Innovative Technologies and Products for Dry Grind Ethanol Process

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Innovative Technologies and Products for Dry Grind Ethanol Process

- US Bioeconomy
- Drivers for Bioeconomy
- Role of Dry Grind Ethanol Process
  - Additional coproducts
- Optimized Technology
  - Reducing Substrate and Product Inhibition
- Low Operating Cost
US Bioeconomy

- Biobased markets are 2.2% of GDP or more than $353 billion in economic activity
- Revenue from industrial biotechnology reached $127 billion in 2013

Note: prices are average prices, price ranges for the different products based on publicly available data
Source: BCC Research, FO Licht, NOVA Institut, OECD-FAO Agricultural Outlook 2013, Deloitte Analysis

% = percentage of global fermentation market
World Corn Production, 2014-15

Dry Grind Ethanol Process

United States: 37%
China: 22%
USDA/FAS, January 2015
Sugar Platform Based Biochemicals

Adapted from Industrialization of Biology: A roadmap to Accelerate the Advanced Manufacturing of Chemicals
Corn Dry Grind Ethanol Process

One bushel of Corn (25.4 kg or 56 lb)

Corn Dry Grind Facility

2.7 gal (10.2 L) of Ethanol

0.7 lb (0.31 Kg) of Corn Oil

Poultry Food

15 lb (6.8 kg) of DDGS

Ruminant Food
Conventional Dry Grind Process

I. Coproducts
II. Enzymes
III. SSF
Proteins in Corn

- Water and salt soluble proteins
  - Physiologically active proteins
    - Albumins
    - Globulins
    - Better amino acid profiles

- Dilute acid and base soluble proteins
  - Storage Proteins
    - Prolamins
    - Glutelins
    - Poor amino acid profiles
Lipids in Corn

- Saponifiables (>99%)
  - Acyl Lipids
  - Triacylglycerols (TAG)

- Nonsaponifiables
  - Phytosterols
    - Free
    - Acyl esters
    - OH-cinnamate esters
  - Tocols
    - Tocopherols (Vitamin E)
    - Tocotrienols
  - Carotenoids

- Others (squalene, phospholipids, glycolipids)

Antioxidants

Nutraceuticals
Differential in Corn and DDGS Prices

www.ers.usda.gov/Data/feedgrains/
Corn Fractionation Technologies to Recover Additional Value Added Coproducts
(Front End Fractionation)
Wet Fractionation

- Soaking corn in water and separating coproducts in aqueous medium
- Uses wet grinding mills, hydrocyclones and screens for separation
Example of Wet Fractionation:
Enzymatic Dry Grind Corn Process (E-Mill)

Enzymatic Dry Grind Corn Process (E-Mill)

### DDGS Composition: Wet Fractionation (E-Mill Process)

<table>
<thead>
<tr>
<th></th>
<th>Conv.</th>
<th>E-Mill</th>
<th>SBM</th>
<th>CGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein (%)</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>
</tr>
<tr>
<td>Ash (%)</td>
<td>3.61</td>
<td>3.24</td>
<td>----</td>
<td>----</td>
</tr>
<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>

DDGS Fractionation
(Back End Fractionation)
DDGS Fractionation: Elusieve (ES) Process

Modified Dry Grind Process: Elusieve (ES) Process

## Sieving Results

<table>
<thead>
<tr>
<th>Size Category</th>
<th>Nominal Particle Size (Microns)</th>
<th>% (w/w) Retained on Screen</th>
<th>Protein %</th>
<th>Fat %</th>
<th>NDF %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Material</td>
<td>All</td>
<td>100</td>
<td>33.6</td>
<td>12.5</td>
<td>32.5</td>
</tr>
<tr>
<td>24T</td>
<td>&gt; 869</td>
<td>27</td>
<td>29.3</td>
<td>12.5</td>
<td>33.4</td>
</tr>
<tr>
<td>34T</td>
<td>582 to 869</td>
<td>19.4</td>
<td>26.9</td>
<td>11.3</td>
<td>37.8</td>
</tr>
<tr>
<td>35M</td>
<td>447 to 582</td>
<td>13.3</td>
<td>31.2</td>
<td>10.9</td>
<td>33.6</td>
</tr>
<tr>
<td>60M</td>
<td>234 to 447</td>
<td>20.1</td>
<td>37.5</td>
<td>11.3</td>
<td>29.3</td>
</tr>
<tr>
<td>Pan</td>
<td>&lt; 234</td>
<td>20.2</td>
<td>42.2</td>
<td>12.9</td>
<td>19.0</td>
</tr>
</tbody>
</table>

NDF—Neutral Detergent Fiber

### Elutriation Results

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>53.3</td>
<td>19.3</td>
<td>7.05</td>
</tr>
<tr>
<td>Bulk</td>
<td>33.4</td>
<td>29.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Heavier</td>
<td>32.6</td>
<td>35.6</td>
<td>14.2</td>
</tr>
</tbody>
</table>

*24T, Air Velocity = 3.35 m/s, Yield (Lighter) = 27.8%*

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>58.7</td>
<td>15.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Bulk</td>
<td>37.8</td>
<td>26.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Heavier</td>
<td>32.4</td>
<td>33.1</td>
<td>13.8</td>
</tr>
</tbody>
</table>

*34T, Air Velocity = 2.55 m/s, Yield (Lighter) = 33.4%*

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>56.0</td>
<td>16.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Bulk</td>
<td>33.6</td>
<td>31.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Heavier</td>
<td>27.6</td>
<td>35.4</td>
<td>13.1</td>
</tr>
</tbody>
</table>

*35M, Air Velocity = 1.84 m/s, Yield (Lighter) = 19.3%*

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DDGS Fractionation Process

- DDGS fractionation
  - Modified DDGS with high protein, high fat and low fiber content compared to conventional DDGS
  - Depending upon separation parameters DDGS can be produced with
    - Protein content, 42%
    - NDF, 19%
  - Cost of retrofitting a 45 Mil gallon/yr is less than $1.0 M
  - Payback period is less than 2 years

Thin Stillage/Syrup Fractionation
(Back End Fractionation)
Syrup Fractionation: Crude Oil Recovery

Conclusions – Corn Fractionation Technologies

- Corn Fractionation processes in a dry grind ethanol plant
  - Allow recovery of multiple coproducts
  - Increase ethanol production by approx. 8-27%
  - Increase the protein and reduce fiber content of DDGS
  - DDGS produced can be utilized for non ruminant animals
  - Less variation in DDGS composition
- Thin stillage/syrup fractionation recovers oil as additional coproduct and reduces oil content in DDGS
- DDGS fractionation process reduces fiber content and increases protein and fat content of DDGS
Reducing Substrate and Product Inhibition
Reducing Substrate Inhibition:
Optimal Control of SSF Processes
Conventional Controller Schematic

- Acid/Base Enzymes
- HPLC Measurements
- Coolant
- Outlet
- Recirculation Pump
Overall Control System Architecture

Control System Implementation at Plant

Optimal Controller: Plant Results

Optimal Controller: Plant Results

Glucose concentration < 2% w/v with Dynamic Controller

Reducing Product Inhibition: Fermentation and *Insitu* Ethanol Removal
Ethanol Inhibition to the Yeast

Ethanol inhibition to yeast decreases fermentation efficiency

- High solids fermentation
- CO₂
- Ethanol & Yeast
- Viable yeast
- Ethanol concentration
- Fermentation time
Vacuum Stripping to Remove Product Inhibition

Vacuum separation of ethanol reduces inhibition to yeast

Diagram showing a vessel with ethanol and yeast, and a vacuum system to remove ethanol.
Reducing Product Inhibition: Fermentation and *Insitu* Ethanol Removal

- Corn
- Water + GSH Enzyme
- Grinding
- Mash
- Blending
- CO₂
- Distillation
- Yeast
- Overhead product (Recycled back)
- Dehydration column
- Stripping/Rectifying column
- Thin Stillage
- Wet Grains
- Syrup
- DDGS
- Evaporator
- Ethanol
- Distillation
- Overhead product (Recycled back)
- Centrifuge
- DDGS
Removing Substrate and Product Inhibition

Simultaneous Liquefaction, Saccharification, Fermentation & Insitu Ethanol Removal


SLSFD Process


Conclusions - Reducing Substrate and Product Inhibition

- Raw starch hydrolyzing enzymes and optimal control of SSF process reduce substrate inhibition
- SLSFD process reduces product inhibition
  - Slurry solids as high as 40 to 45% can be used
  - Less water use in process
  - Distillers Wet Grains and negligible thin stillage generation
  - Higher ethanol productivity
Reducing Operating Cost of Dry Grind Ethanol Plant
Reducing Operating Cost in Dry Grind

- Corn with endogenous alpha-amylase (amylase corn)
  - No exogenous alpha-amylase requirement
  - Allows high solids (>32% slurry solids) processing
- Yeast producing glucoamylase
  - Greatly reduces or eliminates glucoamylase requirement
- Process design for Insitu ethanol removal
  - Allows high solids fermentation with no product inhibition
- Combination of amylase corn with yeast producing glucoamylase
- Combination of amylase corn with yeast producing glucoamylase and Insitu ethanol removal
Conventional Dry Grind Process

- Corn
- Water
- Grinding (Hammermill)
- Blending
- Liquefaction
- Alpha-Amylase
- Saccharification & Fermentation
- Yeast & Glucoamylase
- CO₂
- Dehydration column
- Overhead product (Recycled back)
- Ethanol
- Centrifuge
- Stripping/Rectifying column
- Thin Stillage
- DDGS
- Syrup
- Evaporator
- Wet Grains
- DDGS
Development of Amylase Corn
Amylase Corn for Dry Grind Process

Development of New Yeast Producing Glucoamylase
Combining Amylase Corn and Yeast Producing Glucoamylase
Amylase Corn and New Yeast Process

1. **Corn**
2. **Grinding (Hammermill)**
3. **Water**
4. **Alpha-Amylase**
5. **Mash**
6. **Liquefaction**
7. **Alpha-Glucosidase**
8. **Saccharification & Fermentation**
9. **CO2**
10. **Yeast & Glucose**
11. **Centrifuge**
12. **Dehydration column**
13. **Ethanol**
14. **Overhead product (Recycled back)**
15. **Thin Stillage**
16. **Syrup**
17. **Evaporator**
18. **DDGS**
19. **Wet Grains**
Combining Amylase Corn and Yeast Producing Glucoamylase with *Insitu* Ethanol Removal
Simultaneous Liquefaction, Saccharification, Fermentation & \textit{Insitu} Ethanol Removal

Amylase Corn and New Yeast Process with High Solids with Insitu Ethanol Removal

- Amylase Corn
- Water
- Grinding
- Mash
- Blending
- GA Producing
- Yeast
- Vacuum
- CO\textsubscript{2} + Ethanol
- DDGS
- Dryer
Conclusions

- New technologies will make grains to ethanol process more efficient
  - Biorefineries – multiple products
  - Better control of unit operations – more efficiency, higher productivity
  - Lower operating cost