Woody Biomass for Biofuels

Woody Biomass Utilization Workshop
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US Energy Demand

US Renewable Fuel Demand

Source: Renewable Fuels Association 2010
Global Carbon Cycle (billion metric tons)

+ 3.2 Billion tons per year to atmosphere
Woody Biomass as a Resource

- Low Value Raw Material
  - Mixed species
  - Low quality wood (defects, abnormal wood, etc.)
  - Often includes bark and dirt
- Replacement for Fossil Fuel Carbon
- Renewable Resource for Energy
- Using it can Reduce Wildfire Hazard
- Low Cost ??
Are Trees are Natures Answer to the Energy Crisis?

• Solar Collector
• Consume CO₂
• Energy Storage (Battery)
• Provides:
  – Heat
  – Electricity
  – Transportation Fuels
## Biochemical Potential

<table>
<thead>
<tr>
<th>Component</th>
<th>Softwoods</th>
<th>Hardwoods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>40-44 %</td>
<td>43-47 %</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>25-29</td>
<td>25-35</td>
</tr>
<tr>
<td>Lignin</td>
<td>25-31</td>
<td>16-24</td>
</tr>
<tr>
<td>Extractives</td>
<td>1-5</td>
<td>2-8</td>
</tr>
<tr>
<td>Ash</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>
Conversion Pathways

Combustion

Biochemical
  • Anaerobic digestion
  • Hydrolysis/Fermentation

Thermochemical
  • Pyrolysis
  • Gasification

Heat
Electricity

Alcohol
Other organic chemicals

Heat
Electricity
Bio-oil
Alcohol
Other organic chemicals
Biofuels

• **Solid**
  – Wood (chips, chunks, densified)
  – Charcoal
  – Lignin residues

• **Liquid**
  – Bio-oil (low viscosity tar)
  – Bio- diesel
  – Ethanol (Ethyl alcohol)
  – Methanol (methyl alcohol)
  – Biobutanol (butyl alcohol)

• **Gaseous**
  – Producer gas (syngas)
## Competing Cellulosic Feedstocks for Biofuels

<table>
<thead>
<tr>
<th></th>
<th>Cellulose</th>
<th>Hemi-Cellulose</th>
<th>Energy Content (BTU/lb)</th>
<th>Yield (tons/acre)</th>
<th>Bulk Den. (kg/m³)</th>
<th>Conversion ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switchgrass</strong></td>
<td>45%</td>
<td>45%</td>
<td>7,000</td>
<td>20</td>
<td>108</td>
<td>5</td>
</tr>
<tr>
<td><strong>Miscanthus</strong></td>
<td>45</td>
<td>24</td>
<td>7,700</td>
<td>60</td>
<td>80</td>
<td>5</td>
</tr>
<tr>
<td><strong>Corn Stover</strong></td>
<td>35</td>
<td>25</td>
<td>7,300</td>
<td>40</td>
<td>&lt;1-1.2</td>
<td></td>
</tr>
<tr>
<td><strong>Bagasse</strong></td>
<td>40</td>
<td>22</td>
<td>7,500</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td><strong>Wood</strong></td>
<td>42</td>
<td>25</td>
<td>8,000</td>
<td>10</td>
<td>450</td>
<td>0.8 - 1</td>
</tr>
</tbody>
</table>

Transportation costs and energy conversion ratio are imp tw.
Biomass to ETOH Technologies

• Hydrolysis/Fermentation
  – Concentrated Sulfuric Acid
  – Dilute Sulfuric Acid
  – Dilute Nitric Acid
  – Enzymatic

• Thermal Reduction/Chemical Conversion
  – Gasification/Catalytic Conversion (Fischer-Tropsch)
Hydrolysis/Fermentation

- Dilute nitric acid hydrolysis
  - Separates the 5 and 6 carbon sugars from the lignin

- Yeast Fermentation
  - Converts sugars to alcohol
Woody Biomass-to-Ethanol

G = Glucose (a type of sugar)
S = Other sugars
E = Ethanol
Woody Biomass-to-Ethanol

Hydrolysis

G = Glucose (a type of sugar)
S = Other sugars
E = Ethanol
Woody Biomass-to-Ethanol

Hydrolysis

Fermentation

Concentrated acid or Dilute acid or Enzyme

Yeast/other organisms

G = Glucose (a type of sugar)
S = Other sugars
E = Ethanol

G-G-G-G 25% Cellulose
S-S-S-S 25% Hemicellulose
G-G-G-G 50% Lignin
Woody Biomass-to-Ethanol

Hydrolysis

Fermentation

Concentrated acid or Dilute acid or Enzyme

Yeast/other organisms

Gasoline

Distillation

Lignin

Low-grade steam

Electricity

Power Plant

G = Glucose (a type of sugar)
S = Other sugars
E = Ethanol

Modified from source slide supplied by USDOE NREL
Pyrolysis Process

Biomass → Pyrolysis → Bio-oil – tar, condensable liquids (acidic, high oxygen content)

Heat → Char & Ash (Charcoal)
Gasification Process

Biomass → Pyrolysis → Char Conversion → Combustion → Micro-turbines or Combustion

Producer gas* → Char & Ash

Char & Ash → Heat → Combustion

Heat → Ash & Exhaust Gases

SO₂ ~ 0.15 lbs per million BTU
NOₓ ~ 0.05 lbs per million BTU
CO ~ 0.05 lbs per million BTU
Particulates ~ 0.025 lbs per million BTU

*Producer gas is a mixture of carbon monoxide, carbon dioxide, hydrogen, nitrogen, and water.

(In excess of 600°C)
Thermal Reduction/Catalytic Conversion

Biomass → Gasification $\rightarrow$ Producer gas (syngas) $\rightarrow$ Catalytic Conversion $\rightarrow$ Bio-diesel, Methanol, Ethanol

- Heat
- C, O, H, tar
Thermochemical Processing
Catalytic Conversion Options

FEEDSTOCK

Fuel Prep.

GASIFICATION

CLEANUP

Cat = Catalytic Conversion Process

Ni, Fe, Cu-Zn

Cu-Zn, Cu-Co

Cu-ZnO

H3PO4, Cr2O3

Fe

Co/K

Cu-ZnO

Mixed Bases
Na, Ca

CaCN

Ni/Mg

Combined Cycle

Cofiring/Reburn

+ Others

SYNGAS

FTL

MeOH

Cat: Zeolite

HYDROGEN
ETHANOL, MIXED ALCOHOLS
METHANOL, DME
OLEFINS
LPG
NAPHTHA
KEROSENE/DIESEL
LUBES
WAXES
GASOLINE
OXOCHEMICALS
e.g., KETONES
AMMONIA
SNG
CHP

Source: NREL
Ethanol

- First Generation Biofuel
- What is the best feedstock?
  - Corn
  - Corn Cellulose (stover)
  - Switchgrass
  - Miscanthus
  - Woody Biomass
  - Bagasse
  - Others?
Life Cycle Inventory Analysis

Raw Material

- Harvest
- Collection
- Transportation
- Feedstock Prep.
- Process
- Residue handling

Product

Emissions

Residue

E
Energy to Deliver 1 million BTU from Source to Vehicle Fuel Tank

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Total Energy (BTU)</th>
<th>Fossil Energy (BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>240,000</td>
<td>240,000</td>
</tr>
<tr>
<td>ETOH (corn starch)</td>
<td>500,000</td>
<td>500,000</td>
</tr>
<tr>
<td>ETOH (corn cellulose, stover)</td>
<td>1,230,000</td>
<td>230,000</td>
</tr>
<tr>
<td>ETOH (herbaceous)</td>
<td>1,200,000</td>
<td>100,000</td>
</tr>
<tr>
<td>ETOH (Wood)</td>
<td>1,600,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Source: Argonne National Laboratory, 2001
A Wood Scientist’s Opinion

The importance of woody biomass as a raw material will increase dramatically through the 21st century becoming the choice for many carbon-based materials, including part of the solution to replacing fossil fuels.