr>
<tr>
<td>Delivery form</td>
<td>Logs</td>
<td>Logs</td>
<td>Logs</td>
<td>Square bales</td>
<td>Cane</td>
<td>Chips</td>
</tr>
<tr>
<td>Trees per ha</td>
<td>2,965</td>
<td>567</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Establishment cost ($/ha)</td>
<td>637</td>
<td>552</td>
<td>0.0</td>
<td>181</td>
<td>416</td>
<td>n/a</td>
</tr>
<tr>
<td>Maintenance cost ($/ha)</td>
<td>62.4 (^1)</td>
<td>62.4 (^1)</td>
<td>0.0</td>
<td>85.3 (^2)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1 = Second year of plantation; 2 = Maintenance cost per year, year 2 through 10
# Life Cycle Inventory

## Feedstock Production Outputs

<table>
<thead>
<tr>
<th>Productivity level</th>
<th>Loblolly Pine</th>
<th>Eucalyptus</th>
<th>Hardwood</th>
<th>Forest Residues</th>
<th>Switchgrass</th>
<th>Sweet Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption, collection</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
</tr>
<tr>
<td>Plantation establishment and maintenance, diesel</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plantation establishment and maintenance, gasoline</td>
<td>0.86</td>
<td>0.65</td>
<td>0.52</td>
<td>0.12</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Harvesting, diesel</td>
<td>10.1</td>
<td>7.58</td>
<td>6.06</td>
<td>10.1</td>
<td>7.58</td>
<td>6.06</td>
</tr>
<tr>
<td>Storage</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
<td>Liter per dry ton</td>
</tr>
<tr>
<td>Transportation forest to facility</td>
<td>Dry ton*km</td>
<td>79</td>
<td>69</td>
<td>62</td>
<td>219</td>
<td>190</td>
</tr>
<tr>
<td>Transportation farm to storage</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transportation storage to facility</td>
<td>Dry ton*km</td>
<td>327</td>
<td>283</td>
<td>253</td>
<td>51</td>
<td>44</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>kg per Dry Ton</td>
<td>UREA</td>
<td>2.1</td>
<td>1.6</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Potassium</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lime</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Herbicide</td>
<td>kg per Dry Ton</td>
<td>General herbicide, glyphosate</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>Pursuit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MSO</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2,4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Azarine 90 DF</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dipel ES</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: 500,000 BDT/year, 10% covered area
GHG Emissions per dry tonne

<table>
<thead>
<tr>
<th>Biomass Growth</th>
<th>Establishment/Maintenance</th>
<th>Harvest/Storage</th>
<th>Transportation</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>Eucalyptus</td>
<td>Unmanaged Hardwood</td>
<td>Forest Residues</td>
<td>Forest Residues w/ Burdens</td>
</tr>
</tbody>
</table>

Note: 500,000 BDT/year, 10% covered area
### GHG Emissions per dry tonne

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Biomass</th>
<th>Establishment/Maintenance</th>
<th>Harvest/Storage</th>
<th>Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>-103.25</td>
<td>1.51</td>
<td>1.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>-103.99</td>
<td>2.26</td>
<td>1.37</td>
<td>0.35</td>
</tr>
<tr>
<td>Unmanaged Hardwood</td>
<td>-102.83</td>
<td>0.00</td>
<td>1.39</td>
<td>1.44</td>
</tr>
<tr>
<td>Forest Residuals</td>
<td>-102.54</td>
<td>0.00</td>
<td>1.07</td>
<td>1.48</td>
</tr>
<tr>
<td>Forest Residuals w. Burdens</td>
<td>-102.63</td>
<td>0.09</td>
<td>1.07</td>
<td>1.48</td>
</tr>
<tr>
<td>Forest Feedstock Avg.</td>
<td>-103.62</td>
<td>1.89</td>
<td>1.37</td>
<td>0.36</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>-110.21</td>
<td>8.34</td>
<td>1.55</td>
<td>0.32</td>
</tr>
<tr>
<td>Sweet Sorghum</td>
<td>-117.17</td>
<td>4.66</td>
<td>11.34</td>
<td>1.16</td>
</tr>
<tr>
<td>Agricultural Feedstock Avg.</td>
<td>-113.69</td>
<td>6.50</td>
<td>6.45</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Note: 500,000 BDT/year, 10% covered area
Direct Land Use Change

- Emissions resulting from converting uses of land
- IPCC and FICAT Data
- Factors:
  - Soil type
  - Land type
  - Moisture type
  - Region

Land Use Change

GHG Emissions
Land Use Change Results (FICAT, NCASI, IPCC data)

From Cropland  From Grassland  From Deciduous Natural Forest  From Coniferous Natural Forest  Net GHG/ha over 100 years (No LUC)

Note: 500,000 BDT/year, 10% covered area
Net GHG & Land Use Change

<table>
<thead>
<tr>
<th>Pine</th>
<th>Eucalyptus</th>
<th>Unmanaged Hardwoods</th>
<th>Switchgrass</th>
<th>Sweet Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.04E+06</td>
<td>-3.11E+06</td>
<td>-3.92E+05</td>
<td>-2.82E+06</td>
<td>-2.31E+06</td>
</tr>
</tbody>
</table>

-3,750,000 to -250,000 tonne CO$_2$ eq. per hectare over 100 years

- No L/U Change
- Cropland
- Grassland
- Deciduous Natural Forest
- Coniferous Natural Forest
Delivered Cost and GHG Emissions Per Dry Ton

Note: 500,000 BDT/year, 10% covered area
TRACI Impact Assessment Method

- Global warming
- Acidification
- Carcinogenics
- Non Carcinogenics
- Respiratory effects
- Eutrophication
- Ozone depletion
- Ecotoxicity
- Smog

- Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI)
Impact Assessment
TRACI Method

Note: 500,000 BDT/year, 10% covered area
Integrated Conversion

- **Feedstock**
  - Loblolly Pine 1,2
  - Unmanaged Hardwood 1,2
  - Eucalyptus 1,2
  - Forest Residues 1,2
  - Switchgrass 1,2
  - Sweet Sorghum 1

- **Conversion Technology**
  1=Biochemical (Dilute Acid)
  2=Thermochemical (Gasification)
Outline

• Introduction
• General LCA Modeling Approach
• Life Cycle Assessment
  – Biomass Feedstock Production (cradle-to-gate)
  – Bioethanol from Thermochemical Conversion (gate-to-gate)
  – Bioethanol production and use: (cradle-to-grave)
• Summary
• Future Work
• Acknowledgements
System Boundary: Gate-to-Gate Model

- **Feedstocks**
  - Production
  - Transportation
  - Sequestered Carbon

- **Conversion Process**
  - Biomass Gasification

- **Process Chemicals**
  - Olivine
  - MgO
  - Molybdenum

- **Distribution/Use**
  - Fuel Transportation
  - Combustion Emissions

- **Landfill**
  - Inorganic Ash

- **Waste Treatment**
  - Non-organic Effluent
Thermochemical Conversion: Biomass to Biofuels

• Gasification: conversion of organic or fossil materials at high temperature without combustion to produce high energy synthetic gas (also called syngas).

• The synthetic gas can be
  – burned for energy
  – reacted to produce liquid fuels

• Advantage: feedstock flexibility
  – (SW, HW, agricultural biomass, wastes)
Process Simulation
Thermochemical Ethanol Conversion

Conversion Process
- NREL Phillips et al. 2007
- Dutta et al. 2011

Feedstocks:
- Loblolly Pine
- Unmanaged Hardwoods
- Eucalyptus
- Forest Residues
- Switchgrass
Conversion Technology:
Thermochemical conversion

- Feed handling and drying
- Dry wood
- Gasification
- Raw syngas
- Gas cleanup and conditioning
- Clean syngas
- Methanol recycle
- Alcohol synthesis
- Alcohol separation
- Ethanol
- Ethanol & higher alcohol products
- Propanol
- Utilities
- Steam and power

Heat flow through the process.
Alcohol Yield and GHGs
Outline

• Introduction
• General LCA Modeling Approach
• Life Cycle Assessment
  – Biomass Feedstock Production (cradle-to-gate)
  – Bioethanol from Thermochemical Conversion (gate-to-gate)
  – Bioethanol production and use: (cradle-to-grave)
• Summary
• Future Work
• Acknowledgements
Cradle-to-Grave System Boundary

System Boundary

**Feedstocks**
- Production
- Transportation
- Captured Carbon

**Conversion Process**
- Biomass Gasification

**Distribution/Use**
- Fuel Transportation
- Combustion Emissions
Cradle-to-Grave GHG Emissions

![Graph showing Cradle-to-Grave GHG Emissions for different feedstocks and conversion methods.](image)

- Pine: Feedstock - 2.13E-02, Conversion - 1.67E-02, Net - 2.00E-02
- Eucalyptus: Feedstock - 2.00E-02, Conversion - 2.02E-02, Net - 2.03E-02
- Unmanaged Hardwood: Feedstock - 2.72E-02, Conversion - 2.72E-02, Net - 2.72E-02
- Forest Residues no burden: Feedstock - 2.72E-02, Conversion - 2.72E-02, Net - 2.72E-02
- Forest Residues w/burden: Feedstock - 2.72E-02, Conversion - 2.72E-02, Net - 2.72E-02
- Switchgrass: Feedstock - 2.72E-02, Conversion - 2.72E-02, Net - 2.72E-02

Graph categories:
- Feedstock
- Conversion
- Combustions
- Net

Kg CO2 eq. per MJ Fuel
Ethanol Vs. Gasoline

**Kg CO2 eq. per MJ Fuel**

- Pine: 2.13E-02
- Eucalyptus: 1.67E-02
- Unmanaged Hardwood: 2.00E-02
- Forest Residues no burden: 2.02E-02
- Forest Residues w/burden: 2.03E-02
- Switchgrass: 2.72E-02
- Gasoline: 8.74E-02

**% GHG Reduction Vs. Gasoline**

- Pine: 75.58%
- Eucalyptus: 80.88%
- Unmanaged Hardwood: 77.11%
- Forest Residues no burden: 76.94%
- Forest Residues w/burden: 76.76%
- Switchgrass: 68.89%
- Gasoline: 90.00%

Net vs. % Reduction for various feedstocks compared to gasoline.
## Renewable Fuel Standards

### Lifecycle GHG Thresholds Specified in EISA
( percent reduction from 2005 baseline )

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>GHG Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable fuel</td>
<td>20%</td>
</tr>
<tr>
<td>Advanced biofuel</td>
<td>50%</td>
</tr>
<tr>
<td>Biomass-based diesel</td>
<td>50%</td>
</tr>
<tr>
<td>Cellulosic biofuel</td>
<td>60%</td>
</tr>
</tbody>
</table>

All feedstocks result in greater than 60% reduction.
Summary

• Forest based feedstock production
  – Lower GHG emissions
  – Lower overall environmental impacts
  – Lower delivered costs

• Cradle to grave ethanol GHG emission
  – Ethanol from all feedstocks reduce GHG emissions compared to gasoline
  – Ethanol produced from biomass gasification should qualify as a cellulosic biofuel under EISA
  – Forest based feedstocks resulted in lower GHG emissions

• The production and use of biomass feedstocks could decrease fossil fuel use

• Bioethanol made from sustainably managed forest could decrease environment impacts of transportation fuels
Future Work

- Cradle-to-grave LCA and economics on complete fuel production and use systems for all feedstock scenarios
  - Thermochemical conversion
  - Biochemical conversion
- In depth land use change and spatial analysis modeling
- As part of the Southern Partnership for Integrated Biomass Supply Systems (IBSS) USDA AFRI, combine results with social, wildlife and other environmental impacts
Acknowledgments

• Consortium for Research on Renewable Industrial Materials (CORRIM)

• Southern Partnership for Integrated Biomass Supply Systems (IBSS), USDA AFRI

• Biofuels Center of North Carolina
Questions?
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.