A Mass-Balance Based Engineering Economic Spreadsheet Model for Evaluating Pre- and Post-Fractionation Processes for Dry Grind

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Corn composition

Source: S. Watson and P. Ramstad, 1987
Corn Composition Distribution

Endosperm

Germ

Pericarp + Tipcap

Source: S. Watson and P. Ramstad, 1987
Prefractionation

- Removal of some of the corn constituents before fermentation.

Post Fractionation

- Removal of some of the corn constituents after fermentation
Prefractionation

• Approximately 28% of the corn kernel dry solids are nonfermentable......the germ, coarse fiber (pericarp), cellular fiber and protein.

• Both wet and dry fractionation recovers the germ and coarse fiber. The e-milling process for ethanol also recovers the cellular fiber (not shown here).
Post Fractionation

• Does not affect upstream operation.
• Coproducts not of food grade quality.
• Low investment cost.
• Loses all advantages of removal to fermentation.
Advantages of Prefractionation

- Can be accomplished using dry milling or wet milling equipment.
- Removes the nonfermentables so at the same solids level the sugar concentration is higher. More alcohol per turn of fermenter.
- Fiber inhibits or blocks enzyme activity.
- Fiber also increases viscosity of slurry.
- More and higher valued coproducts.
Dry Fractionation

- Uses dry milling equipment
- Only system in commercial operation.
- Loses more starch in coproducts (4% minimum vs 2% maximum loss in wet fractionation)
- Lower (?) capital cost
- Doesn’t change water flow in plant
Dry Fractionation

- Subject to “stuck” fermentations due to soluble nutrients left in germ.
- Not practical to extract oil from germ. Oil 20%-25% of germ recovered.
- Goal is different from conventional dry milling in that the purity of the coproducts is more important then the purity of the endosperm pieces.
MODIFIED DRY GRIND – DRY MILLING

- Water Spray
- Tempering Tank
- Tempering Sugar
- Tails
- Dryer
- Vibratory Screen
- 3 1/2 M
- Roller Mill
- Sifter
- 10 M
- Sifter
- Dried Germ
- Aspirator
- Hammer Mill
- Roller Mill
- 3 1/2 M
- 10 M
- 15 M
- 60 M
- Degerminator
- Roll
- Milling
- 10 M
- 15 M
- 60 M
- Fiber
- Multiple Effect Evaporator
- Condensate Out
- Water Out
- Cooling Water In
- Water In
- Water Out
- Dehydration Column
- Ethanol
- Recycle Water
- DDG
- DDGS
- Yeast and Enzymes
- Fermenter
- Yeast
- Enzymes
- Jet Cooker
- CO2
- Conveyer Mixer
- Rotary Dryer
Wet Fractionation (QQ)

- Uses wet milling equipment
- More precise separation of components
- During soaking the germ solubles are leached into the water. This water is put into fermenter and prevents stuck fermentations.
- Oil is concentrated to 40-45%. Profitable to extract or expel the oil.
Existing Models

• Economic models for dry grind ethanol:
  - Purdue University, Dale and Tyner (2006)
    Thermodynamic Excel spreadsheet
  - ERRC-USDA, Kwiatkowski et al. (2006)
    SuperPro
  - University of Minnesota, Tiffany (2005), Excel spreadsheet.
Why another model?

- Purdue model is mass balanced only for sugar and starch. Coproducts are selected values for yield.
- Tiffany’s model is not mass balanced.
- USDA Superpro model is mass balanced but not user friendly.
- None of the models are set up to evaluate modified dry grind processes with prefractionation.
<table>
<thead>
<tr>
<th>Model</th>
<th>Mass Balanced</th>
<th>Easy to Use</th>
<th>Handles Modified DDGS</th>
<th>Compositionally Driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purdue</td>
<td>Partially</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>USDA</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Tiffany</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Illinois</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Unique Characteristics of Model

• The value of modified DDGS is estimated from a regression equation based on 5 years of historical data.

• To account for variations in the protein and fiber (NDF; neutral detergent fiber), the modified DDGS equation was created using six animal feed coproducts.
Six products used to develop DDGS price model

<table>
<thead>
<tr>
<th>Products</th>
<th>% Protein</th>
<th>% NDF</th>
<th>% Dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDGS</td>
<td>28.7</td>
<td>44.0</td>
<td>90</td>
</tr>
<tr>
<td>Corn gluten feed</td>
<td>21.0</td>
<td>45.0</td>
<td>90</td>
</tr>
<tr>
<td>Corn gluten meal&lt;sup&gt;2&lt;/sup&gt;</td>
<td>60.0</td>
<td>12.6</td>
<td>90</td>
</tr>
<tr>
<td>Hominy Feed</td>
<td>10.0</td>
<td>49.5</td>
<td>90</td>
</tr>
<tr>
<td>Soybean meal&lt;sup&gt;1&lt;/sup&gt;</td>
<td>48.0</td>
<td>7.1</td>
<td>89</td>
</tr>
<tr>
<td>Cotton seed meal&lt;sup&gt;1&lt;/sup&gt;</td>
<td>41.5</td>
<td>23.9</td>
<td>92</td>
</tr>
</tbody>
</table>

1. Price discounted 15% based on different nutritional quality of protein.
2. Price discounted 33% based on inflated value of caratenoids.
\[ D = -23.495 + 217.01P + 51.456C - 53.865CN \]

Where:
- \( D \) = DDGS price (\$/ton)
- \( P \) = Protein content (decimal fraction)
- \( C \) = Corn price (\$/bushel)
- \( N \) = NDF content (decimal fraction)
Market Price and Model Projected Price of Regular DDGS at Constant Composition
DDGS Composition Comparison

![Bar Chart]

- **Protein**: Conventional (30.00%), Dry Fractionation (45.00%), Wet Fractionation (45.00%)
- **NDF**: Conventional (30.00%), Dry Fractionation (25.00%), Wet Fractionation (15.00%)
- **Oil**: Conventional (10.00%), Dry Fractionation (5.00%), Wet Fractionation (1.00%)
- **Sugar**: Conventional (15.00%), Dry Fractionation (15.00%), Wet Fractionation (20.00%)
## Processing Information Comparison:
Corn: 4 $/bushel; Ethanol: 1.6 $/gallon

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Dry fractionation</th>
<th>Wet fractionation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-end</td>
<td></td>
<td>14.80%</td>
<td>15.50%</td>
</tr>
<tr>
<td>Plant Capacity (Bushels/Day)</td>
<td>36,749</td>
<td>42,188</td>
<td>42,463</td>
</tr>
<tr>
<td>Ethanol Yield Effic.</td>
<td>2.78</td>
<td>2.60</td>
<td>2.72</td>
</tr>
<tr>
<td>Ethanol Yield</td>
<td>37,532,311</td>
<td>40,343,686</td>
<td>42,431,253</td>
</tr>
<tr>
<td>Ethanol Concentration</td>
<td>13.83%</td>
<td>14.48%</td>
<td>15.92%</td>
</tr>
<tr>
<td>DDGS Price ($/ton)</td>
<td>128.5</td>
<td>146.5</td>
<td>174.7</td>
</tr>
</tbody>
</table>
Energy Consumption Comparison

The diagram compares the energy consumption of various methods for natural gas and electricity. The methods compared are Conventional, Dry Fractionation, and Wet Fractionation.

For natural gas, Conventional consumption is significantly higher than the other methods. Dry Fractionation and Wet Fractionation have similar lower consumption levels.

For electricity, the consumption is lower than for natural gas, with the same methods and their respective consumption levels.
Economic Comparisons
Corn: 4; Ethanol: 1.6; Electricity: 0.078/KWh; NG: 4/mmbtu
Economic Comparisons
Corn: 4; Ethanol: 1.6; Electricity: 0.078/KWh; NG: 4/mmbtu
Sensitivity Analysis
Plant capacity: 38 MGY

Ethanol Price used in block of 6

<table>
<thead>
<tr>
<th>Ethanol Price</th>
<th>Increased Revenue ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.25</td>
<td></td>
</tr>
<tr>
<td>$1.75</td>
<td></td>
</tr>
<tr>
<td>$2.25</td>
<td></td>
</tr>
<tr>
<td>$2.75</td>
<td></td>
</tr>
<tr>
<td>$3.25</td>
<td></td>
</tr>
<tr>
<td>$3.75</td>
<td></td>
</tr>
</tbody>
</table>

Dry Fractionation
Wet Fractionation

Corn Price

$2 $4 $6 $8 $2 $4 $6 $8 $2 $4 $6 $8 $2 $4 $6 $8
## Effect of Corn Oil Price on Profit

<table>
<thead>
<tr>
<th>Corn Oil Price</th>
<th>Conventional Dry Grind</th>
<th>Wet Frac</th>
<th>Dry Frac</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.38</td>
<td>$5.3 Million</td>
<td>$11.2 Million</td>
<td>$6.3 Million</td>
</tr>
<tr>
<td>$0.45</td>
<td>$5.3 Million</td>
<td>$12.6 Million</td>
<td>$7.5 Million</td>
</tr>
<tr>
<td>$0.55</td>
<td>$5.3 Million</td>
<td>$14.8 Million</td>
<td>$9.2 Million</td>
</tr>
<tr>
<td>$0.75</td>
<td>$5.3 Million</td>
<td>$19.3 Million</td>
<td>$12.5 Million</td>
</tr>
</tbody>
</table>
References

Dale, R. T., and W. E. Tyner. 2006. *Economic and technical analysis of ethanol dry milling: Model description*. Purdue University, College of Agriculture, Department of Agricultural Economics.


Gratefully acknowledge the support of this research by the Illinois Council of Food and Agricultural Research (C-FAR) and the Illinois Agricultural Research Station.

Also, I would like to thank my collaborators:

Dr. Luis Rodriguez, University of Illinois
Dr. Mahdu Khanna, University of Illinois
Dr. Aslihan Spaulding, Illinois State University
Mr. Tao Lin, University of Illinois
Mr. Tim Schmidgall, Illinois State University

Thank You!