Ethanol Production in US

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October 17, 2007
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Presentation Outline

- Ethanol Production Process (Video)
- Ethanol Industry
  - Ethanol Production Capacity
  - Growth in Industry
- Issues Facing Ethanol Industry
- Emerging Dry Grind Ethanol Processes
- Future of Ethanol Industry
  - Cellulosic Ethanol
Ethanol Production Video
Ethanol Production in US

2004: 3.4 billion gallons   2006: 5.6 billion gallons   2008: 8.9 billion gallons
U.S. Dry Grind Corn Facilities

Plants in Production (115)

Plants Under Construction (79)

Source: Renewable Fuels Association
4.3.07
Benefits of Ethanol

- Reduces dependence on foreign oil imports
- Extend the domestic supplies of gasoline
- Environment friendly, reduces green house gases
- Increase octane rating of gasoline
- Clean burning fuel
- Increases demand for corn, stabilizes prices
- Rural Development
Issues Related To Ethanol Industry

- Water Used
  - Approximately 4 gallon water/gallon of ethanol produced
- Emissions/Odor
- Food versus Fuel
  - Corn is also used for human consumption
- Low Coproduct Value
- Energy Independence
  - Ethanol from corn is limited by corn production
  - Converting all the corn in the US into ethanol will only meet 20 to 25% of the annual gasoline demand
Corn Dry Grind Ethanol Process

One bushel of Corn (24.5 kg or 56 lb)

Corn Dry Grind Facility

2.7 gal (10.2 L) of Ethanol

15 lb (6.8 kg) of DDGS

Ruminant Food
Conventional Dry Grind Process

Corn

Grinding (Hammermill)

Water

Alpha-Amylase

Mash

Liquefaction

Saccharification & Fermentation

Yeast & Glucoamylase

CO₂

Dehydration column

Overhead product (Recycled back)

Ethanol

Centrifuge

Thin Stillage

Wet Grains

Syrup

Evaporator

DDGS
DDGS Utilization (2005)

Source: Steve Markham, Commodity Specialists Company
Coproduct values

Emerging Technologies in Dry Grind Ethanol Production:
Corn Fractionation Process
Wet Corn Fractionation:
Enzymatic Dry Grind Corn Process (E-Mill)

Bushel of Corn
(24.5 kg or 56 lb)

Density Separation

3.3 lb
(1.49 kg)
Germ

Density Separation

4 lb
(1.81 kg)
Pericarp Fiber

Size Separation

4 lb
(1.81 kg)
Endosperum Fiber

Corn Dry Grind Facility

2.6 gal
(9.84 L)
Ethanol

3.7 lb
(1.68 kg)
Residual DDGS

Ruminant Food

4 lb
(1.81 kg)
Nonruminant Food

Nonruminant Food
Other Benefits of Fractionation Process: Recovery of Valuable Coproducts

- Recovery of germ, pericarp and endosperm fiber as valuable coproducts
  - Germ
    - Corn Germ Oil
  - Pericarp and Endosperm Fiber
    - Corn Fiber Oil
    - Corn Fiber Gum
    - Ethanol
Fermentation Profiles: Conventional and E-Mill Processes

DDGS Composition: Conventional and E-Mill Processes

<table>
<thead>
<tr>
<th></th>
<th>Conv.</th>
<th>E-Mill</th>
<th>Soy Meal</th>
<th>CGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Prot. (%)</td>
<td>28.50</td>
<td>58.50</td>
<td>53.90</td>
<td>66.70</td>
</tr>
<tr>
<td>Crude Fat (%)</td>
<td>12.70</td>
<td>4.53</td>
<td>1.11</td>
<td>2.77</td>
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<tr>
<td>Ash (%)</td>
<td>3.61</td>
<td>3.24</td>
<td>----</td>
<td>----</td>
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<tr>
<td>Acid Det. Fiber (%)</td>
<td>10.8</td>
<td>2.03</td>
<td>5.95</td>
<td>6.88</td>
</tr>
</tbody>
</table>

Emerging Technologies in Dry Grind Ethanol Production:
Development of New Corn
Transgenic Corn for Dry Grind Process

Transgenic Corn

Grinding (Hammermill)

Water

Alpha-amylase

Mash

Blending

Liquefaction

Saccharification & Fermentation

Yeast & Glucoamylase

CO₂

Dehydration column

Overhead product (Recycled back)

Ethanol

Centrifuge

Wet Grains

Stillage

Thin Stillage

Syrup

Evaporator

DDGS
500 ml Fermentations
Control vs 3, 5 and 10% amylase corn addition

500 ml Fermentations
Control vs 1, 2 and 3% amylase corn addition

## DDGS Composition

<table>
<thead>
<tr>
<th>Components</th>
<th>3% amylase corn addition</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein (%)</td>
<td>26.1 ± 0.2</td>
<td>25.8 ± 0.1</td>
</tr>
<tr>
<td>Crude Fat (%)</td>
<td>14.1 ± 0.1</td>
<td>13.6 ± 0.2</td>
</tr>
<tr>
<td>Crude Fiber (%)</td>
<td>6.6 ± 0.1</td>
<td>6.8 ± 0.1</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>3.78 ± 0.1</td>
<td>3.35 ± 0.1</td>
</tr>
</tbody>
</table>

No significant difference in composition of DDGS for 3% amylase corn addition and control treatment

Feedstock Development: Transgenic Corn

- Reduces requirement of exogenous alpha amylase
- Only 3% amylase corn addition is required with dent corn for complete liquefaction
- No differences in DDGS composition between 3% amylase corn treatment and conventional treatment
Emerging Technologies in Dry Grind Ethanol Production: Raw Starch Hydrolyzing Enzymes
Raw Starch Hydrolyzing Enzymes

Corn

Grinding (Hammermill)

Water + RSH Enzyme

Blending

Mash

Alpha-Amylase

Liquefaction

Alpha-Amylase

Glucoamylase

Saccharification & Fermentation

Yeast & CO₂

Overhead product (Recycled back)

Ethanol

Dehydration column

Centrifuge

Thin Stillage

Evaporator

Overhead product (Recycled back)

Evaporator

Water

Corn

Grinding (Hammermill)

Blending

Mash

Liquefaction

Alpha-Amylase

Glucoamylase

Saccharification & Fermentation

Yeast & CO₂

Ethanol

Dehydration column

Centrifuge

Thin Stillage

Evaporator

Overhead product (Recycled back)

Evaporator

Water

DDGS

Syrup

Wet Grains
Granular Starch Hydrolyzing (GSH) Enzymes

- These enzymes have high granular starch (raw starch or native starch) hydrolyzing activity

- Can liquefy and saccharify starch into glucose at low temperature (< 48°C)
  - Stargen 001, Genencor International
  - BPX, Novozymes NA
Results: Glucose Concentration

Results: Maltotriose Concentration

Results: DP4+ Concentration

Granular Starch Hydrolyzing Enzymes

- Final ethanol yield with GSH enzymes is comparable to conventional enzymes
- Glucose, maltose and maltotriose concentrations are consistently low with GSH enzymes throughout fermentation
- GSH enzymes work at same temperature conditions as conventional SSF
  - With GSH enzymes simultaneous liquefaction, saccharification and fermentation can be conducted
Water Use in Dry Grind Ethanol Plant

Plant Feed → MM/GS Filters → Storage Tank → Reverse Osmosis → RO Product Tank → Process RO → Dry Grind Process → Process Out → Cooling Tower BD

Boiler Makeup → Boiler → Deaerator → RO Reject → Process Non RO → Cooling Tower → Plant Output

Steam → Boiler BD → Softner Regen
Regenerative Thermal Oxidizer
Food Versus Fuel

U.S. Corn Supply & Total Use, 88-89 to 07-08

Source: USDA, ERS; ProExporter Network
Note: 07-08 is based on ProExporter Network projections
Food Versus Fuel

Ethanol Use vs. All Other Corn Uses

Source: USDA, ERS; ProExporter Network
Note: 07-08 Demand Figures from ProExporter Network; growth is absolute, 98-99 to 07-08
Food Versus Fuel

2006/07 U.S. Corn Usage

- Ethanol: 17.2%
- HFCS: 4.1%
- Sweeteners: 1.9%
- Starch: 2.2%
- Alcohol: 1.1%
- Cereals: 1.5%
- Surplus: 7.9%
- Feed & Residual: 46.8%

Source: USDA, ERS; Feed Outlook, June 13, 2007
Note: Percentages based on Total Supply
Future: Ethanol from Lignocellulosic Feedstocks

- Wood chips
- Switchgrass / Miscanthus
- Sugarcane
- Paper
- Cottonwoods
- Corn stover
Thanks!