Evolution of New Processes and Products from Dry Grind Fuel Ethanol Processing

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OVERVIEW

1. Ethyl alcohol
2. Coproducts
3. Ongoing research
4. New opportunities
5. Concluding thoughts
# Ethyl Alcohol – The Fuel of the Future

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860</td>
<td>Nicholas Otto (b. 1832, d. 1891), a German inventor, used ethanol to fuel an internal combustion engine</td>
</tr>
<tr>
<td>1896</td>
<td>Henry Ford’s (b. 1863, d. 1947) first automobile, the quadricycle, used corn-based ethanol as fuel</td>
</tr>
<tr>
<td>1908</td>
<td>Hart-Parr Company (Charles City, IA) manufactured tractors that could use ethanol as a fuel</td>
</tr>
<tr>
<td>1918</td>
<td>World War I caused increased need for fuel, including ethanol; demand for ethanol reached nearly 60 million gal/year</td>
</tr>
<tr>
<td>1940</td>
<td>The U.S. Army constructed and operated a fuel ethanol plant in Omaha, NE</td>
</tr>
</tbody>
</table>

Ethanol was extensively used as a motor fuel additive prior to the end of World War II (ca. 1933)
Ethyl Alcohol – The Fuel of the Future

The first distillation column for the production of fuel ethanol was invented by Dennis and Dave Vander Griend at South Dakota State University in 1978/1979.
Many people have asked what the fuel ethanol industry is going to do about the growing piles of non-fermented leftovers.

- “Grain distillers have developed equipment and an attractive market for their recovered grains” (Boruff, 1947)
- “Distillers are recovering, drying, and marketing their destarched grain stillage as distillers dried grains and dried solubles” (Boruff, 1952)

This question has been around for quite some time, and it also appears that a viable solution had already been developed as far back as the 1940s.
DDGS Historically

• In the 1940s / 1950s
  – 17 lb (7.7 kg) of distillers feed was produced for every 1 bu (56 lb; 25.4 kg) of grain that was processed into ethanol
    • Similar to today
  – But over 700 gal (2650 L) of water was required to produce this feed (Boruff, 1947; Boruff, 1952; Boruff et al., 1943)
    • vs. < 4 gal. of water today
GRAIN ALCOHOL DISTILLERY (ca. 1947)
MODERN DRY GRIND PROCESS
U.S. ETHANOL GROWTH

Feb. 2011: 204 plants, 13,771 Mg/y
RFS: 15,000 Mg/y of biofuel by 2015

Growth of U.S. fuel ethanol industry
U.S. ETHANOL GROWTH

US EIA, 2011
Since 1950s, generally 5 to 9% of total U.S. energy supply has been renewable

US EIA, 2011
COPRODUCTS
ETHANOL COPRODUCTS

- Distillers Dried Grains with Solubles
- Condensed Distillers Solubles
- Distillers Wet Grains
COPRODUCT PRICES

DDGS Price ($/t) vs Date
COPRODUCT PRICES

Date
Jan-11 Feb-11 Apr-11 Jun-11 Jul-11 Sep-11 Nov-11

DDGS Price Relative to (%)
0 10 20 30 40 50 60 70 80 90 100

Corn
SBM
COPRODUCT VALUES

[Graph showing price/unit protein for SBM, DDGS, and Corn from Jan-11 to Nov-11]
COPRODUCT VALUES
As ethanol industry grows, supply of coproducts will grow

Balance = key to sustainability
ONGOING RESEARCH
ongoing research

- Fuel
  - vs.
- Food
  - vs.
- Feed
  - vs.
- Plastics
  - vs.
- Chemicals
  - vs.
- Other uses

**Goals:**
- Augment current uses
- Develop new market opportunities
- Develop/optimize processes and products
- Improve sustainability

**Context:**
- Application of physics and chemistry to biological systems
- Manufacturing with biological polymers: proteins, fibers, lipids
ONGOING RESEARCH

• Material handling
• Pelleting/densification
• Aquaculture
• Human foods
• Plastic composites
MATERIAL HANDLING
### MATERIAL HANDLING

<table>
<thead>
<tr>
<th>Sieve Opening Size (mm)</th>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
<th>Image 4</th>
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<td>2.38</td>
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<td><img src="image3" alt="Image 3" /></td>
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<td>1.68</td>
<td>Scale bar = 3.91 mm</td>
<td>Scale bar = 2.50 mm</td>
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<td>1.19</td>
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<td>0.841</td>
<td>Scale bar = 0.689 mm</td>
<td>Scale bar = 0.52 mm</td>
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<td>0.595</td>
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<td>Scale bar = 0.52 mm</td>
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### Material Handling

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<th>Carbohydrate</th>
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<td>2.28</td>
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<td>1.68</td>
<td></td>
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<tr>
<td>1.19</td>
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<tr>
<td>0.841</td>
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<table>
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<th>Particle Diameter (mm)</th>
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</tr>
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</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
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<table>
<thead>
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<th>Plant</th>
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<tr>
<td>2</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
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<tr>
<td>3</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
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<tr>
<td>4</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
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<tr>
<td>5</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
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</tbody>
</table>
MATERIAL HANDLING

\[ z = a + bx + cy \]
\[ x = \text{AoR (°)} \]
\[ y = \text{HR (-)} \]
\[ z = \text{MFR (g/min)} \]

\[ R^2 = 0.99 \]
\[ \text{Error} = 2.42 \]

- MFR < 100 = Poor Flow
- 100 < MFR < 120 = Fair Flow
- MFR > 120 = Good Flow
\[ z = a + \frac{b}{x} + cy \]

\[ x = \text{AoR (°)} \]
\[ y = \text{HR (-)} \]
\[ z = \text{Moisture content (%, db)} \]

\[ R^2 = 0.71 \]
\[ \text{Error} = 4.50 \]

Moisture content

- Moisture < 9.9 (Good Flow)
- 9.9 < Moisture < 17.5 (Fair Flow)
- 17.5 > Moisture (Poor Flow)
PELLETING/DENSIFICATION
# PELLETING/DENSIFICATION

<table>
<thead>
<tr>
<th>Mag.</th>
<th>DDGS</th>
<th>Mfg</th>
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</thead>
<tbody>
<tr>
<td>x</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>10</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>60</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>200</td>
<td>![Image]</td>
<td>![Image]</td>
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</tbody>
</table>
PELLETING/DENSIFICATION

Resulting slack costs and costs of pelleting for each rail car due to differing DDGS sales prices and annualized pelleting cost
a) breakeven occurs at points of intersection

- $50/ton DDGS Sales Price, s
- $100/ton DDGS Sales Price, s
- $150/ton DDGS Sales Price, s
- $200/ton DDGS Sales Price, s
- 15 $/ton pelleting cost, Cop
- 10 $/ton pelleting cost, Cop
- 5 $/ton pelleting cost, Cop
PELLETING/DENSIFICATION

Resulting slack costs and costs of pelleting for each rail car due to differing DDGS sales prices and annualized pelleting cost
b) magnification of the intersections clearly shows the proportion of DDGS which needs to be pelleted to achieve breakeven
Percent of DDGS pelleted, $p\ (%)$, required to achieve breakeven increases as both DDGS Sales Price, $s\ ($/ton), and Pelleting Cost, $Cop\ ($/ton), increase.
AQUACULTURE

Nile tilapia

Yellow Perch

Rainbow Trout
AQUACULTURE

- DDGS ~ 1/10 to 1/20 the price of fish meal

![Diagram showing the relative feed cost for Tilapia, Perch, and Trout with fish meal and DDGS prices.](chart.png)
• Diabetic and Celiac patients
  – High protein, high fiber, low starch
HUMAN FOODS

• Flat breads
  – Chipathí
    • Southern Asia
    • Similar to tortilla
  – Naan
    • Northern India and near East
    • Tandoori clay ovens ~ 650-780 °F
  – Barbari
    • Persian
    • Brick-lined ovens ~ 480 °F
### Phenolic resin & DDGS

<table>
<thead>
<tr>
<th>DDGS (%)</th>
<th>Biodegradability (mass % degraded)</th>
<th>Durometer Hardness (Shore D)</th>
<th>Density g/cm³ (lb_m/ft³)</th>
<th>Water Absorption (mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0 ± 0%</td>
<td>93 ± 2%</td>
<td>1.20 (75.2) ± 52%</td>
<td>0.1 ± 0%</td>
</tr>
<tr>
<td>25</td>
<td>8.6 ± 12%</td>
<td>82 ± 2%</td>
<td>1.24 (77.5) ± 15%</td>
<td>1.6 ± 1%</td>
</tr>
<tr>
<td>50</td>
<td>24.4 ± 10%</td>
<td>72 ± 3%</td>
<td>1.23 (77.0) ± 35%</td>
<td>5.0 ± 2%</td>
</tr>
<tr>
<td>75</td>
<td>38.4 ± 6%</td>
<td>68 ± 3%</td>
<td>1.22 (76.4) ± 41%</td>
<td>6.2 ± 3%</td>
</tr>
</tbody>
</table>

**Notes:**
- Young's modulus: DDGS (present study)
- Elongation: DDGS (present study)
- Tensile strength: DDGS (present study)
- Tensile strength: mixed lignin (Kharade and Kale 1988)
- Tensile strength: sugar cane pulp (Lele et al., 2004)

**Diagram:**
- Ratio of property value with biofiller to property value at 0% biofiller
- Bio filler concentration by weight, %

**Figure:**
- Mechanical property and study chart
- Graph showing properties at different biofiller concentrations.
Polylactic acid (PLA) & DDGS

<table>
<thead>
<tr>
<th>Property</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile stress (UTS)</td>
<td>8894</td>
<td>6481</td>
<td>4097</td>
<td>3385</td>
<td>3290</td>
</tr>
<tr>
<td>(psi (MPa))</td>
<td>(61.3)</td>
<td>(44.7)</td>
<td>(28.2)</td>
<td>(23.3)</td>
<td>(22.7)</td>
</tr>
<tr>
<td>Break stress</td>
<td>8754</td>
<td>6436</td>
<td>3448</td>
<td>3051</td>
<td>2887</td>
</tr>
<tr>
<td>(psi (MPa))</td>
<td>(60.4)</td>
<td>(44.4)</td>
<td>(23.8)</td>
<td>(21.0)</td>
<td>(19.9)</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>270,690</td>
<td>304,130</td>
<td>278,160</td>
<td>251,830</td>
<td>305,140</td>
</tr>
<tr>
<td>(psi (MPa))</td>
<td>(1866)</td>
<td>(2097)</td>
<td>(1918)</td>
<td>(1736)</td>
<td>(2104)</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>342,732</td>
<td>326,891</td>
<td>338,135</td>
<td>338,071</td>
<td>300,872</td>
</tr>
<tr>
<td>(psi (MPa))</td>
<td>(2363)</td>
<td>(2254)</td>
<td>(2331)</td>
<td>(2331)</td>
<td>(2074)</td>
</tr>
<tr>
<td>Elongation to UTS, %</td>
<td>5.1</td>
<td>3.3</td>
<td>2.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Elongation to break, %</td>
<td>5.4</td>
<td>3.4</td>
<td>2.8</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Hardness – Shore D</td>
<td>79</td>
<td>77</td>
<td>77</td>
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</table>
PLASTIC COMPOSITES
NEW OPPORTUNITIES
NEW OPPORTUNITIES

- Evolving processes
- Fractionation
- Biorefining / bioprocessing
- Anaerobic digestion
- Integrated systems
EVOLVING PROCESSES

• Wet vs. dry coproducts
  – DDGS vs. DWGS

• Oil extraction from stillage (40-60 cents/lb)
  – ~ 10% down to 8-9% fat
  – Every 1% fat reduction = $3-$6 /ton finisher diet increase
  – Jan. 2012: 47% of plants extracting oil
Evolving Processes
EVOLVING PROCESSES
## LOW FAT DDGS

### Properties of low fat DDGS

<table>
<thead>
<tr>
<th></th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>8.0</td>
<td>8.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>26.0</td>
<td>29.9</td>
<td>29.0</td>
</tr>
<tr>
<td>Fiber (%)</td>
<td>15.0</td>
<td>7.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>5.5</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>543 – 571</td>
<td>466 – 470</td>
<td>440 – 446</td>
</tr>
<tr>
<td>Packed Bulk Density (kg/m³)</td>
<td>623 – 650</td>
<td>525 – 543</td>
<td>476 – 499</td>
</tr>
<tr>
<td>AoR</td>
<td>40.5 – 45.5</td>
<td>39.5 – 43.5</td>
<td>40.0 – 43.0</td>
</tr>
</tbody>
</table>
LOW FAT DDGS

8% Fat

8% Fat
LOW FAT DDGS

- Removal of corn oil does not change flow properties of DDGS

- Biggest obstacles
  - Variability / consistency
  - Syrup addition
  - Drying conditions
Coproducts

Component Fractionation

High-value components
Mid-value components
Low-value components
## HIGH-PROTEIN DDGS

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Type of Fractionation</th>
<th>Crude Protein</th>
<th>Crude Fat</th>
<th>Crude Fiber</th>
<th>ADF</th>
<th>NDF</th>
<th>Ash</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poet</td>
<td>Dakota Gold BPX DDGS</td>
<td>No fractionation</td>
<td>28.2</td>
<td>10.8</td>
<td>7.1</td>
<td>10.0</td>
<td>26.1</td>
<td>4.8</td>
<td>Dakota Gold, 2009a</td>
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<tr>
<td></td>
<td>Dakota Bran</td>
<td>Pre-fermentation</td>
<td>14.0</td>
<td>8.9</td>
<td>7.0</td>
<td>8.0</td>
<td>38.1</td>
<td>5.5</td>
<td>Dakota Gold, 2009b</td>
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<tr>
<td></td>
<td>Dakota Germ - Corn Germ Dehydrated</td>
<td>Pre-fermentation</td>
<td>15.8</td>
<td>17.1</td>
<td>6.2</td>
<td>8.2</td>
<td>23.4</td>
<td>5.9</td>
<td>Dakota Gold, 2009c</td>
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<td>Dakota Gold HP DDG</td>
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<td>41.0</td>
<td>4.0</td>
<td>8.1</td>
<td>13.0</td>
<td>24.0</td>
<td>2.1</td>
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<tr>
<td>FWS Technologies</td>
<td>Enhanced DDGS</td>
<td>Pre-fermentation</td>
<td>35.0-37.0</td>
<td>6.5</td>
<td></td>
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<td>21.0</td>
<td>3.8</td>
<td>FWS, 2009</td>
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<td>Renessen</td>
<td>Enhanced DDG(S)</td>
<td>Pre- / post-fermentation</td>
<td>35.0-50.0</td>
<td>2.5-4.0</td>
<td>7.0-11.0</td>
<td>15.0-25.0</td>
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<tr>
<td>Solaris</td>
<td>Energia</td>
<td>Pre- / post-fermentation</td>
<td>30.0</td>
<td>2.5</td>
<td>8.2</td>
<td></td>
<td></td>
<td></td>
<td>Lohrmann, 2006</td>
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<tr>
<td></td>
<td>Glutenol</td>
<td>Post-fermentation</td>
<td>45.0</td>
<td>3.3</td>
<td>3.8</td>
<td>9.23</td>
<td>15.3</td>
<td>4.0</td>
<td>Lohrmann, 2006</td>
</tr>
<tr>
<td></td>
<td>Neutra-Fiber</td>
<td>Pre-fermentation</td>
<td>6.8</td>
<td>1.5</td>
<td>17.1</td>
<td></td>
<td></td>
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<td>Lohrmann, 2006</td>
</tr>
<tr>
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<td>NeutraGerm</td>
<td>Pre-fermentation</td>
<td>17.5</td>
<td>45.0</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
<td>Lohrmann, 2006</td>
</tr>
<tr>
<td></td>
<td>ProBran</td>
<td>Pre- / post-fermentation</td>
<td>9.5</td>
<td>2.0</td>
<td>16.6</td>
<td></td>
<td></td>
<td></td>
<td>Lohrmann, 2006</td>
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</table>
FRACTIONATION

a) Original DDGS; b) big DDGS; c) pan DDGS

<table>
<thead>
<tr>
<th>Property</th>
<th>Big</th>
<th>Mean</th>
<th>St Dev</th>
<th>Original</th>
<th>Mean</th>
<th>St Dev</th>
<th>Pan</th>
<th>Mean</th>
<th>St Dev</th>
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<tbody>
<tr>
<td>Protein</td>
<td>31.85 a</td>
<td>1.06</td>
<td></td>
<td>33.00 a</td>
<td>0.99</td>
<td></td>
<td>37.25 b</td>
<td>0.21</td>
<td></td>
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<tr>
<td>Lipid</td>
<td>8.65 a</td>
<td>0.07</td>
<td></td>
<td>7.95 b</td>
<td>0.07</td>
<td></td>
<td>7.00 c</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>4.70 a</td>
<td>0.01</td>
<td></td>
<td>4.70 a</td>
<td>0.01</td>
<td></td>
<td>5.00 b</td>
<td>0.01</td>
<td></td>
</tr>
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<td>Carbohydrate</td>
<td>54.80 a</td>
<td>1.13</td>
<td></td>
<td>54.35 a</td>
<td>0.92</td>
<td></td>
<td>50.75 b</td>
<td>0.21</td>
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<tr>
<td>ADF</td>
<td>11.60 a</td>
<td>0.71</td>
<td></td>
<td>12.40 b</td>
<td>0.57</td>
<td></td>
<td>11.45 a</td>
<td>0.07</td>
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<tr>
<td>NDF</td>
<td>34.55 a</td>
<td>0.49</td>
<td></td>
<td>37.80 b</td>
<td>0.14</td>
<td></td>
<td>29.15 c</td>
<td>0.21</td>
<td></td>
</tr>
</tbody>
</table>
FRACTIONATION

DDGS fiber

Protein: 21%
Lipid: 1.7%
Fiber: 52%
Ash: 4.0%
FRACTIONATION

CDS

Thin Stillage
BIOREFINING

Gas (psi)

In vitro true DM digestibility (TDMD)

15
17
19
21
23
25
27
DDGS
Blank

15
17
19
21
23
25
27
DDGS
Blank

In vitro true DM digestibility (TDMD)
BIOREFINING
Cumulative biogas and average methane

Potential methane production

ANAEROBIC DIGESTION
INTEGRATED SYSTEMS
INTEGRATED SYSTEMS
CONCLUDING THOUGHTS

- Coproducts key to economic viability of renewable fuels
- Many opportunities to increase value and utility
- Several keys to sustainability
THANK YOU

– Questions?

– Comments?

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