Introduction

• Global energy needs/national security
  – Continue to escalate
    • Increasing demand for energy
      – Non-renewable fossil fuels

• Biofuels
  – Can help meet these increasing needs
  – Renewable from biomass
    • Leading biofuel is ethanol
      – Straw, stover, grasses, legumes, woods, other organic/biological residues & wastes
    • Corn grain is most heavily utilized substrate
Introduction

• Concern over resource inputs & outputs
  – Led to many Life Cycle Assessment studies
• Have become focal point
  – Public discussions
  – Policy analyses

• Each manufacturing facility
  – Must contribute to mission of sustainability
• Residues/coprodcts are essential

Does Ethanol Pay ???
Today’s Outline

1) Ethanol manufacturing – process & coproducts
2) Current trends
3) What are the industry’s needs?
4) Addressing these issues
5) Implications & future directions
Ethanol Manufacturing Process

Process flow diagram of a typical dry-grind corn-to-ethanol manufacturing process

Bioenergy-I: Tomar, Portugal

Dry Mill Coproducts
DS: Distillers Solubles
DDGS: Distillers Dried Grains with Solubles *
DWG: Distillers Wet Grains
DDG: Distillers Dried Grains
Ethanol Manufacturing

- Dry grind manufacturing

  - 3 main products
    - Primary: fuel ethanol
    - Secondary: CO$_2$ & non-fermentable components

  - Anecdotally
    - 1 kg corn = 1/3 kg ethanol + 1/3 kg CO$_2$ + 1/3 kg DDGS

  - Actuality: broad range of conversion rates
    - 1 kg corn = 0.388 L ethanol
    - 1 kg corn = 0.282 – 0.323 kg DDGS
    - 1 kg corn = 0.287 – 0.329 kg CO$_2$

  \[\text{Depends on each facility's operations}\]

Ethanol Manufacturing Residues

**General Process**

- Corn → Dry Mill → Ethanol, DDGS, CO₂

**Carbon Dioxide and Steam**

Nonfermentable residues – distillers solubles (DS).

Nonfermentable residues – distillers dried grains (DDG).

*Bioenergy-I: Tomar, Portugal*
Ethanol is a Key Player

- US fuel ethanol industry
  - Rapid growth in recent years
    - 2005: 87 plants, 4.2 billion gal/yr (15.9 billion L/yr)
    - 2006: 16 new plants, additional 1.1 billion gal/yr (4.2 billion L/yr)
    - US Energy Bill: 7.5 billion gal/yr (28.4 billion L/yr) by 2012

- As ethanol production capacity grows
  - So too does growth in manufacturing coproducts
    - Dry grind plants
      - Distillers Dried Grains with Solubles (DDGS)
Trends in Ethanol Production

- DDGS (million metric tons): 0.3, 0.9, 1.8, 3.0, 3.5, 7.3, 8.5, 10.0 (Projected)
- Ethanol (million gallons): 300%, 200%, 167%, 117%, 209%, 116%, 118%

Adapted from UMN, 2005
Coproduct Utilization

• Sales of coproducts
  – Substantial revenue source for ethanol processors
  – Vital to profitability

• As the industry continues to expand
  – How will marketplace handle increasing demand for corn?
  – How will marketplace handle increasing supply of DDGS?

<table>
<thead>
<tr>
<th>Value of DDGS ($/ton DDGS)</th>
<th>Value to Ethanol ($/L ethanol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>0.062</td>
</tr>
<tr>
<td>100</td>
<td>0.078</td>
</tr>
<tr>
<td>120</td>
<td>0.093</td>
</tr>
</tbody>
</table>
Coproduct Utilization

• Currently
  – Primary outlet for nonfermentable residues (coproducts)
    • **DDGS**
    • Others
      – DDG, WDG, WDGS, CDS, etc.
  • Livestock feeds
    – Dairy, beef, swine, poultry
    – Excellent feed ingredients
    – Numerous research studies (UMN, 2006)
    – Much work remains – maximize/optimize
DDGS Utilization

Adapted from UMN, 2005
DDGS Utilization

![DDGS Utilization Chart]

**Bioenergy-I: Tomar, Portugal**
Projected Coproduct Growth

When will market saturation occur?

DDGS-10% Growth
DDGS-15% Growth
DDGS-20% Growth

Bioenergy-I: Tomar, Portugal
Copropduct Utilization

• How much can be used as livestock feed?
  – Maximum level of utilization is a key question
    • Several estimates
      – Lower inclusion limits [100% market utilization]
        » ~ 13.7 million tons (Cooper, 2006)
      – Upper inclusion limits [100% market utilization]
        » ~ 40.3 million tons (Cooper, 2006)
        » ~ 60 million tons (Staff, 2005)

• Long-term sustainability of the industry
  – Two thrusts are key
    • Marketing to livestock producers
    • Need to pursue other value-added alternatives for DDGS
      – Diversified utilization portfolio

• Thus, to achieve these, we need to ask:
  – What are the industry’s current needs?
  – What other possibilities exist?
What are the Industry’s Needs?

• Focus group meeting
  – Held on June 2, 2005
  – At USDA-ARS research laboratory in Brookings, SD

• 50 participants
  – Government agency officials (local, state, federal)
  – SD Congressional delegation
  – Livestock producers
  – Ethanol industry
    • Processors
    • Marketers
    • Research & development
  – University research faculty
What are the Industry’s Needs?

• Purpose of the focus group
  – To determine current needs of
    • Companies that produce distillers grains
    • Customers that utilize distillers grains

• Identify
  – Current constraints
  – Future directions
Three Primary Objectives

1) Identification of major issues
   – That impact value of distillers grains
   – Current and future

2) Identification of specific research needs

3) Prioritization of these research needs
Major Issues Affecting DDGS Utilization

- Amino acid digestibility
- Availability and pricing of alternative feeds
- Correct nutrient values for specific species
- DDGS form – grain, pellet, cake, tub
- DDGS produced by old vs. new plants
- Design of equipment and facilities
- Distribution problems – distance from markets
- Educating livestock producers on the use of DDGS
- Effect on feed efficiency
- Effect on growth rate
- Energy consumption in plants (for drying DDGS)
- Environmental impacts – phosphorus, microbes, water content
- Evaluation of carcass effects
- Extracting oil – production of biodiesel
- Feed analysis tags
- Fiber content
- Flowability
- Food uses – cookies, breads, pastas
- Fractionation of nutrients – oil, fiber, protein
- Handling concerns – bulk density, pelleting, cubing
- Limiting inclusion rates due to nitrogen, phosphorus, sulfur in animal manure

Many participants
Many perspectives

Rosentrater & Giglio, 2005
Major Issues Affecting DDGS Utilization

- Maintaining quality during processing, handling, and storage
- Maximum inclusion rates
- Mycotoxin content potential
- Nutrient digestibility
- Nutrient energy evaluation versus traditional rations
- Nutrient/manure management plans
- Oil content
- Other options for DDGS use beyond livestock - crop fertilizer, foods, industrial
- Product consistency/variability – color, particle size, nutrient quantity and quality
- Rapid, non-destructive tests – (NIRS)
- Seasonality in DDGS nutrient content
- Species-specific livestock markets – beef, dairy, swine, poultry
- Standard analytical laboratory methods
- Storage and handling of wet products
- Target animals – need more research for poultry, swine, fish, petfoods
- Tech-transfer to producers and the public
- Transportation – flowability, costs, rail, truck, off-loading
- Use in non-ruminant rations
- Value-added products that can be made from DDGS
- Wet vs. dry DDGS
Research Needed to Address these Issues

- Cellulosic fermentation coproducts
- Densification
- Developing and augmenting species-specific markets – dairy, beef, swine, poultry
- Developing livestock feeds with higher value – designer feeds
- Educational activities for livestock producers – benefits of using distillers grains
- Environmental issues – manure and soil management
- Flowability
- Fractionating nutrients into concentrated streams – protein, fiber, oil
- Improving nutritional content, quality, and value – nutrient digestibility/availability
- Phosphorous levels
- Protein, oil, fiber contents
- Standard analytical laboratory methods – especially moisture determination
- Transportation issues – product form (pelleting)
- Utilizing next generation coproducts from new ethanol processes (dry-grind modifications)
- Utilization guidelines

Many of us are already addressing these issues
Top 10 Research Priorities

1) Augmenting use in species-specific livestock markets
2) Improving nutritional content, quality, and value
3) Optimizing and maximizing inclusion rates
4) Developing livestock feeds with higher value
5) Utilizing next generation coproducts from new ethanol processes
6) Standardizing analytical laboratory methods
7) Educational activities for livestock producers
8) Transportation issues
9) Fractionating nutrients into concentrated streams
10) Environmental issues
Addressing These Issues

• Very dynamic industry
  – Many research programs currently addressing these issues
    • Ethanol processors
    • Private enterprise
    • Commodity groups
    • Universities
    • Government agencies

• Briefly review our efforts
  – USDA – ARS, NCARL, Brookings, SD
  – Some of these research priorities
Addressing These Issues

- NCARL’s research objectives

  1) Identify, characterize, quantify, and improve flowability and storability behavior of DDGS
  2) Develop and improve conversion processes for value-added products from DDGS
     a) Animal feeds
     b) Food ingredients
     c) Industrial products
Flowability

- **Objective #1 – Storability & Flowability**
  - Significant constraint to long-distance transportation of DDGS
    - Inter-particle bridging & caking
      - Rail cars & storage structures do not unload (~5-10%)
    - Currently result in economic losses
      - Large railroads no longer ship DDGS with their cars
        » Rail car damage & repair
        » Marketers & ethanol plants must own cars
  - Goals
    - Identify, characterize, and determine the cause
      - Physical and chemical properties of DDGS
    - Develop methods to prevent or reduce occurrence
Flowability

Mass flow

Funnel flow

Bioenergy-I: Tomar, Portugal
Flowability
Objective (initial studies)
• Examine the effects of moisture content and soluble levels on the resulting physical and chemical properties of DDGS

Independent
• Soluble Content: 10, 15, 20, & 25% (db)
• Moisture Content: 10, 15, 20, 25, & 30 % (db)

Dependent
• Physical Properties
  • Carr indices – ASTM D6393
  • Bulk density: aerated and packed (g/cc)
  • Angle (Repose, Fall, Spatula) (°)
  • Compressibility (%)
  • Particle size distribution – Uniformity (-)
  • Dispersibility (%)
  • Color – Hunter L,a,b (-)

• Chemical Properties
  • Fat
  • Protein
Flowability

Results

<table>
<thead>
<tr>
<th>Property</th>
<th>MC (%db)</th>
<th>Soluble (%db)</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>*Flow Index (-)</td>
<td>10</td>
<td>79.50 a</td>
<td>0.50</td>
<td>78.33 a-c</td>
<td>0.83</td>
<td>80.00 a</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>77.67 a-d</td>
<td>1.20</td>
<td>75.17 d-f</td>
<td>0.44</td>
<td>78.00 a-d</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>77.33 a-d</td>
<td>1.45</td>
<td>76.33 b-f</td>
<td>1.17</td>
<td>78.83 ab</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>75.33 c-f</td>
<td>1.20</td>
<td>74.00 f</td>
<td>2.31</td>
<td>78.33 a-c</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>75.67 c-f</td>
<td>0.88</td>
<td>73.67 f</td>
<td>0.67</td>
<td>77.17 a-e</td>
</tr>
<tr>
<td>**Flood Index (-)</td>
<td>10</td>
<td>59.25 ab</td>
<td>0.00</td>
<td>56.25 a-e</td>
<td>0.25</td>
<td>58.67 ab</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>57.83 a-c</td>
<td>2.68</td>
<td>56.42 a-e</td>
<td>0.60</td>
<td>57.83 a-c</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>55.33 b-e</td>
<td>2.03</td>
<td>57.50 a-d</td>
<td>0.52</td>
<td>56.92 a-e</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>57.00 a-e</td>
<td>3.83</td>
<td>55.92 a-e</td>
<td>1.72</td>
<td>53.25 c-e</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>54.50 b-e</td>
<td>1.25</td>
<td>56.58 a-e</td>
<td>0.36</td>
<td>54.92 b-e</td>
</tr>
</tbody>
</table>

*Flowability
70-79: Fair
80-89: Good
90-100: Excellent

**Floodability
40-59: Inclined to flood
60-79: Floodable
80-100: Very floodable

- Fair-to-good flowability
  - Somewhat unstable (floodable) flow
  - Have not quite encapsulated cause of flowability issues in transportation

- Next steps
  - Consolidation with time + chemical reactions (cooling after drying)
  - Compression/compaction – Jenike shear cell
    - Effects of bulk storage
    - Vibration in transportation

Bioenergy-I: Tomar, Portugal

Ganesan et al., 2005
Animal Feeds

• Objective #2a – Value-Added Materials

  – Livestock nutrition research – ubiquitous (UMN, 2005)

  – Goal
    • Develop and optimize processes to
      – Convert DDGS into high-value feeds
        » Aquaculture feeds
        » Pet foods
        » Extrusion processing
Aquaculture Feeds

Historically: some DDGS research / little market utilization


Currently many opportunities
Aquaculture Feeds

**Objective** (initial studies)
- To study the effect of feed and processing parameters on the resulting physical properties of extruded feed

**Independent**
- Formulation: 3 isocaloric feeds (360 kcal/100gram) with 20, 30, 40% (db) DDGS
- Moisture content: 15, 20, 25% (db)
- Screw speed: 130, 160, 190 rpm

**Dependent**
- Material throughput (kg/hr)
- Bulk density (kg/m³)
- Durability (%)
- Porosity (%)
- Specific gravity (-)
- Color (-)

<table>
<thead>
<tr>
<th>Feed Ingredients</th>
<th>Weight of ingredients (g/96g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20% DDG</td>
</tr>
<tr>
<td>DDGS</td>
<td>20</td>
</tr>
<tr>
<td>Soy flour</td>
<td>32</td>
</tr>
<tr>
<td>Corn flour</td>
<td>35</td>
</tr>
<tr>
<td>Fish meal</td>
<td>6</td>
</tr>
<tr>
<td>Mineral mix</td>
<td>1</td>
</tr>
<tr>
<td>Vitamin mix</td>
<td>2</td>
</tr>
</tbody>
</table>
Results

Bioenergy-I: Tomar, Portugal

Chevanan et al., 2005a
Aquaculture Feeds

• Key results
  – DDGS is a very good source base material for aquaculture feeds
  – Bulk density: from 328 to 487 kg/m³ (mean=418 kg/m³)
  – Pellet durability: from 18 to 96% (mean=70%)
  – Specific gravity: from 0.82 to 1.05 (-) (mean=0.94)

• Major challenge
  – Material bonding – lack of starch

• Next stage
  – Whey protein
    • Commonly used as a feed binder and protein source
Aquaculture Feeds

Pellet durability

- Next steps
  - Process optimization
  - Feeding trials

Specific gravity

- vs. 0.70
- vs. 0.94

Chevanan et al., 2005b
Implications & Future Directions

• Achieving these specific project objectives
  – Will help address some current industry needs
    • New & refined methods for handling and storage
    • Value-added applications
      – Feed, food, industrial products
        » New market opportunities
  – Potential for benefits
    • Ethanol processors
    • Livestock producers
Implications & Future Directions

• Achieving not only these objectives
  – But also addressing current challenges & constraints

  – Will be key as DDGS evolves
  • Dynamic industry
    – “Next generation” products
      » Fractionation
      » Enzymes/fermentation technology
      » Novel process modifications
  • Impact coproduct generation & properties
    – Physical, chemical, functional properties
    – Alter utilization opportunities
Acknowledgments

• Many thanks to those who have contributed to the project thus far…

K. Boateng  
W. Bokhoven  
P. Brown  
N. Chevanan  
S. Colby  
T. Cooper  
R. Flores  
R. Fuller  
V. Ganesan  
R. Garcia  
K. Hicks  
M. Janes

J. Julson  
K. Kephart  
P. Krishnan  
D. McCalla  
K. Muthukumarapann  
A. Otieno  
M. Schlicher  
M. Stowers  
B. Tatara  
J. Visser  
P. Weimer  
G. Williams
References


Thank You

• Questions?

• Comments?