Biorefinery Process Economics

An in-depth, independent technical and economic evaluation by the PEP program

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Biorefinery Process Economics

Agenda

- Biorefinery Research
- Whole Corn Biorefinery
  - Core Conversion Technologies
  - Capital Costs
  - Process Economics
- Economic Issues
  - Feedstock
  - Coproducts
- Waste Issues
- Conclusions
Early Biorefineries

**Corn Dry Mill**
- Corn Grain
- Enzymes
  - Milling & Saccharification
  - Sugars
  - Anaerobic Fermentation
  - Distillation
  - Ethanol
  - DDGS

**Raw Sugar Mill**
- Sugarcane
  - Milling & Evaporation
  - Bagasse
- Water
  - Crystallization
  - Raw Sugar
- Molasses
  - Fermentation
  - Distillation
  - Ethanol
Feedstock Price as Driving Factor

Opportunity grows for renewable resources

- Crude Oil, $/ft³
- Natural gas, $/thous ft³
- Corn, $/bushel

[Graph showing the price trends for Crude Oil, Natural gas, and Corn from 1995 to 2005]
Biorefinery Research

Worldwide Interest

• **Brazil**
  - Leverage sugar mills

• **Europe**
  - Kyoto driven
  - BREW project funded by EC

• **United States**
  - Leverage corn milling and other agricultural assets
  - Projects funded by Dept. of Energy (DOE) and Dept. of Agriculture (USDA)
2003 DOE/USDA Funded Projects

- Integrated Corn Biorefinery (ICBR)
  - DuPont, Diversa, NREL, MSU
- Sugars from lignocellulosics
  - NatureWorks, Iowa State University
- Corn fiber separation and conversion
  - National Corn Growers, ADM, PNNL
- Starch and biomass conversion pilot plant
  - Abengoa, Novozymes, NREL
  - Large scale pilot facility in York, Nebraska
Whole corn biorefinery utilizes entire corn plant

<table>
<thead>
<tr>
<th>Grain</th>
<th>% Dry Basis</th>
<th>Stover</th>
<th>% Dry Basis</th>
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<tr>
<td>Starch</td>
<td>72.0</td>
<td>Cellulose</td>
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<td>Celluloses</td>
<td>10.5</td>
<td>Xylan</td>
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<td>Protein</td>
<td>9.5</td>
<td>Lignin</td>
<td>17.5</td>
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<td>Oil</td>
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<td>Galac./Man.</td>
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<td>Sugars</td>
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<td>Arabinan</td>
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<td>Extractives</td>
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Core Conversion Technologies

- Sugar platform technologies
  - Pretreatment
  - Saccharification
- Fermentation technologies
  - Engineered microorganisms e.g. *S. cerevisiae, Z. mobilis* and *E. coli*
- Milling technologies
  - Starch conversion to sugar
Whole Corn Biorefinery

Whole Corn

Stover

Kernels

Gypsum
Water
Enzyme
Pretreatment

Sacch. & CoFerm
Distillation
Ethanol
Lignin

Dry Mill & Sacch.
Fermentation
1,3-Propanediol

Recovery & Purification

DDGS Recovery
DDGS

Enzymes
Air
Capital Costs

Base Case:
580 mill. Lb/yr PDO
65 mill. Gal/yr EtOH

Source: PEP Report 257
Whole Corn Biorefinery
Battery Limits Investment

- Recovery & Purification: 27%
- Pretreatment & Conditioning: 26%
- Saccharification & Co-Fermentation: 17%
- Distillation & Dehydration: 14%
- DDGS Recovery: 11%
- Dry Mill & Saccharification: 3%
- Aerobic Fermentation: 2%
Biorefinery Off-Sites Capital

- General Facilities: 39%
- Other Utilities: 15%
- Steam: 7%
- Cooling: 6%
- Lignin Combustor: 26%
- Other Waste Treatment: 33%
- Other Waste Treatment: 7%
Dedicated Plant using glucose feedstock at 9 cents/lb

Biorefinery

EtOH $1.08/gal
DDGS $115/ton

PDO Capacity, million lb/yr

Net Production Cost, cents/lb PDO

Source: PEP Report 257
Process Economic Issues

- Feedstock
  - Cost and composition
- Coproducts
  - Recovery costs
  - Market value
- Enzymes
  - Make versus buy
- Waste Treatment
  - Aqueous
  - Solid
Feedstock flow chart for biomass planning tool I-FARM as planned in Task 8 of the USDA-DOE project.

Source:
Department of Agricultural and Biosystems Engineering
Iowa State University.
# Biomass Cost Reduction Target

Goal of $30-35/t by 2015

<table>
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<tr>
<th>Year</th>
<th>FY03 Cost per Dry Ton</th>
<th>Selective Harvest</th>
<th>Single-Pass Harvester</th>
<th>Transportation &amp; Bulk</th>
<th>Storage &amp; Pretreatment</th>
<th>Nth Plan Savings (5%)</th>
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<td>2000</td>
<td>53.29</td>
<td>47.96</td>
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<td>2025</td>
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Source: Sokhansanj and Turhollow, ORNL 2005
Coproducts

• 1,3-Propanediol
  ■ Monomer for PTT
• Ethanol
  ■ Established commodity as fuel
• Lignin
  ■ Energy value
  ■ Potential chemical derivatives
• Protein
  ■ Established feed markets
• Carbon Dioxide
• Other Byproducts
  ■ Acetic acid, furfural, other organics
Lignin (Partial Structure)

Phenylpropane monomers:
More potential value than simple combustion

R = CHO or CH₂OH
R = CH or OC
Aqueous Waste

- Fermentation requires large volumes of water
  - *E. coli* produces 135 g/L PDO
  - Water recycle challenging
- Numerous fermentation by-products
  - Feedstock composition variability
  - Organism pathways
    - Acetic acid and other organics
  - High biological oxygen demand
  - Salts
Gypsum

- Potential sources
  - Pretreatment
  - Product recovery

- Disposal options limited
  - Land farming
  - Landfilling
Conclusions

What can we learn from this analysis?

• Biorefineries are capital intensive
  ▪ Pretreatment
  ▪ Product recovery
• Coproducts provide economic synergies
• Technical challenges remain for waste issues
  ▪ Lignin
  ▪ Waste water
  ▪ Gypsum
Thank you for your attention

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