Ethanol Production in Oklahoma

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Scope of our study

• To determine if the production of ethanol would be a worthwhile investment in the state of Oklahoma.
  – If so, determine the NPW, crops used, and plant location(s).
  – If not, determine why it is not feasible.
Outline

• Introduction
  – Why Ethanol?
  – Market Analysis
• Feedstock
  – Selection Criteria
  – Crop Availability
• Possible Technologies
  – Fermentation
  – Dilute Acid Hydrolysis
  – Gasification

• Results
  – Why is a model needed?
  – Model Variables
  – Sensitivity Analysis
  – Conclusions and Recommendations
Why do we need Ethanol?

- Causes gas to burn more efficiently.

Comparisons of Oxygenated and Non-Oxygenated Gasoline
Why do we need Ethanol?

• Used as an additive in gasoline.

Gasoline Composition Currently

- Total AHC 30%
- Total SHC 37%
- Total USHC 7%
- MTBE 11%
- m/p Xylene 5.2%
- o-xylene 2%
- Ethylbenzene 0.3%
- Benzene 0.5%
- Toluene 7%
Problems with MTBE

• Contaminates groundwater.

Blue = MTBE Flow in Groundwater
Red = Ethanol Flow in Groundwater
Legislation

• Several states have passed or enacted MTBE phase-outs (MN, IA, NE, CA).

• Need subsidies to make ethanol production more competitive.
Current Production

- 68 Ethanol Plants
- Produced a total of 2.1 billion gallons in 2002
Projected Ethanol Demand

<table>
<thead>
<tr>
<th>Region</th>
<th>MGal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.8</td>
</tr>
<tr>
<td>B</td>
<td>9.4</td>
</tr>
<tr>
<td>C</td>
<td>74.2</td>
</tr>
<tr>
<td>D</td>
<td>3.9</td>
</tr>
<tr>
<td>E</td>
<td>106.2</td>
</tr>
<tr>
<td>F</td>
<td>15.1</td>
</tr>
<tr>
<td>G</td>
<td>10.3</td>
</tr>
<tr>
<td>H</td>
<td>13.0</td>
</tr>
<tr>
<td>I</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Distillers Grain

• Two different types:
  1) Dry Distillers Grain
  2) Wet Distillers Grain.

• Sells for $30/ton in wet form, and $75/ton in dry form.
• Sold to feed different types of cattle.
• Total cattle population is 5.25 million in Oklahoma
Ethical Concerns?

• Some groups vehemently protest using Ethanol.

• Why use feed crops to make gasoline?
Feedstock Analysis

• 44 million acres of land/ 11 million for agriculture.

• Possible feeds: barley, cotton, peanuts, switchgrass, wheat, and corn.
Selection Criteria

- Harvest Time
- Starch content of feedstock
- Transportation/Storage Cost
- Production of marketable by-products
- Cost of processing

*Crops chosen: Wheat, Grain Sorghum and Switchgrass*
Availability of Crops

Total Feed Supply from Each District

- Central OK: 15%
- South Central OK: 7%
- North Central OK: 21%
- Panhandle: 11%
- Northeast OK: 11%
- East Central OK: 7%
- Southeast OK: 3%
- West Central OK: 12%
- Southwest OK: 13%
- Southeast OK: 3%
Wheat Selection

• Highest selling cash crop in US and 3rd in Oklahoma (6 million acres, about 1.3 million in North Central district)
• Estimated 165 million bushels in 2003 and selling for $3.20/Bu
Wheat Distribution in Oklahoma
Total of 3.9 million tons of wheat produces a year

Wheat Harvested by District in Oklahoma

- West Central OK: 18%
- Southwest OK: 20%
- South Central OK: 1%
- North Central OK: 30%
- Panhandle: 16%
- Northeast OK: 6%
- Central OK: 9%
- Southeast OK: 0.2%
- East Central OK: 0.5%
Grain Sorghum Selection

- Over 310,000 acres was harvested in 2002, and about 14 million bushels is to be produced in 2003/2004
- Over 70% goes to livestock in OK
- WDG byproduct high in protein content
Sorghum Distribution in Oklahoma
Total of 0.49 million tons of sorghum produces a year

![Pie chart showing sorghum distribution by district in Oklahoma.]

- Panhandle: 34%
- North Central OK: 30%
- Northeast OK: 7%
- Southwest OK: 19%
- East Central OK: 1%
- Central OK: 3%
- South Central OK: 1%
- South Central OK: 1%
- Central OK: 3%
- Southeast OK: 1%
Switchgrass Selection

• Over 3 million acres to be harvested in 2003/2004.

• Central OK is the leading switchgrass producing district in Oklahoma (~1 million acres)

• Has a high conversion to ethanol during processing.
Switchgrass Distribution in Oklahoma

Total of 4.78 million tons of switchgrass produces a year

Switchgrass Harvested by District in Oklahoma

- South Central OK: 13%
- Central OK: 23%
- Southeast OK: 6%
- East Central OK: 12%
- Southwest OK: 7%
- West Central OK: 8%
- Northeast OK: 16%
- Panhandle: 5%
- North Central OK: 10%
- Panhandle: 5%
Harvesting time

Monthly Trend of Harvested Crop

- Switchgass
- Sorghum
- Wheat

Tons of Crop

Months
Processing Technologies

1) Dry Mill Simultaneous Saccharification/Fermentation

2) Dilute Acid Hydrolysis

3) Gasification
Fermentation Process (Dry Mill)
Mash Grinding/Cooking/Liquefaction

- **Grain**
- **Hammer Mill**
- **Slurry Tank**
- **Cooker (250 F)**
- **Liquefaction Vessel (185 F)**

**Process Steps:***
- Grain is milled in a hammer mill.
- Milled grain is slurried in a slurry tank.
- Slurry is heated with steam in a cooker.
- Enzyme (alpha amylase) is added to the cooker.
- Liquefaction vessel operates at 185°F.
- Dextrin/Maltose is produced.

**Notes:**
- **Cooking Column:**
  - Starch Form: Amylose, Amylopectin
- **Liquefaction Vessel:**
  - Enzyme: alpha amylase
Fermentation Process (Dry Mill)
Simultaneous Saccharification/Fermentation

Saccharomyces Cerevisiae Yeast
Beta-Amylase

Mash

CO₂ to Scrubber

\[(C₆H₁₀O₅)ₙ + nH₂O \xrightarrow{\text{enzymes}} nC₆H₁₂O₆\] (starch) (glucose)

\[C₆H₁₂O₆ \xrightarrow{\text{yeast}} 2\text{CH₃CH₂OH} + 2\text{CO}_₂ + \text{heat}\] (glucose) (ethanol)

85 F

Oxygen

9 wt% ETOH
74 wt % H₂O
17 % inert organic glucose
Fermentation Process (Dry Mill)
Distillation/Stillage Recovery

Stillage to Evaporators
(inert organics/glucose)

Beer Column
45 wt% ETOH
55 wt% H2O

Rectifying Column
95 wt% ETOH

Condensate to Hammer Mill

74 wt% H₂O
9 wt% ETOH
17 wt% Inert Organics/Glucose
Molecular Sieve/Dehydration

3 Å molecular sieves
H₂O adsorbs onto sieve structure
Uses regeneration cycle to prolong bead life/ lower operating costs
Fermentation Process (Dry Mill)
## Equipment Pricing (20 MGY)

<table>
<thead>
<tr>
<th>Major Equipment (quantity)</th>
<th>Description (each)</th>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer Mill</td>
<td>1.5 in to 100 mesh</td>
<td></td>
<td>$490,000</td>
</tr>
<tr>
<td>Cooker</td>
<td>5100 gallons</td>
<td>carbon steel</td>
<td>$70,000</td>
</tr>
<tr>
<td>Liquefaction Vessel</td>
<td>7650 gallons</td>
<td>carbon steel</td>
<td>$85,000</td>
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<tr>
<td>Fermenter (4)</td>
<td>250,000 gallons</td>
<td>stainless steel</td>
<td>$1,600,000</td>
</tr>
<tr>
<td>Pre-Fermentor Heat Exchangers (4)</td>
<td>840 ft^2, Fixed Tube Sheet</td>
<td>stainless steel</td>
<td>$73,000</td>
</tr>
<tr>
<td>Vent Scrubber</td>
<td></td>
<td></td>
<td>$15,000</td>
</tr>
<tr>
<td>Byproduct Storage</td>
<td></td>
<td>carbon steel</td>
<td>$30,500</td>
</tr>
<tr>
<td>Cooling Tower</td>
<td>10 degree, 25 F range</td>
<td>carbon steel</td>
<td>$257,000</td>
</tr>
<tr>
<td>Beer Column</td>
<td>D=5.5 ft 22 trays</td>
<td>stainless steel</td>
<td>$273,000</td>
</tr>
<tr>
<td>Beer Column Condenser</td>
<td>1870 ft^2, Fixed Tube Sheet</td>
<td>stainless steel</td>
<td>$31,000</td>
</tr>
<tr>
<td>Beer Column Reboiler</td>
<td>5600 ft^2, Fixed Tube Sheet</td>
<td>stainless steel</td>
<td>$73,000</td>
</tr>
<tr>
<td>Rectifying Column(1)</td>
<td>D=7.5 ft, 30 trays</td>
<td>stainless steel</td>
<td>$316,000</td>
</tr>
<tr>
<td>Rectifying Column Condenser</td>
<td>1000 ft^2, Fixed Tube Sheet</td>
<td>stainless steel</td>
<td>$18,000</td>
</tr>
<tr>
<td>Rectifying Column Reboiler</td>
<td>2300 ft^2, Fixed Tube Sheet</td>
<td>stainless steel</td>
<td>$34,000</td>
</tr>
<tr>
<td>Syrup Tank(2)</td>
<td>one 100,000 gallon, one 50,000 gallon</td>
<td>carbon steel</td>
<td>$170,000</td>
</tr>
<tr>
<td>Boiler</td>
<td></td>
<td>carbon steel</td>
<td>$609,000</td>
</tr>
<tr>
<td>Gasoline Storage Tank</td>
<td>40000 gallons</td>
<td>carbon steel</td>
<td>$80,000</td>
</tr>
<tr>
<td>Ethanol Storage Tank</td>
<td>136,000 gallons, API floating roof</td>
<td>carbon steel</td>
<td>$136,000</td>
</tr>
<tr>
<td>Molecular Sieve (9 pieces)</td>
<td></td>
<td></td>
<td>$572,000</td>
</tr>
<tr>
<td>Centrifuge</td>
<td>HS-805L, 31.5” x 104”</td>
<td></td>
<td>$400,000</td>
</tr>
<tr>
<td>Evaporation System</td>
<td>40000 ft^2</td>
<td></td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Beer Well (5)</td>
<td>four 100,000 gallon, one 50,000 gallon</td>
<td>carbon steel</td>
<td>$460,000</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td><strong>$6,792,500</strong></td>
</tr>
</tbody>
</table>

Total Equipment Cost (20 MGY) = $7 million
Equipment Cost Methodology

- Material Balances were constructed to size necessary equipment and vessels
- Pro II simulations were run to design distillation columns
- Vendor information was used to price most equipment
Dry Mill Economics

20 MGY Plant:
TCI = $35 million
Operating Cost = $10 million
Processes for Lignocellulosic Crops

Hemicellulose

Cellulose
Hemicellulose Hydrolysis

1.1 wt% Sulfuric Acid

Biomass → 335 F → Lime → Water

LP Steam

Air → To Cellulose Hydrolysis

Gypsum

To Xylose Fermentation
Cellulose Hydrolysis

Solids from S/L Separator → Lime → 150 F → Gypsum → To Glucose Fermentation

Cellulase
Fermenters in Parallel

Xylose Fermenters
  • Ferment 5 carbon sugars
  • Use the yeast *Pachysolen tannophilus*

Glucose Fermenters
  • Ferment 6 carbon sugars
  • Use the yeast *Sacromyces cerevisiae*
Dilute Acid Economics

20 million gallon plant:
TCI = $50 million

Operating Cost = $20 million
Fermentation

- Syngas from Gasifier
- Nutrient Feed
- Product Stream
- Outlet Gas

- 80 F
- pH 5.3
Gasification Economics

20 million gallon plant:
TCI = $80 million

Operating Cost = $12 million
## Technology Comparison

Capital and Operating Costs
20 Mgal/yr Ethanol Plant

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>TCI ($ )</th>
<th>Operating Costs ($/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentation</td>
<td>35 M</td>
<td>10 M</td>
</tr>
<tr>
<td>Dilute Acid</td>
<td>50 M</td>
<td>20 M</td>
</tr>
<tr>
<td>Gasification</td>
<td>80 M</td>
<td>12 M</td>
</tr>
</tbody>
</table>
Technology Comparison (cont.)

Feedstock to Ethanol Conversions
(tons ethanol / ton feed)

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Sorghum</th>
<th>Switchgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentation</td>
<td>0.277</td>
<td>0.286</td>
<td>0.023</td>
</tr>
<tr>
<td>Dilute Acid</td>
<td>0.043</td>
<td>0.038</td>
<td>0.299</td>
</tr>
<tr>
<td>Gasification</td>
<td>0.169</td>
<td>0.168</td>
<td>0.171</td>
</tr>
</tbody>
</table>
Decision to make when building a plant

- Can this be done manually?
- How do we calculate all the variables and decide the optimal solution?
Relationship between feed supply and plant

Feed Supply = 7 points
Plant Location = Garber

Decision is

NPW = $29.5 million

Plant Capacity = 131568 tons
Plant Location = Garber

Wheat = 
Sorghum = 
Switchgrass =
What if there is more than 1 plant and many feed sources?

Feed Supply = 78 points

Plant Location = 9 points

Therefore using a model would make the calculations possible
Mathematical Model Flow

- Ethanol Produced
- Plant Location
- Feed Transported
- Feed Location

Graph with nodes and arrows indicating the flow from production to transportation and location.
Decision for building an Ethanol plant based on

\[
NPW = \left(Dft \times Life\right) \left[ \sum (Sales) - \sum \left(\frac{Bought}{Feed}\right) - \sum \left(\frac{Transportt}{ion\ Cost}\right) \right] - \sum \left(\frac{Capital}{Investment}\right) - \sum \left(\frac{Storage}{Cost}\right) - \sum \left(\frac{Operating}{Cost}\right)
\]

The plant is chosen based on MAXIMIZING the NPW.
Variables which affect the profitability of the Ethanol plant

- Bought Feed
- Transported Feed
- Storage
- Operating Cost
Variables which affect the profitability of the Ethanol plant

<table>
<thead>
<tr>
<th>Plant Throughput</th>
<th>Ethanol Produced</th>
<th>Capital Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Feed

\[ \sum \left( \frac{\text{Bought}}{\text{Feed}} \right) \leq \sum \left( \frac{\text{Harvested}}{\text{Feed}} \right) \]

9-plant locations
78-feed locations
3-types of feed
Plant Throughput

\[
\left( \begin{array}{c}
Yearly \\
Throughput
\end{array} \right) \leq \left( \begin{array}{c}
Max \\
Size
\end{array} \right)
\]

\[
\left( \begin{array}{c}
Yearly \\
Throughput
\end{array} \right) \geq \left( \begin{array}{c}
Minimum \\
Throughput
\end{array} \right)
\]

\[
\left( \begin{array}{c}
Ethanol \\
Produced
\end{array} \right) \leq \frac{\left( Yearly Throughput \right)}{12}
\]
Capital Investment

\[
\begin{align*}
\text{Capital Investment} &= (FCI \times \text{Plant Throughput}) + (FCI \times \text{Intercept}) \\
\text{Capital Investment} &\leq (\text{Maximum FCI})
\end{align*}
\]
Storage

1st Month Storage

\[ storage_{t_1} = \sum_i (Bought_{Feed_{t_1}}) - \sum_g (Feed_{Processed_{t_1}}) \]

Subsequent Month Storage

\[ \sum (Storage_t) \leq \sum (Storage_{t-1}) + \sum (Bought_{Feed_t}) - \sum (Feed_{Processed_t}) \]
Operating Cost

\[
\begin{pmatrix}
\text{Operating Cost} \\
\text{Slope}
\end{pmatrix}
= \begin{pmatrix}
\text{OP} \\
\text{Produced}
\end{pmatrix}
\begin{pmatrix}
\text{Ethanol}
\end{pmatrix}
\]
Transportation of Feed

\[
\begin{pmatrix}
\text{Transported Feed}
\end{pmatrix} =
\begin{pmatrix}
\text{Bought Feed}
\end{pmatrix} \times
\begin{pmatrix}
\text{Distance of Source to plant}
\end{pmatrix}
\]
Ethanol Produced

\[ \sum \left( \frac{Ethanol}{Produced} \right) = \sum \left( \frac{Process}{Effeciency} \right) \times \sum \left( \frac{Feed}{Processed} \right) \]

\[ \left( \frac{Ethanol}{Produced} \right) \leq \frac{1.2 \times (Max Size)}{12} \]
Generalized Model

- Consider only locations in Oklahoma.
- Transportation Cost = $0.01678/tons*mile
- Storage Cost = $0.81/tons
- Ethanol price = $390/tons
- Maximum Plant Capacity = 200 million gallon
- Minimum Plant Capacity = 8.7 million gallons
### General Mathematical Result

<table>
<thead>
<tr>
<th>Plants</th>
<th>Capital investment ($)</th>
<th>Wheat</th>
<th>Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>garber</td>
<td>$22,504,130</td>
<td>391.58</td>
<td>8839.26</td>
</tr>
<tr>
<td>clinton</td>
<td>$21,736,270</td>
<td>391.58</td>
<td>8839.26</td>
</tr>
<tr>
<td>hobart</td>
<td>$22,808,630</td>
<td>391.58</td>
<td>8839.26</td>
</tr>
<tr>
<td>broken_bow</td>
<td>$20,554,580</td>
<td>391.58</td>
<td>8839.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacity (million tons)</th>
<th>NPW (million)</th>
<th>Ethanol produced (tons/month)</th>
<th>Total Feed Bought per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.658</td>
<td>$2,508</td>
<td>54822</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The table above shows the general mathematical result for total feed bought per month, including capacity, NPW, and production details for different plants.
Plant Locations

1. Beaver
2. Garber
3. Bixby
4. Clinton
5. Piedmont
6. Okmulgee
7. Hobart
8. Pauls Valley
9. Broken Bow
• Operating Cost

• All plants were built in the first 2 years.

• Start producing Ethanol in the 3rd year.

• Each plant capacity produces 55,000 tons of ethanol per month
• Economic and Sensitivity Analysis based on
  – Feed Source Variation
  – Capacity Variation
  – Cost Variation

• Deterministic and Stochastic Analysis

• Conclusion
• Majority feed comes from Texas, Kansas and Colorado.
• Capacity Variation

- NPW increase linearly with plant capacity
- Linearity is because the capacity is also a linear function of the operating cost and capital investment
• Percent Variation of Bought Feed

• NPW increases with the availability of harvested feed

• Increment is linear because it's a function of bought feed
When Bought Feed < 10% of Total Feed Harvested

NO PLANTS BUILT
• Ethanol Price Variation

• NPW increases the price of ethanol
• Increment is not linear and it is a function of other variables, i.e. process feed and operating cost.
• NPW =0 when ethanol price falls below $0.6/gallon
### Result From Ethanol Price Variation

<table>
<thead>
<tr>
<th>Ethanol Price ($/gal)</th>
<th>Number of Plants</th>
<th>Location</th>
<th>Capacity (tons)</th>
<th>Technology</th>
<th>Cap. Investment ($)</th>
<th>NPW ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.59</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>$0.60</td>
<td>1</td>
<td>Broken Bow</td>
<td>657860</td>
<td>Fermentation</td>
<td>$21,000,000</td>
<td>$4</td>
</tr>
<tr>
<td>$0.75</td>
<td>4</td>
<td>Pauls Valley</td>
<td>657860</td>
<td>Fermentation</td>
<td>$21,000,000</td>
<td>$260</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Garber</td>
<td></td>
<td></td>
<td>$23,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clinton</td>
<td></td>
<td></td>
<td>$22,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broken Bow</td>
<td></td>
<td></td>
<td>$21,000,000</td>
<td></td>
</tr>
<tr>
<td>$1.00</td>
<td>4</td>
<td>Garbar</td>
<td>657860</td>
<td>Fermentation</td>
<td>$23,000,000</td>
<td>$1,250</td>
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<tr>
<td></td>
<td></td>
<td>Clinton</td>
<td></td>
<td></td>
<td>$22,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hobart</td>
<td></td>
<td></td>
<td>$23,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broken Bow</td>
<td></td>
<td></td>
<td>$21,000,000</td>
<td></td>
</tr>
<tr>
<td>$1.10</td>
<td>4</td>
<td>Garbar</td>
<td>657860</td>
<td>Fermentation</td>
<td>$23,000,000</td>
<td>$1,900</td>
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<td></td>
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<td>Clinton</td>
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<td>$22,000,000</td>
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<tr>
<td></td>
<td></td>
<td>Hobart</td>
<td></td>
<td></td>
<td>$23,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broken Bow</td>
<td></td>
<td></td>
<td>$21,000,000</td>
<td></td>
</tr>
</tbody>
</table>
• **Storage Cost Variation**

- NPW decreases with the storage cost
- Increment is not linear and it is a function of other variables, i.e. Bought feed and capacity of plant.
- No plant will be built if the storage cost is above $2.0/ton of feed.
## Result From Storage Cost Variation

<table>
<thead>
<tr>
<th>Storage Cost ($/ton)</th>
<th>Plants</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>NPW ( $ million)</th>
<th>Capacity (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.50</td>
<td>garber</td>
<td>4.70</td>
<td>45.85</td>
<td>$3,970</td>
<td>657860</td>
</tr>
<tr>
<td></td>
<td>clinton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hobart</td>
<td></td>
<td></td>
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Transportation Cost Variation

• NPW decreases with the transportation cost
• Cost is related to the bought feed and distance
• No plant will be built if the storage cost is above $0.2/ton of feed.

NPW vs Transportation cost for Feed

![Graph showing NPW vs Transportation cost for Feed](image)
Transportation Cost = $0.0168/ton

1. Beaver
2. Garber
3. Bixby
4. Clinton
5. Piedmont
6. Okmulgee
7. Hobart
8. Pauls Valley
9. Broken Bow
- Operating Cost Variation

- NPW decreases with the operating cost
- It is a function of the number of plants and process feed.
- NPW = 0 when the operating cost increases by a factor of 3.2
Deterministic Model Results

• It is feasible to pursue ethanol production in Oklahoma provided that:
  – 4 proposed plants use fermentation technology.
  – Feed supply is from Oklahoma and parts of Texas, Colorado and Kansas
  – Feed chosen is mostly sorghum and wheat.
  – Ethanol Price > $.60/gal
  – The storage cost < $2/ton
  – Transportation Cost < $0.2/ton
  – The operating cost < 3.2 times the original
Stochastic Model Optimization

Include mathematical model optimization with scenarios.

Perform risk analysis on Ethanol Plant Feasibility.

50 to 100 scenarios were required for the stochastic model.

Parameters varied:

\[
\begin{align*}
\left( Ethanol \right)_{s} &= normal\left( Ethanol Mean Price, Sdt \right) \\
\left( Harvested \right)_{s} &= normal\left( Harvested Mean, Sdt \right) \\
\left( Operating \right)_{s} &= normal\left( Operating Cost Mean, Sdt \right)
\end{align*}
\]
Stochastic Model Results with 5 scenarios

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Capital Investment for year plant is built (in million dollars)

NPW versus Scenarios

Ethanol Price versus Scenarios
Resource requirement for Stochastic Model Optimization

• **Model Size:**
  – 100 scenarios each for 3 parameters.
  – 118 feed source locations
  – 9 plant locations
  – 3 feed types
  – 3 technologies
  – 240 months of plant life

• **2 GB of RAM used for data compilation**
Conclusions

• It is feasible to pursue ethanol production in Oklahoma according to the Deterministic model
• Preliminary analysis on Stochastic model proposed an alternate solution
• Further analysis on the Stochastic model can be completed once necessary resources are made available