Cellulosic Ethanol Technology Assessment

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Southern Illinois University Edwardsville
Renewable Carbon to Fuel Alcohol

PLANTS → Technology → Present → Sucrose Cane, Beet → Starch-Glucose → Future → Biomass-Cellulose & Hemicellulose → ETHANOL
Impact of corn ethanol for replacing imported oil

% Corn Harvest Going to Ethanol

% Auto Fuel Replaced by Ethanol

Calendar Year (2004-2012)

(RFA & CRA, 2002)
## Biomass Feedstock Availability in the U.S.

<table>
<thead>
<tr>
<th></th>
<th>Estimated Qty.</th>
<th>Energy Use</th>
<th>Available New Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Wood</td>
<td>0.59</td>
<td>0.08</td>
<td>0.51</td>
</tr>
<tr>
<td>Forest Residues</td>
<td>0.38</td>
<td>0.37</td>
<td>0.01</td>
</tr>
<tr>
<td>Mill Residues</td>
<td>0.66</td>
<td>0.65</td>
<td>0.01</td>
</tr>
<tr>
<td>Ag Residues</td>
<td>3.95</td>
<td>0</td>
<td>3.95</td>
</tr>
<tr>
<td>Energy Crops</td>
<td>1.07</td>
<td>0</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>Total (Quads)</strong></td>
<td><strong>6.65</strong></td>
<td><strong>1.1</strong></td>
<td><strong>5.55</strong></td>
</tr>
</tbody>
</table>

M.E. Walsh, D.G. De La Torre Ugarte, et. al., Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Oak Ridge National Laboratory, Updated January 2000
US Biomass Sources

ECONOMICAL

ABUNDANT & AVAILABLE

Sugar Cane
Corn Starch
Cottonwoods
Switch Grass
Corn Fiber
Paper
Wood Chips
Stover
Sugar Cane
Kansas City, KS 66101-5901
Phone: 816-926-2750
Fax: 816-926-2751
www.ee.uark.edu/
Challenge

How Do You Put Low Cost Biomass in Your Automobile?
Composition of Biomass

Cellulose & Hemicellulose are carbohydrates that can be broken down to free sugars and fermented to ethanol. **Lignin** has a high heating value.

*Others: extractables, pectin, and ash.*

Source: www.nrel.gov
Plant Cell Wall Structure

PLANT CELL WALL

Cellulose
Lignin
Hemicellulose
Cellulose Bundles

Robert Shleser, 1994
Utilization of Biomass for Production of Fuel Ethanol

Corn Fiber → Pretreatment → Enzymatic Saccharification → Fermentation → Ethanol Recovery
Amounts of feedstocks to produce 10 ml ethanol

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>Corn</th>
<th>Fiber</th>
<th>DDG</th>
<th>Stover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15%</td>
<td>46%</td>
<td>64%</td>
<td>5%</td>
</tr>
</tbody>
</table>

500 ml graduated cylinders used for comparisons
Corn Kernel Cellulosics

Near Term Technology Validation

- No incremental supply chain Costs
- Potential 10% Yield increase
- 4.5 M gal Ethanol per plant Annually
- Minimal incremental capital
- DDGS weight reduced 44%
- No increase in corn acres
## Selected Pretreatment Strategies

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Pentoses</th>
<th>Inhibitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Acid</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Dilute Acid</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Hot Water</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>AFEX</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alkaline Peroxide</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Enzymatic Hydrolysis of Cellulose

Cellulose → β-glucosidase → Glucose

Endoglucanase → Glucose, Cellobiose, Cellodextrins

Exoglucanase

Inhibition
Recombinant Microorganisms for Fermentation of Mixed Sugars to Ethanol

- Recombinant organisms are now available
  
  - Recombinant *Escherichia coli*
  - Recombinant *Saccharomyces*
  - Recombinant *Zymomonas*
  - Recombinant *Klebsiella oxytoca*

- Commercialization prospects
  - BCI with recombinant *E. coli*
  - Iogen with recombinant *Saccharomyces*
Ethanol Fermentation Of Corn Fiber Hydrolysate by *E. coli* FBR5
Future Strains: Critical Traits

- Pentose utilization
- High ethanol yield and productivity
- Genetic and phenotypic stability
- Hardiness (tolerance to ethanol and inhibitors)
- Efficient use of multiple sugars
- Growth at low pH/high temperature
- Ease of use with current production technology
Ethanol cost derived from $50/ton corn stover versus equivalent corn prices in dry-grind processing

<table>
<thead>
<tr>
<th></th>
<th>Conversion Rate Gallons Per Ton</th>
<th>Enzyme Cost Per Gallon</th>
<th>Cost Per Denatured Gallon</th>
<th>Corn Equivalent Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Future</strong></td>
<td>89.7</td>
<td>$0.10</td>
<td>$1.25</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.25</td>
<td>$1.40</td>
<td>2.98</td>
</tr>
<tr>
<td><strong>Base</strong></td>
<td>68.0b</td>
<td>$0.10</td>
<td>$1.65</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.25</td>
<td>$1.79</td>
<td>4.62</td>
</tr>
</tbody>
</table>

From Tiffany and Eidman, 2004
### Cost Comparison for Corn & Stover

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Stover</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Invest. (MM$)</strong></td>
<td>0.51</td>
<td>0.793</td>
</tr>
<tr>
<td><strong>Feedstock costs1 ($/gal)</strong></td>
<td>0.13</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Co-product Credit ($/gal)</strong></td>
<td>0.793</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Total Prod. Costs (MM$/yr)</strong></td>
<td>47.8</td>
<td>72.0</td>
</tr>
<tr>
<td><strong>Ethanol Prod. Cost ($/gal)</strong></td>
<td>0.96</td>
<td>1.45</td>
</tr>
<tr>
<td><strong>Annual Ethanol (MMGal)</strong></td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

1 Corn at $2.25/bu & stover at $40/ dry ton

**Hope for future**

USDA, ERRC, March 2005
Biomass Processing: Example 1

Biomass

Solid/Liquid Separation

Moderate severity pretreatment & hemicellulose hydrolysis

Cellulose + Lignin

Cellulose Hydrolysis

Glucose Fermentation

Enzymatic Hydrolysis & Fermentation

C5 Sugars Fermentation

Detoxification

C-5 Fermentation

Ethanol

Distillation

Lignin to Boilers
Technological Constraints to Scale-UP

- Pretreatment - Substrate more reactive to enzymes
- Fermentation inhibitors
- Genetic stability, productivity and alcohol tolerance of recombinant microorganisms
- Recovery of dilute alcohol - Solids Loading