Ethanol Production in Oklahoma

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Scope of our study

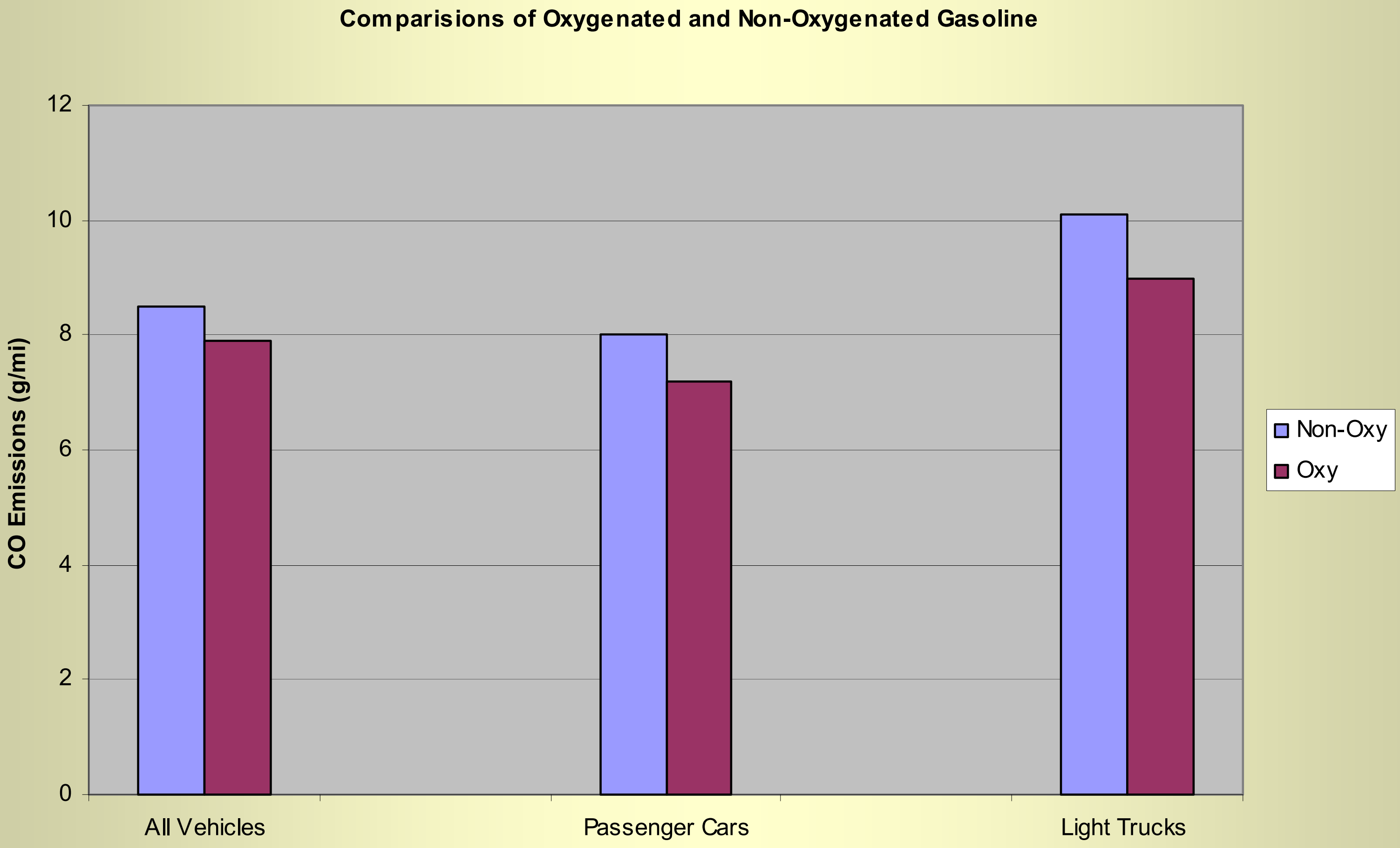
- To determine if the production of ethanol would be a worthwhile investment in the state of Oklahoma.
  - If so, determine the NPW, crops used, and plant location(s).
  - If not, determine why it is not feasible.

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

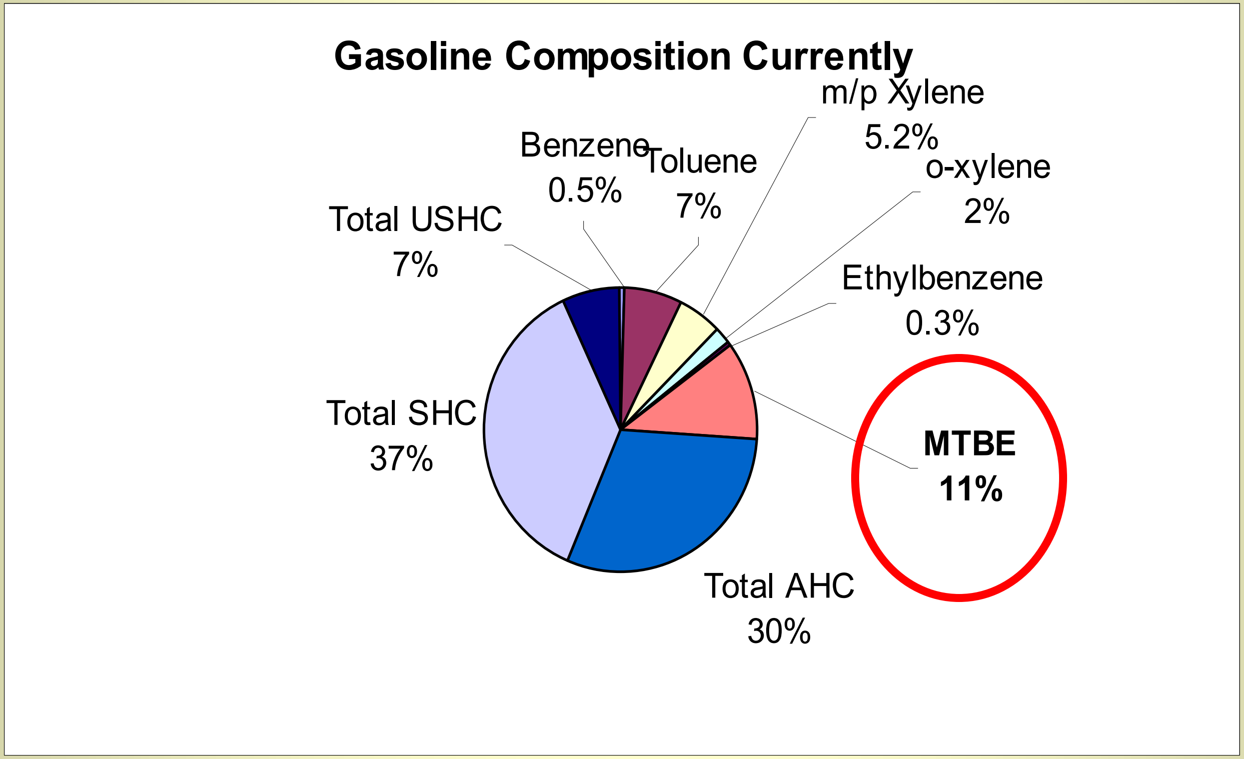
Why do we need Ethanol?

- Causes gas to burn more efficiently.



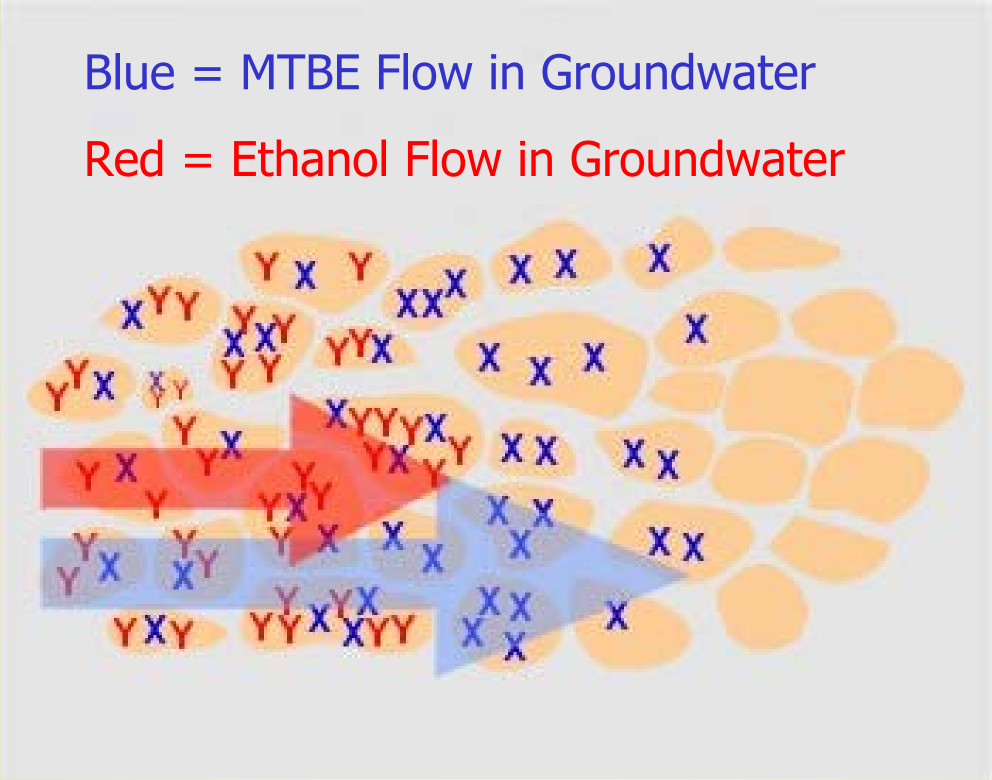
Why do we need Ethanol?

- Used as an additive in gasoline.



Problems with MTBE

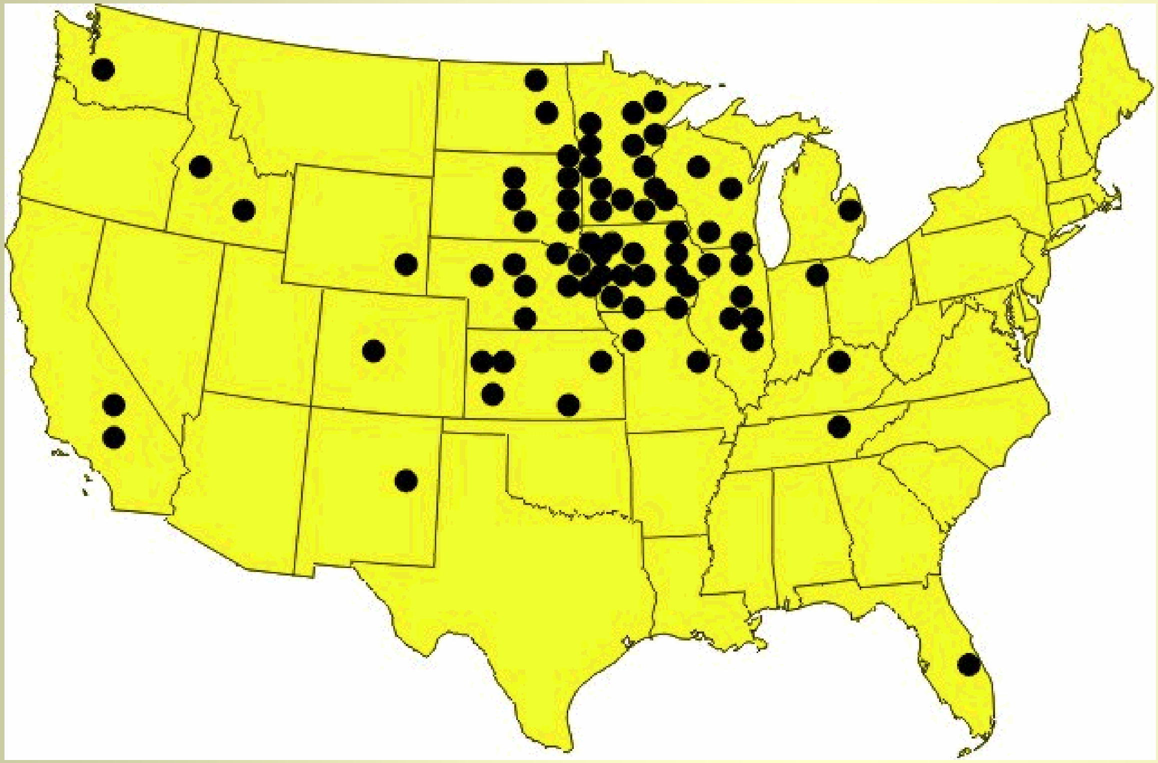
- Contaminates groundwater.



Legislation

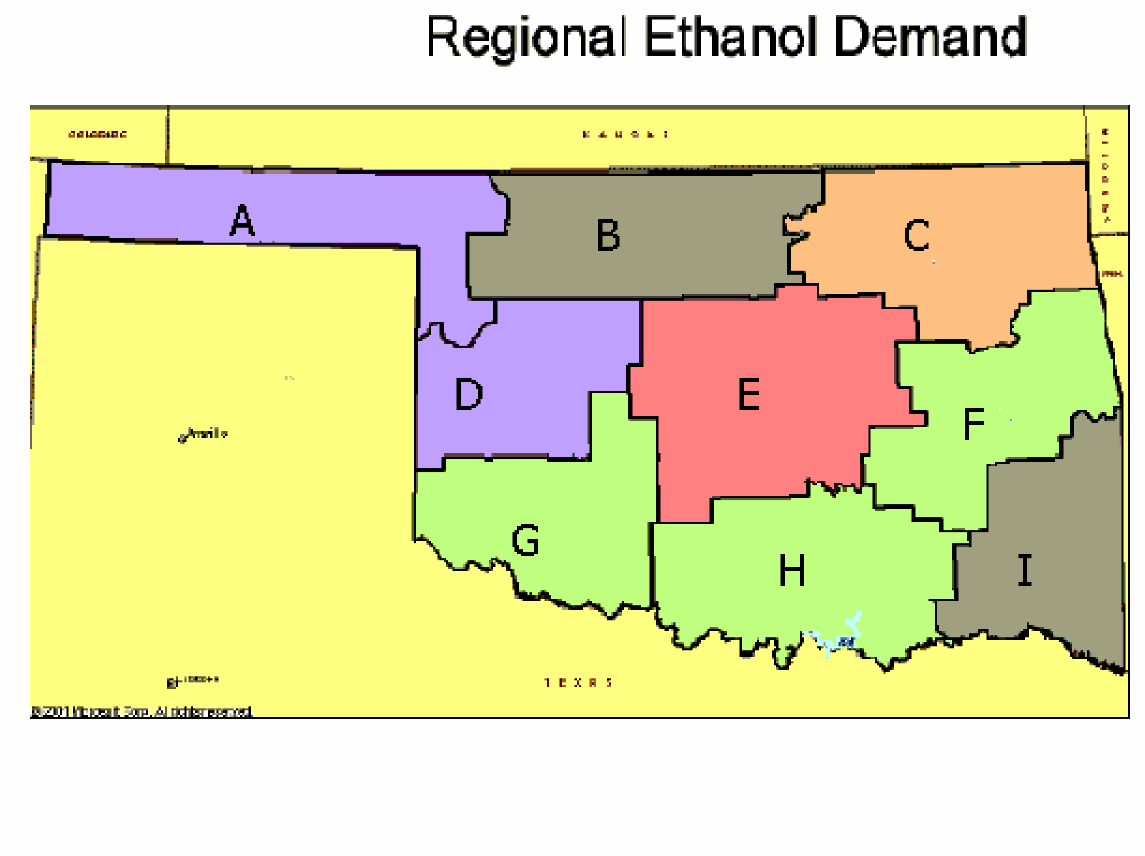
- Several states have passed or enacted MTBE phase-outs (MN, IA, NE, CA).
- Need subsidies to make ethanol production more competitive.

Current Production



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

Projected Ethanol Demand



	MGal
A	1.8
B	9.4
C	74.2
D	3.9
E	106.2
F	15.1
G	10.3
H	13.0
I	6.0

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

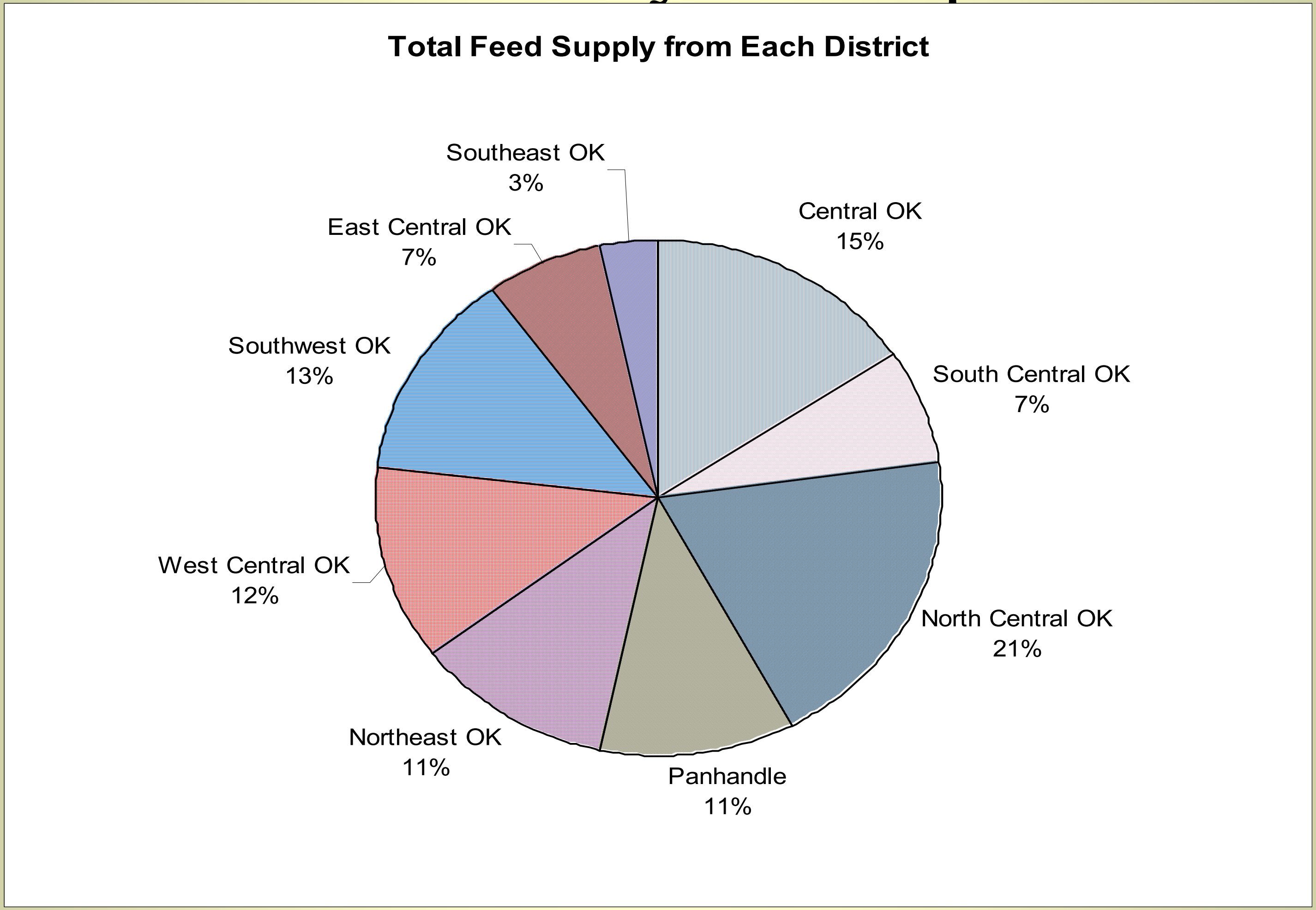
- 44 million acres of land/ 11 million for agriculture.
- Possible feeds: barley, cotton, peanuts, switchgrass, wheat, and corn.

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

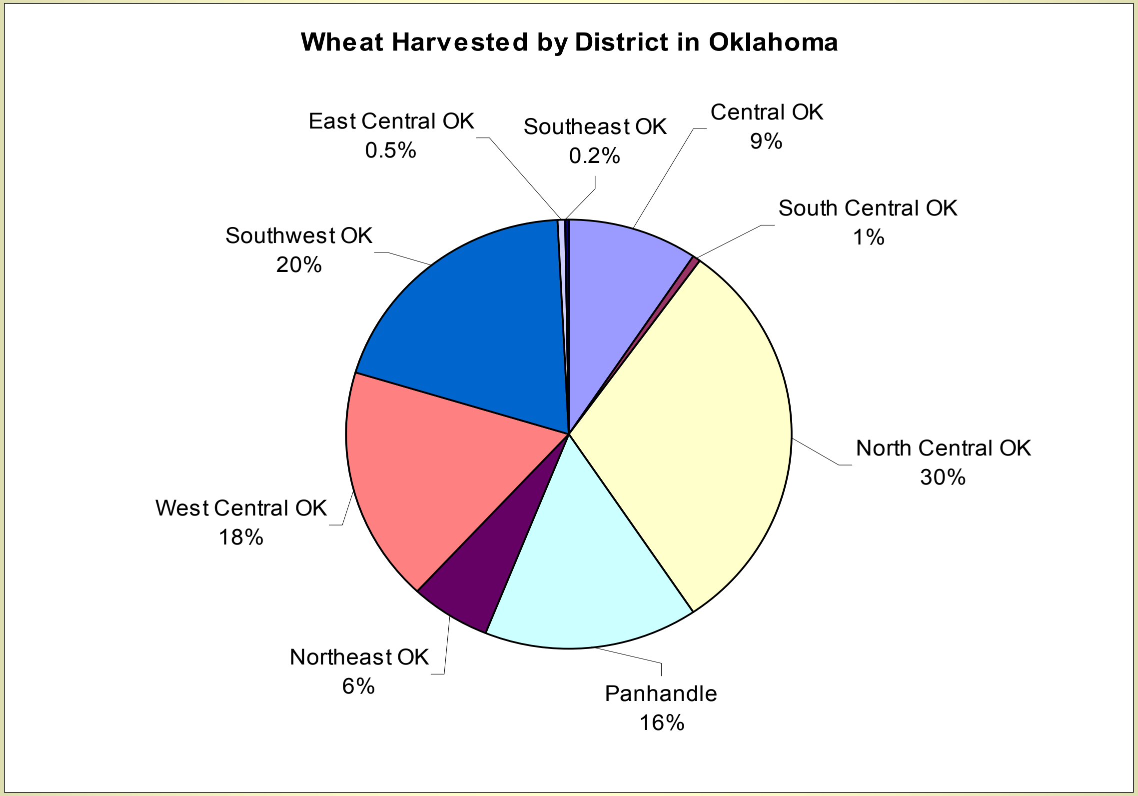
Availability of Crops



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

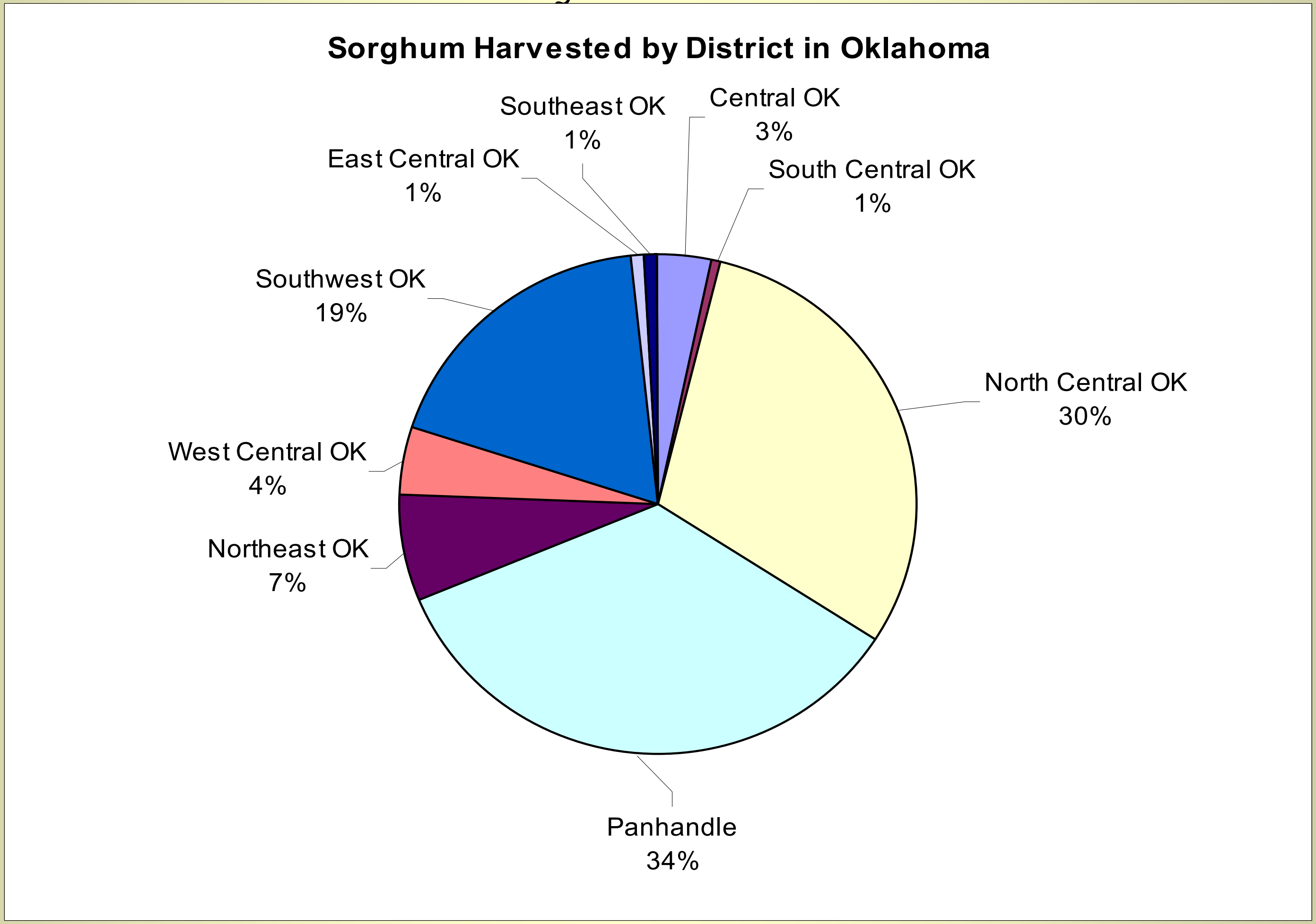
Wheat Distribution in Oklahoma
Total of 3.9 million tons of wheat produces a year



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

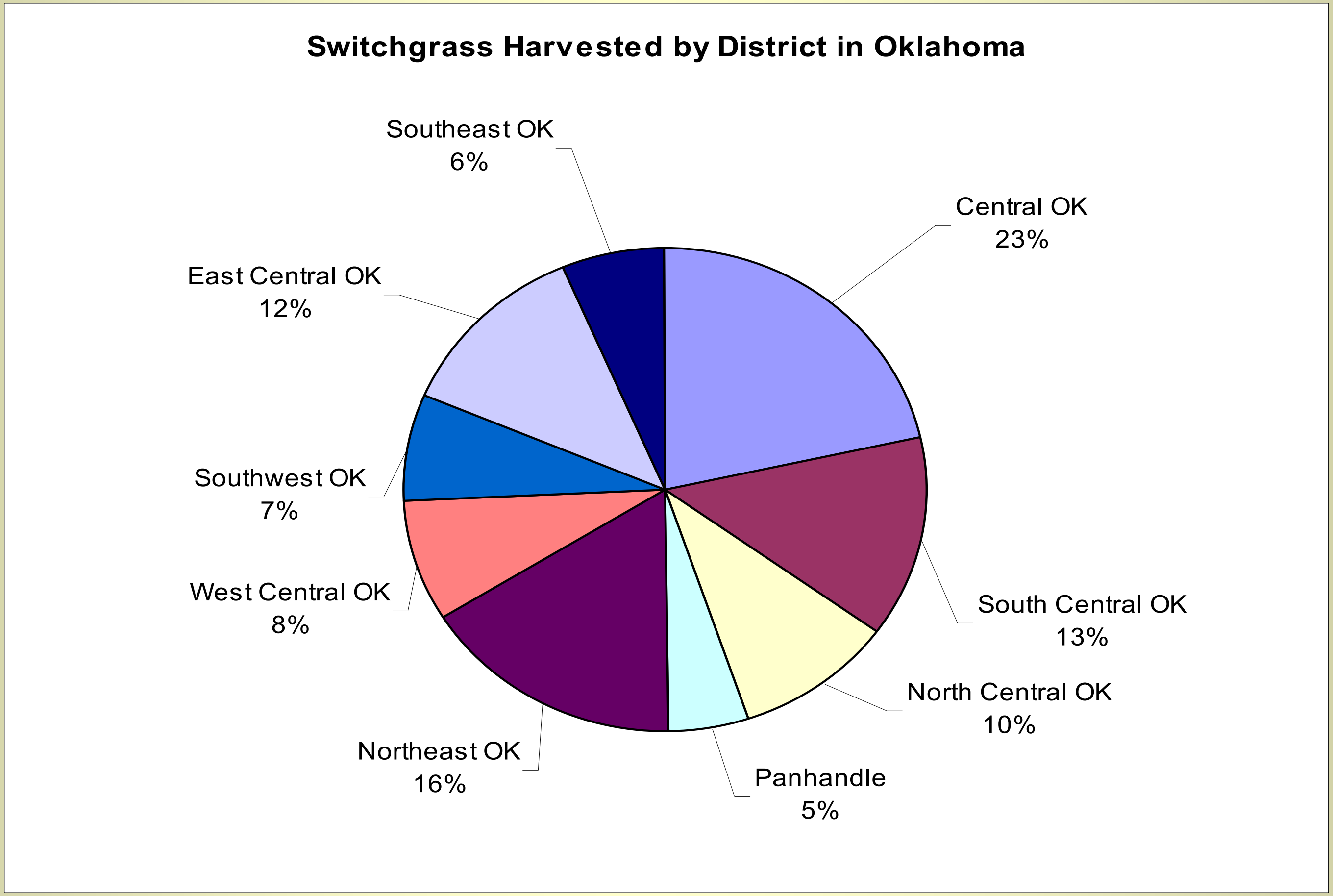


Switchgrass Selection

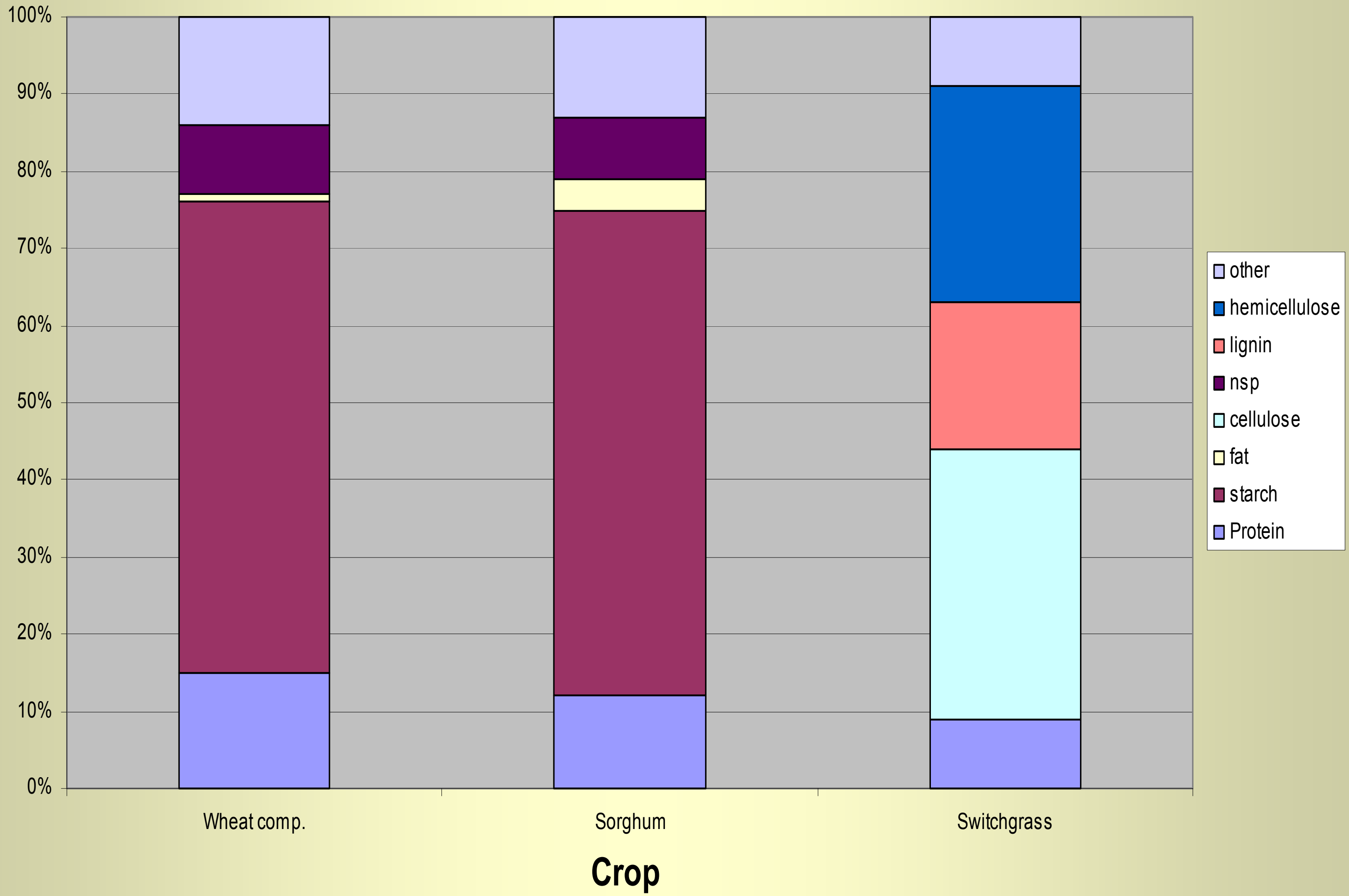
- Over 3 million acres to be harvested in 2003/2004.
- Central OK is the leading switchgrass producing district in Oklahoma (~1 million acres)
- Has a high conversion to ethanol during processing.

Switchgrass Distribution in Oklahoma

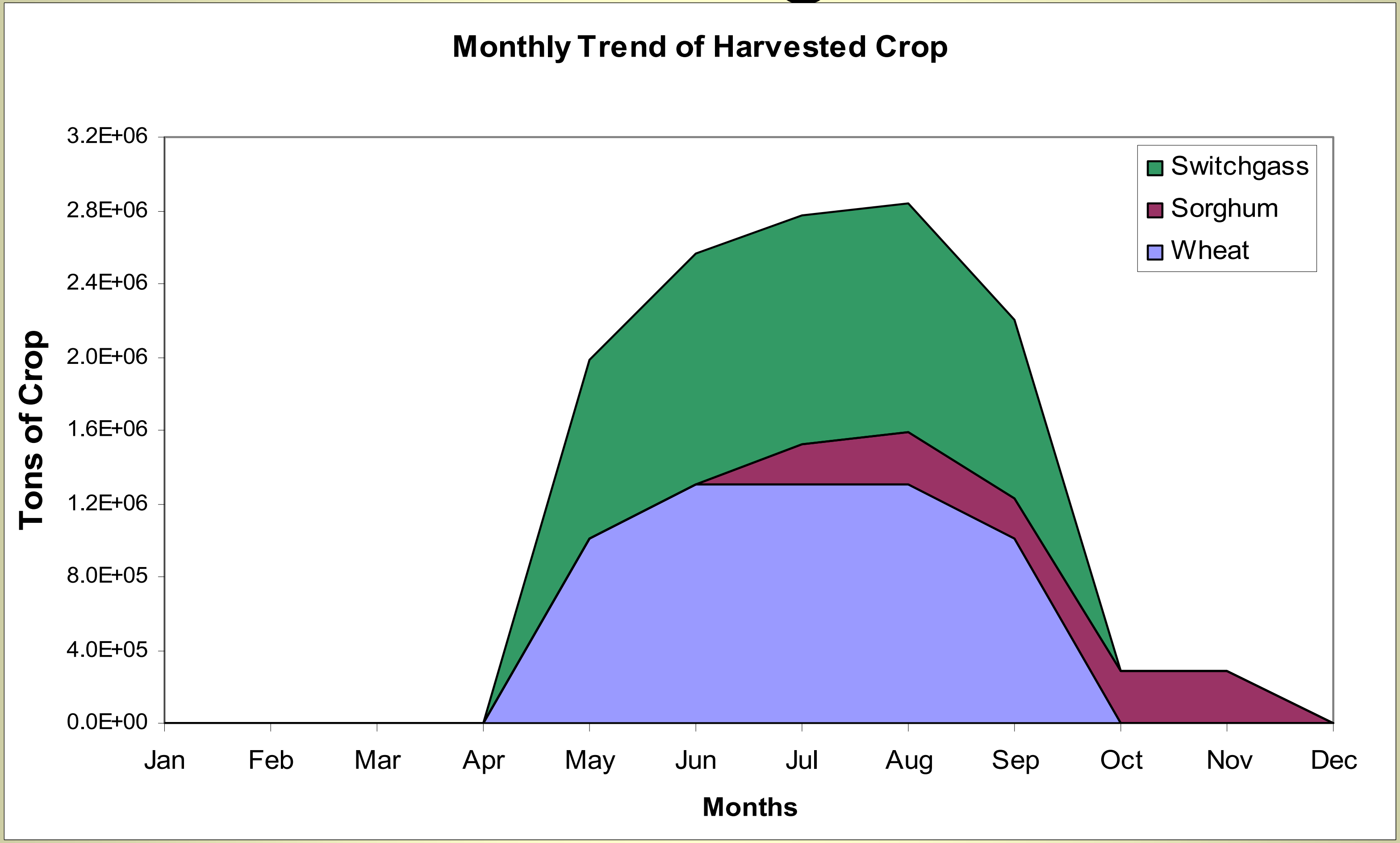
Total of 4.78 million tons of switchgrass produces a year



CROPS COMPOSITION



Harvesting time



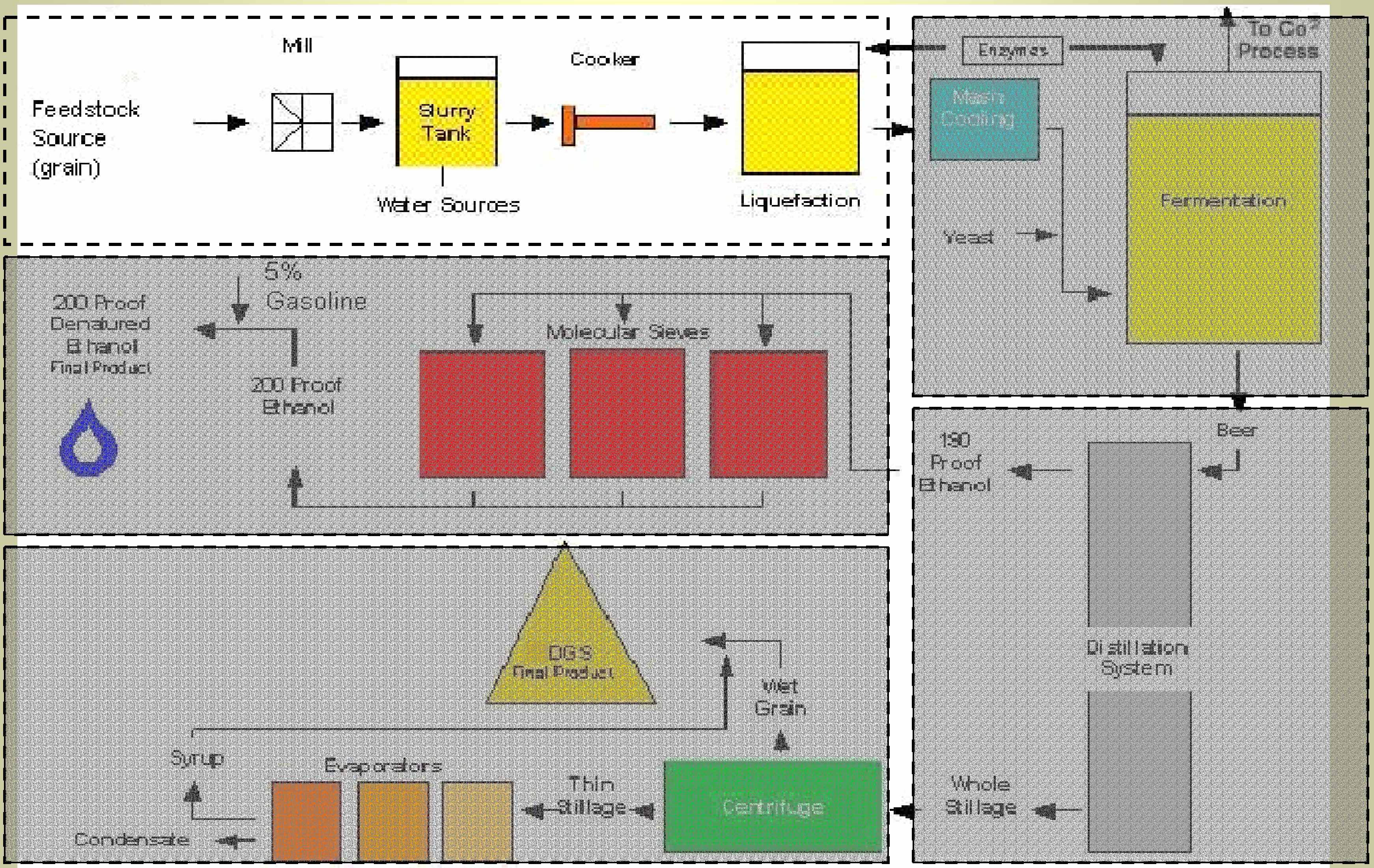
Processing Technologies

1) Dry Mill Simultaneous Saccharification/Fermentation

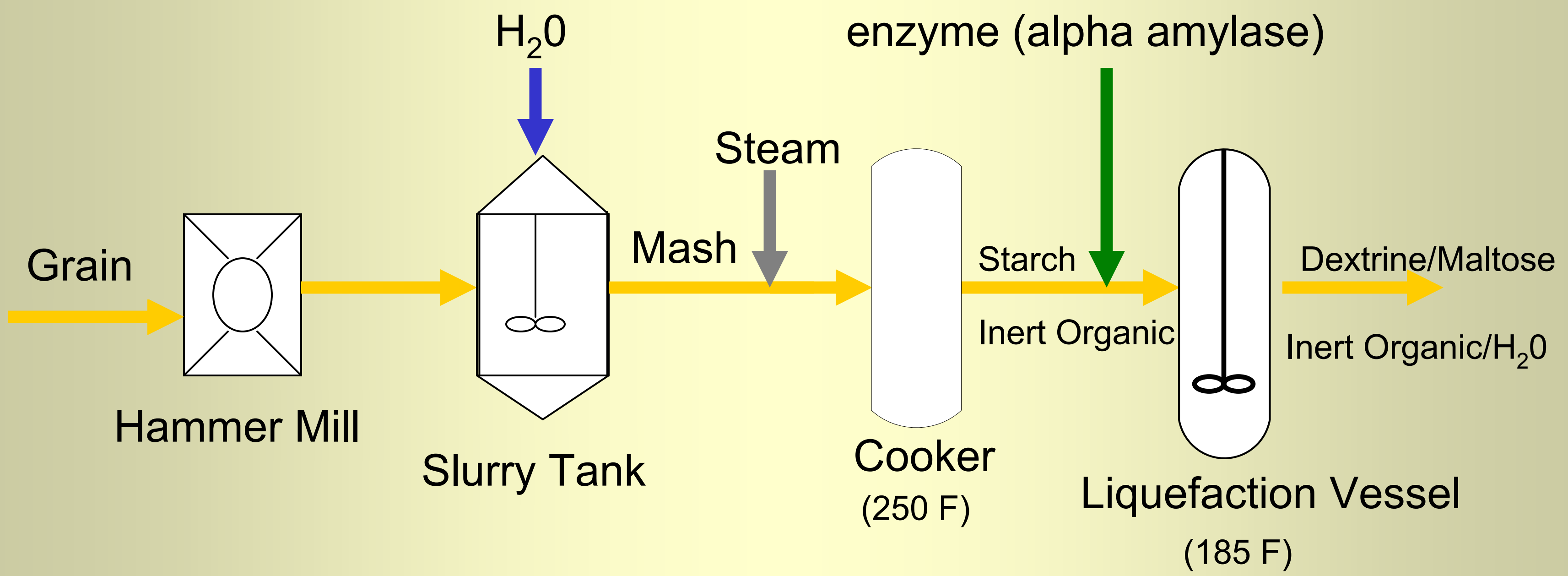
2) Dilute Acid Hydrolysis

3) Gasification

Fermentation Process (Dry Mill)



Mash Grinding/Cooking/Liquefaction



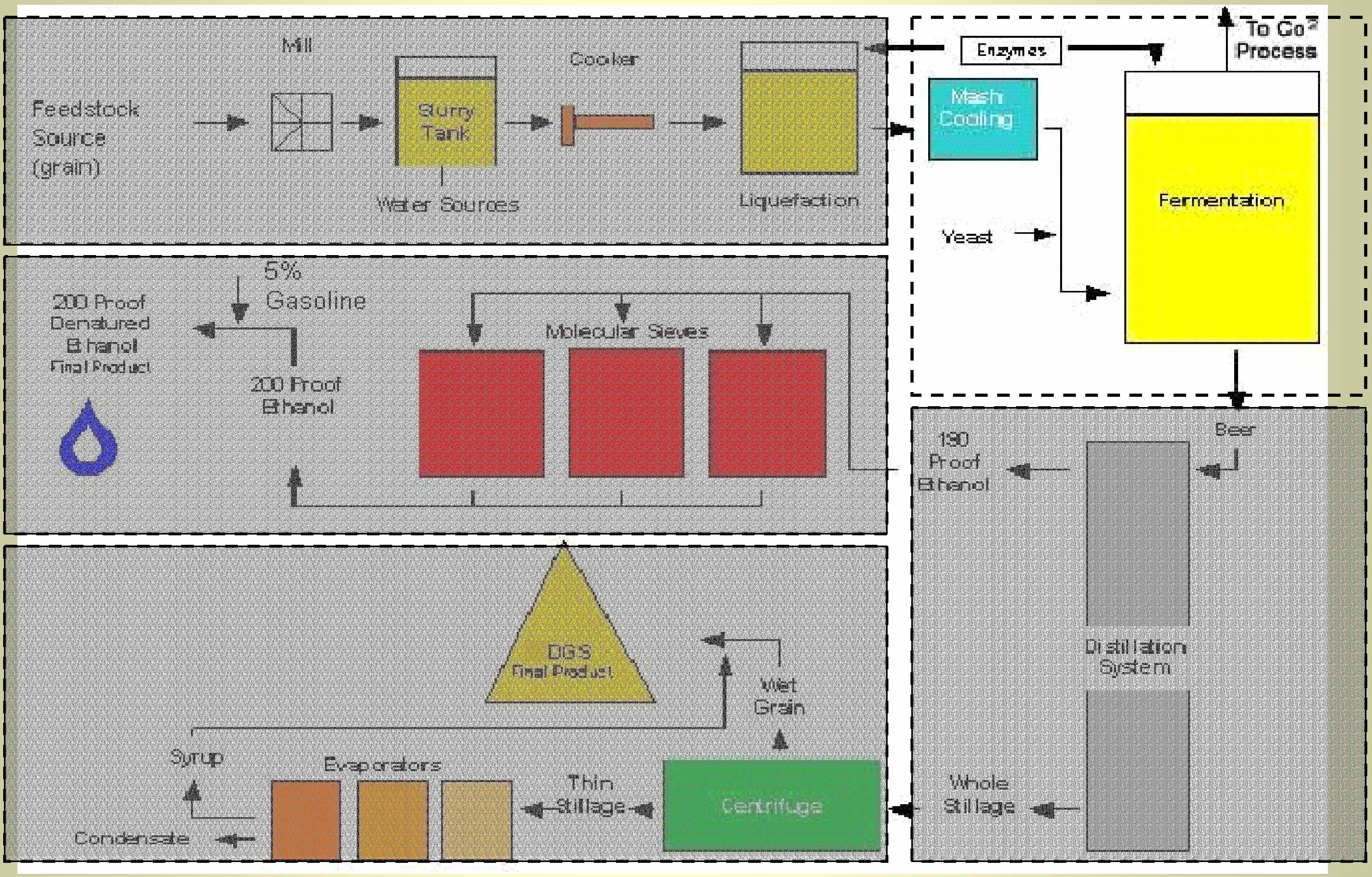
Cooking Column:

Starch Form : Amylose, Amylopectin

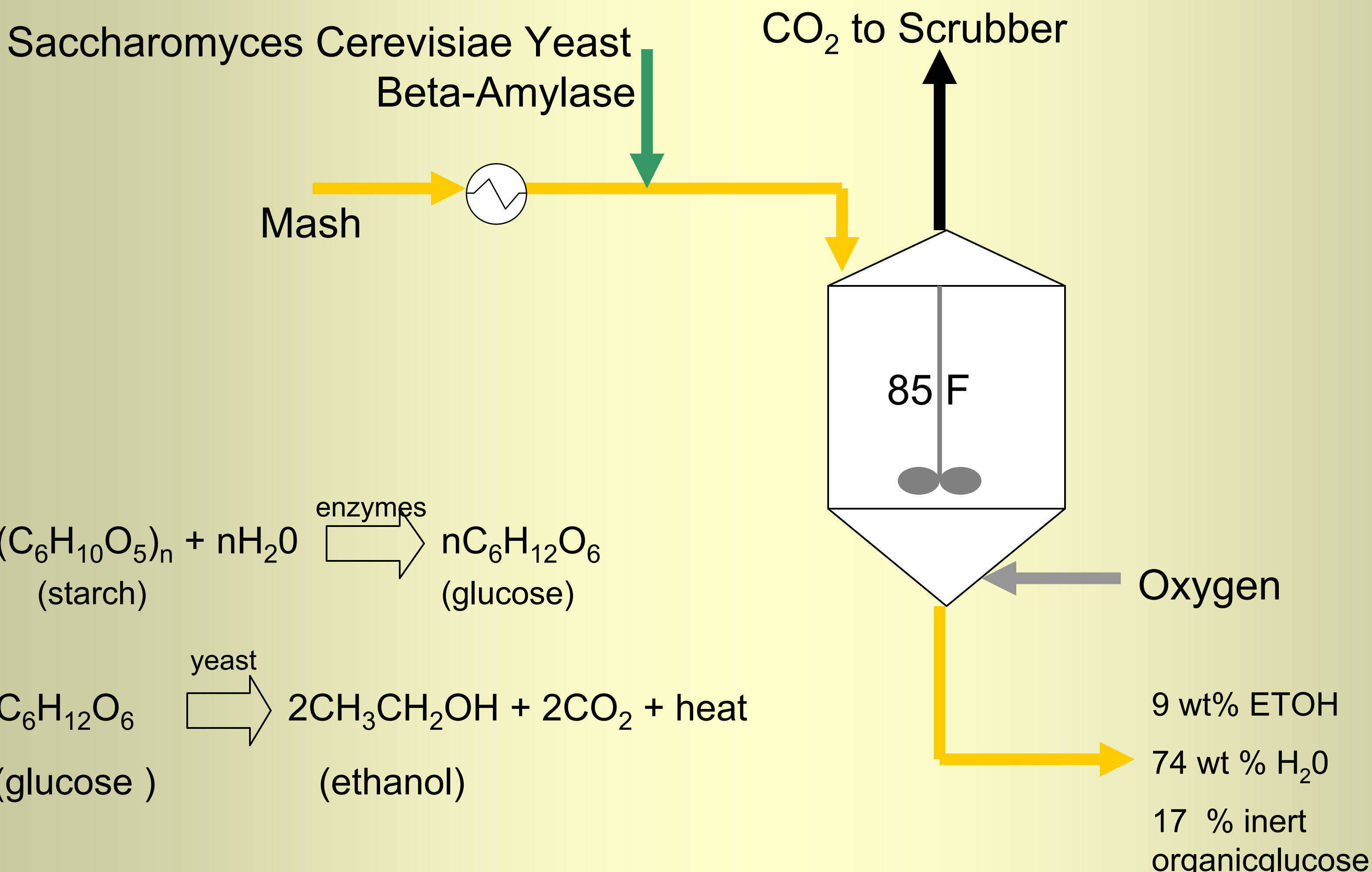
Liquefaction Vessel:

Enzyme: alpha amylase

Fermentation Process (Dry Mill)



Simultaneous Saccharification/Fermentation



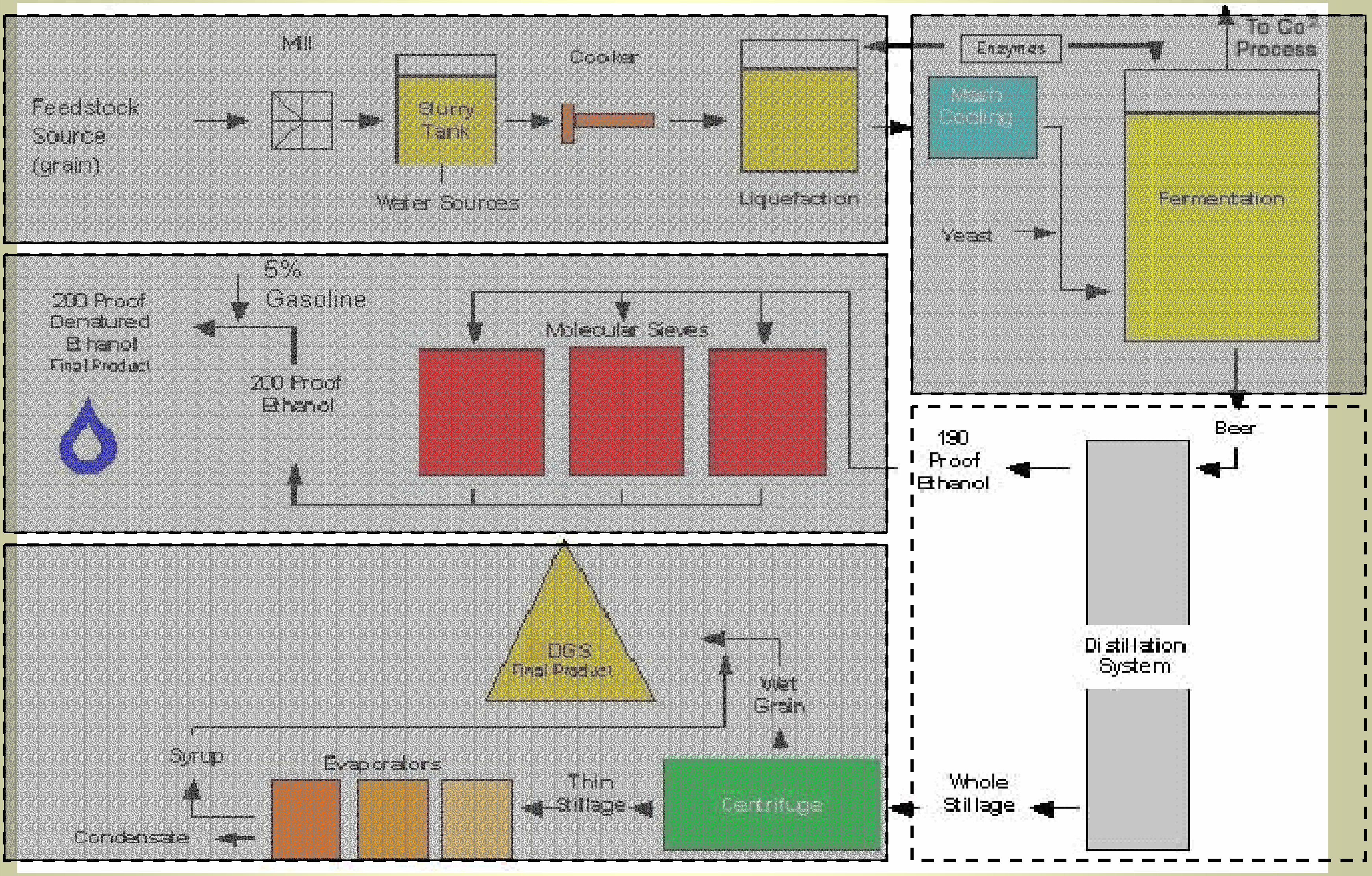
$$(C_6H_{10}O_5)_n + nH_20 \xrightarrow{\text{enzymes}} nC_6H_{12}O_6$$

(starch) (glucose)

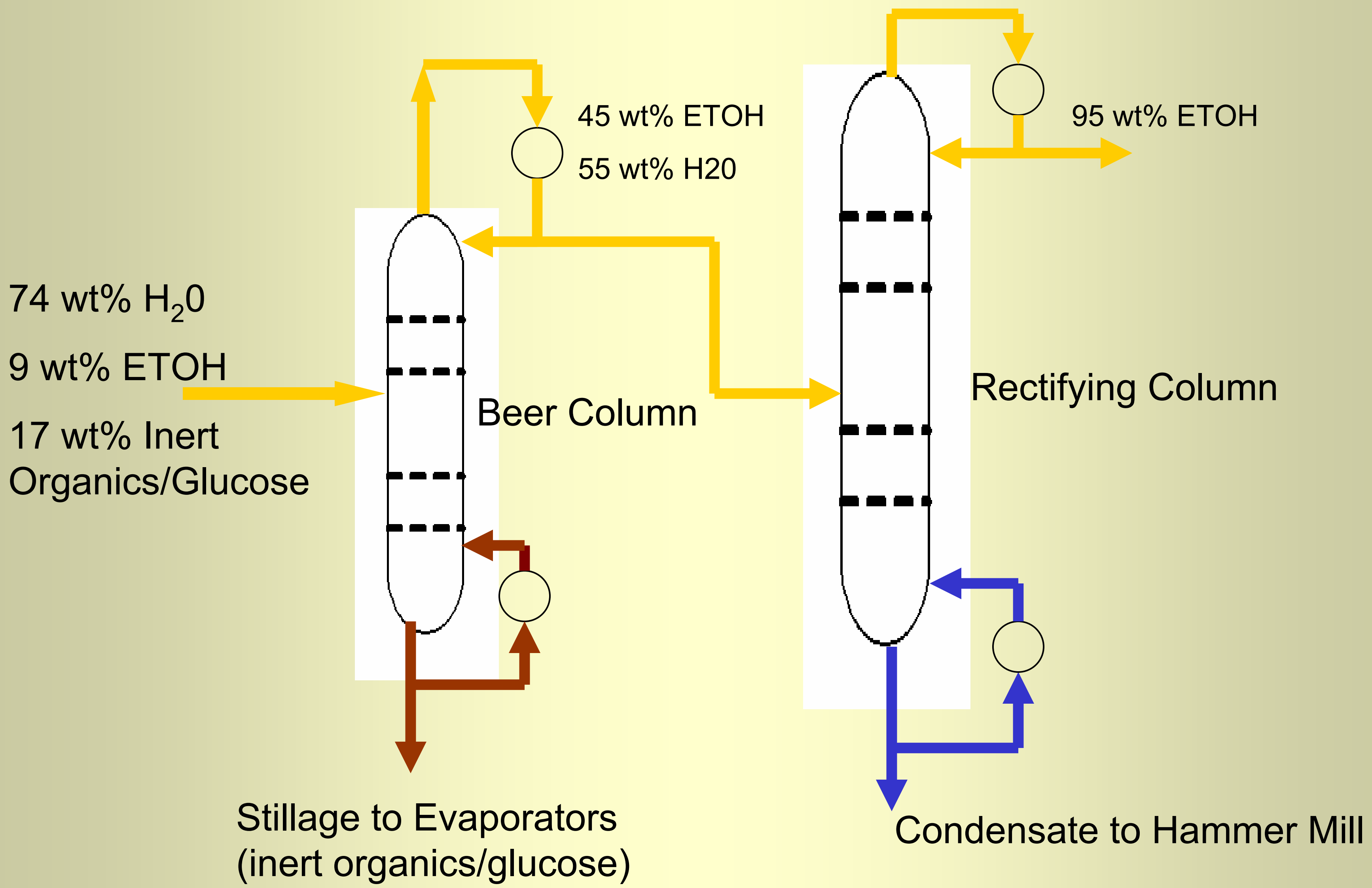
$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2CH_3CH_2OH + 2CO_2 + \text{heat}$$

(glucose) (ethanol)

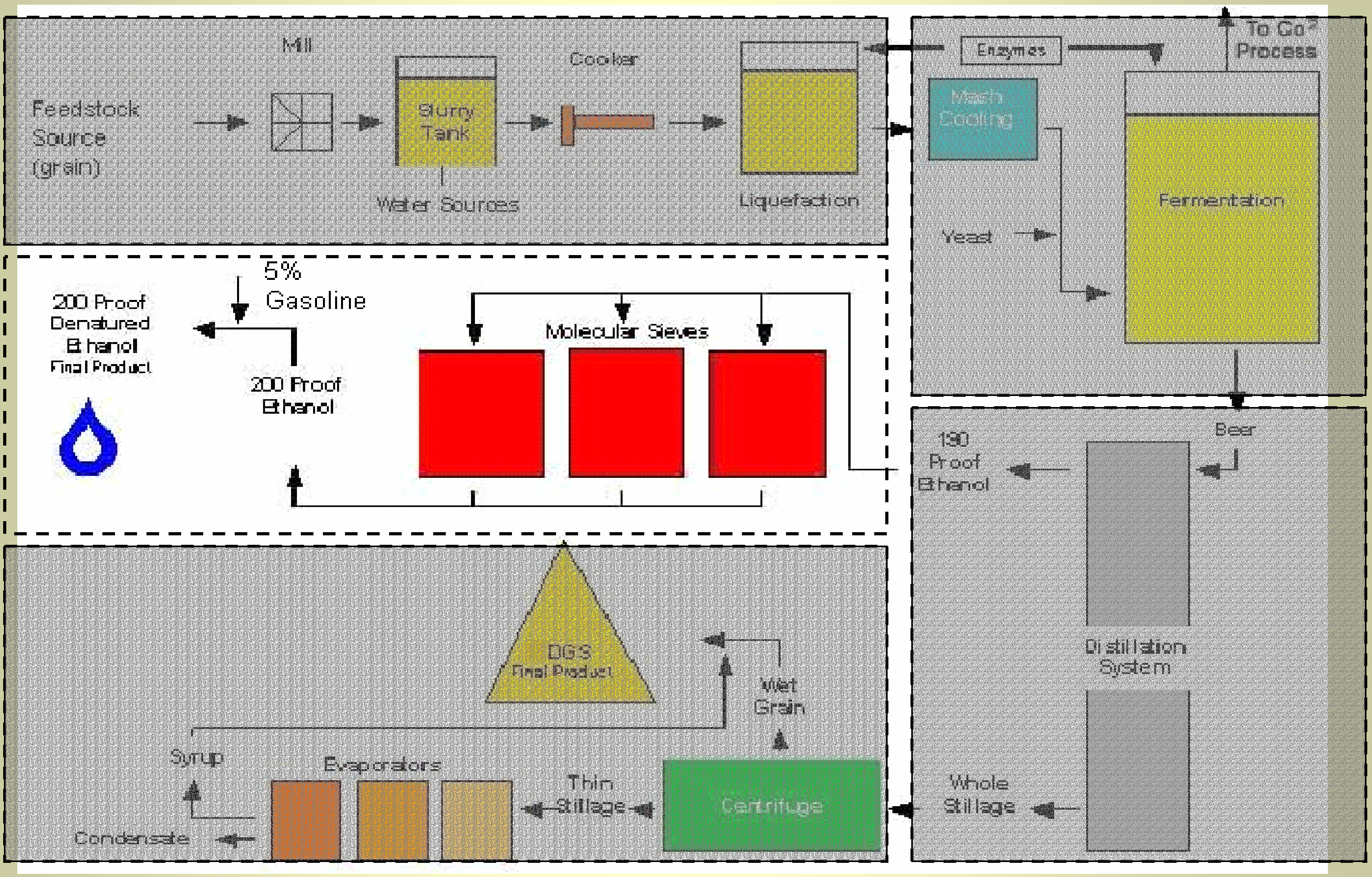
Fermentation Process (Dry Mill)



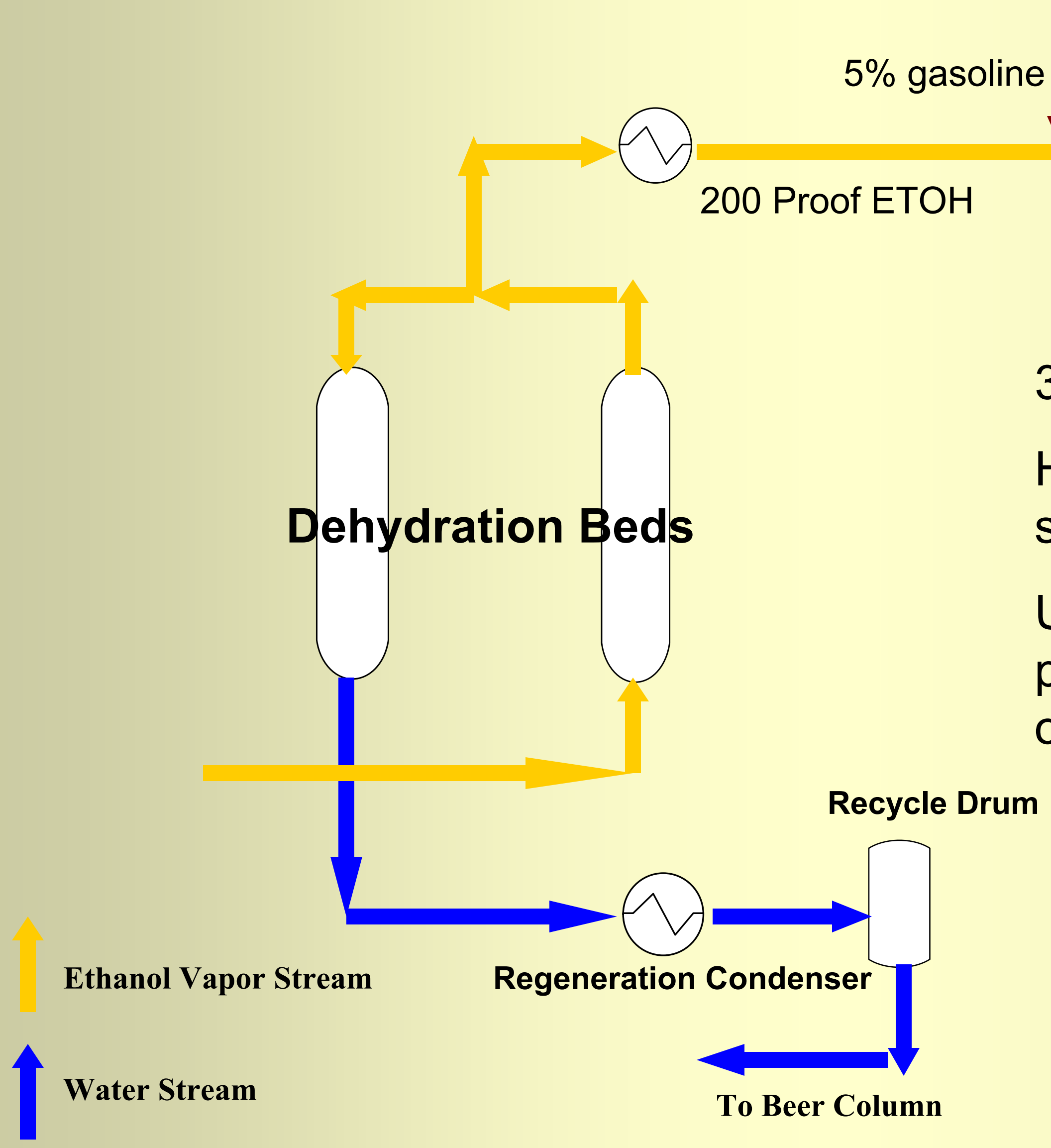
Distillation/Stillage Recovery



Fermentation Process (Dry Mill)



Molecular Sieve/Dehydration

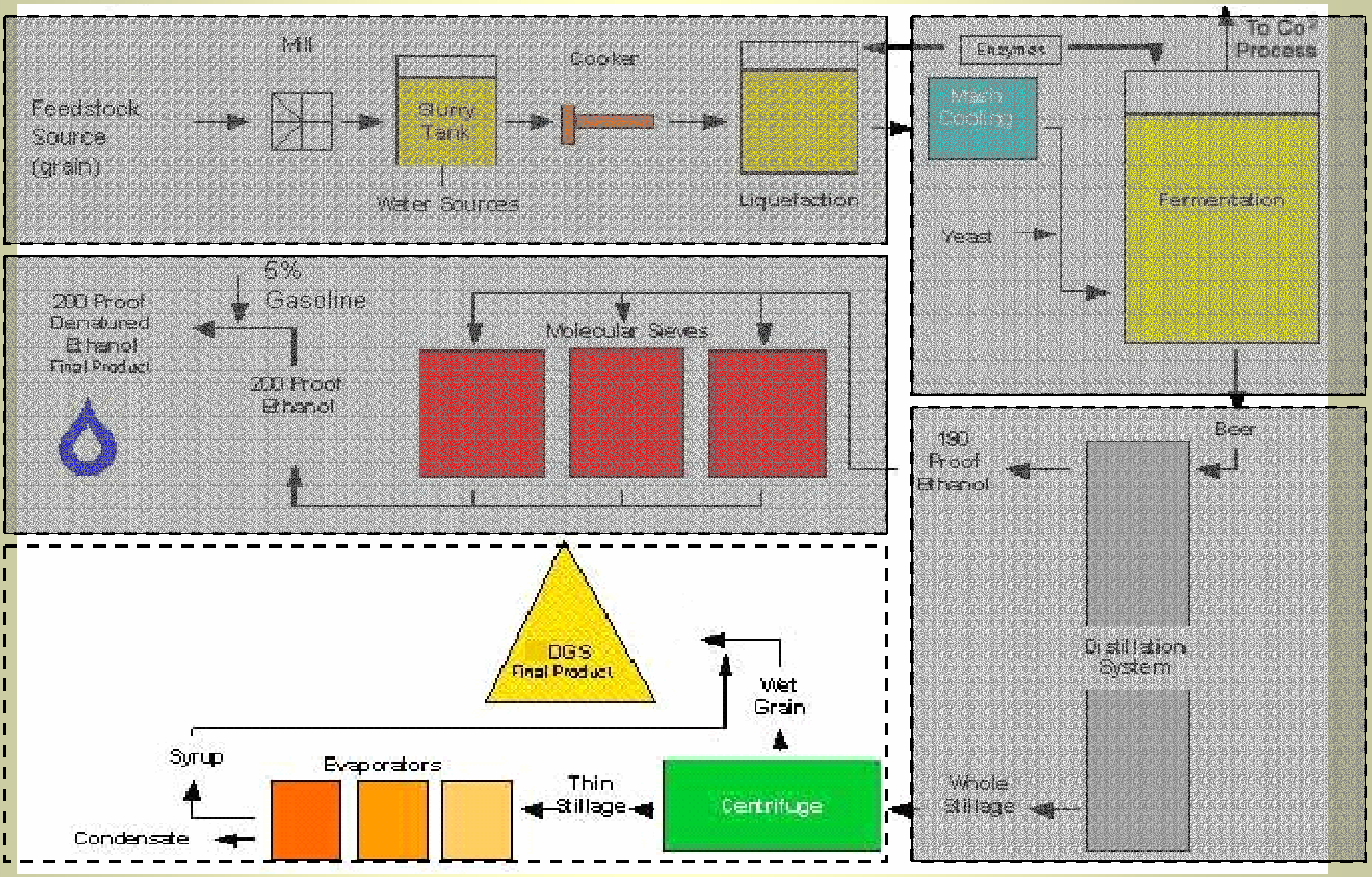


3 Å molecular sieves

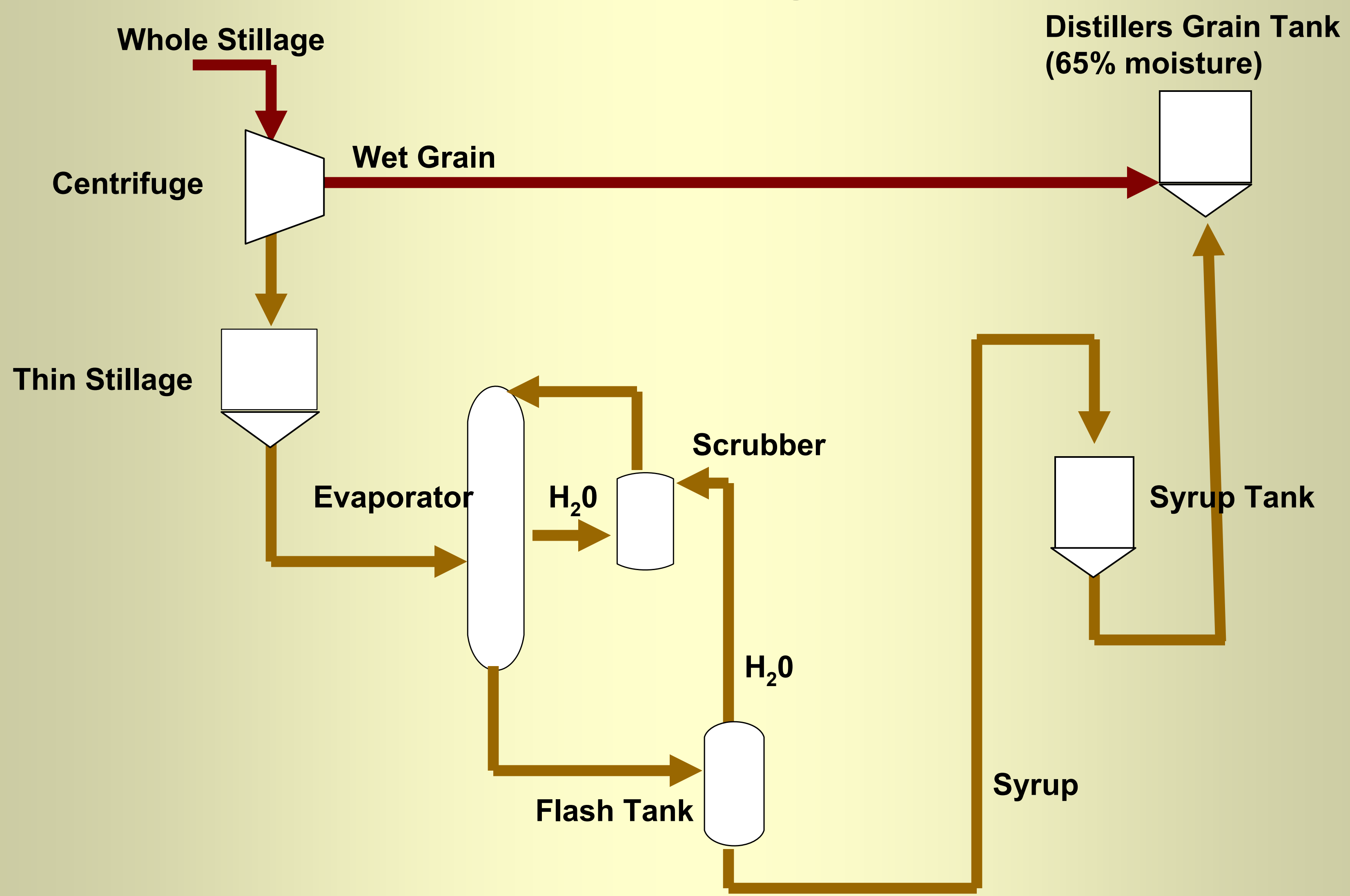
H_20 adsorbs onto sieve structure

Uses regeneration cycle to prolong bead life/ lower operating costs

Fermentation Process (Dry Mill)



Centrifuge/Evaporation Wet Distillers Grain



Equipment Pricing

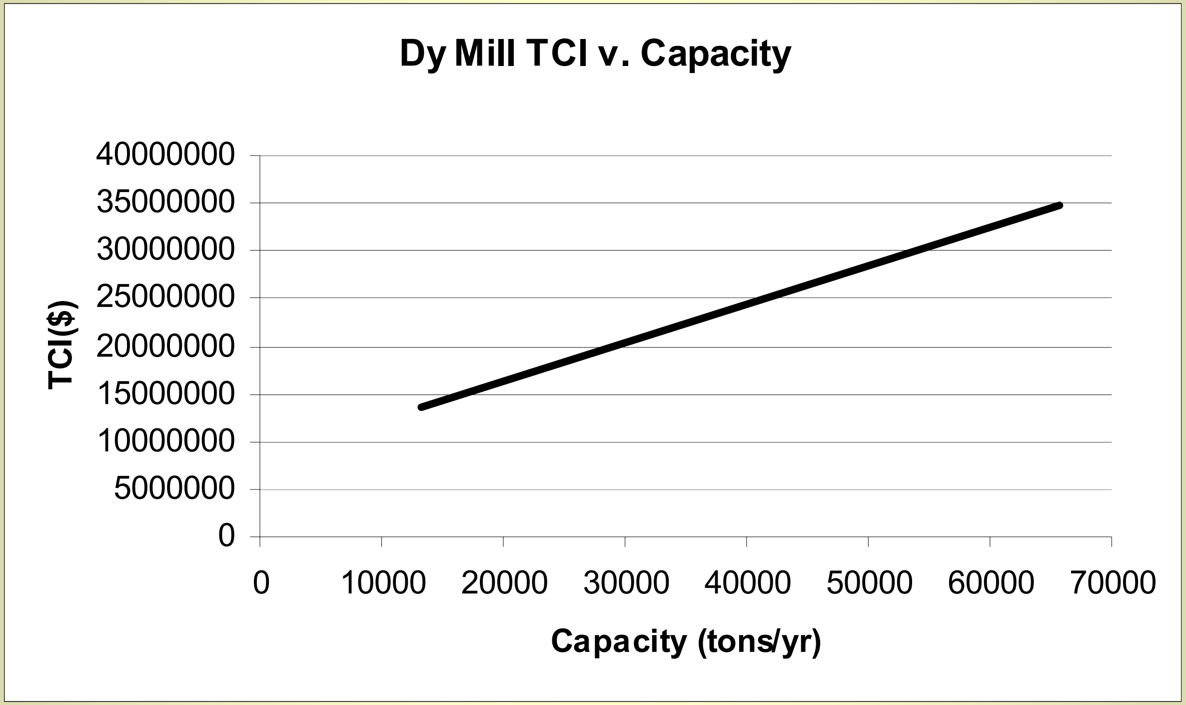
Equipment Pricing (20 MGY)			
Major Equipment (quantity)	**Description (each)**	**Material**	**Cost**
Hammer Mill	1.5 in to 100 mesh		$490,000
Cooker	5100 gallons	carbon steel	$70,000
Liquefaction Vessel	7650 gallons	carbon steel	$85,000
Fermenter (4)	250,000 gallons	stainless steel	$1,600,000
Pre-Fermentor Heat Exchangers (4)	840 ft^2, Fixed Tube Sheet	stainless steel	$73,000
Vent Scrubber			$15,000
Byproduct Storage		carbon steel	$30,500
Cooling Tower	10 degree, 25 F range	carbon steel	$257,000
Beer Column	D=5.5 ft 22 trays	stainless steel	$273,000
Beer Column Condenser	1870 ft^2, Fixed Tube Sheet	stainless steel	$31,000
Beer Column Reboiler	5600 ft^2, Fixed Tube Sheet	stainless steel	$73,000
Rectifying Column(1)	D=7.5 ft, 30 trays	stainless steel	$316,000
Rectifying Column Condenser	1000 ft^2, Fixed Tube Sheet	stainless steel	$18,000
Rectifying Column Reboiler	2300 ft^2, Fixed Tube Sheet	stainless steel	$34,000
Syrup Tank(2)	one 100,000 gallon, one 50,000 gallon	carbon steel	$170,000
Boiler		carbon steel	$609,000
Gasoline Storage Tank	40000 gallons	carbon steel	$80,000
Ethanol Storage Tank	136,000 gallons, API floating roof	carbon steel	$136,000
Molecular Sieve (9 pieces)			$572,000
Centrifuge	HS-805L, 31.5" x 104"		$400,000
Evaporation System	40000 ft^2		$1,000,000
Beer Well (5)	four 100,000 gallon, one 50,000 gallon	carbon steel	$460,000
Total Cost			$6,792,500

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

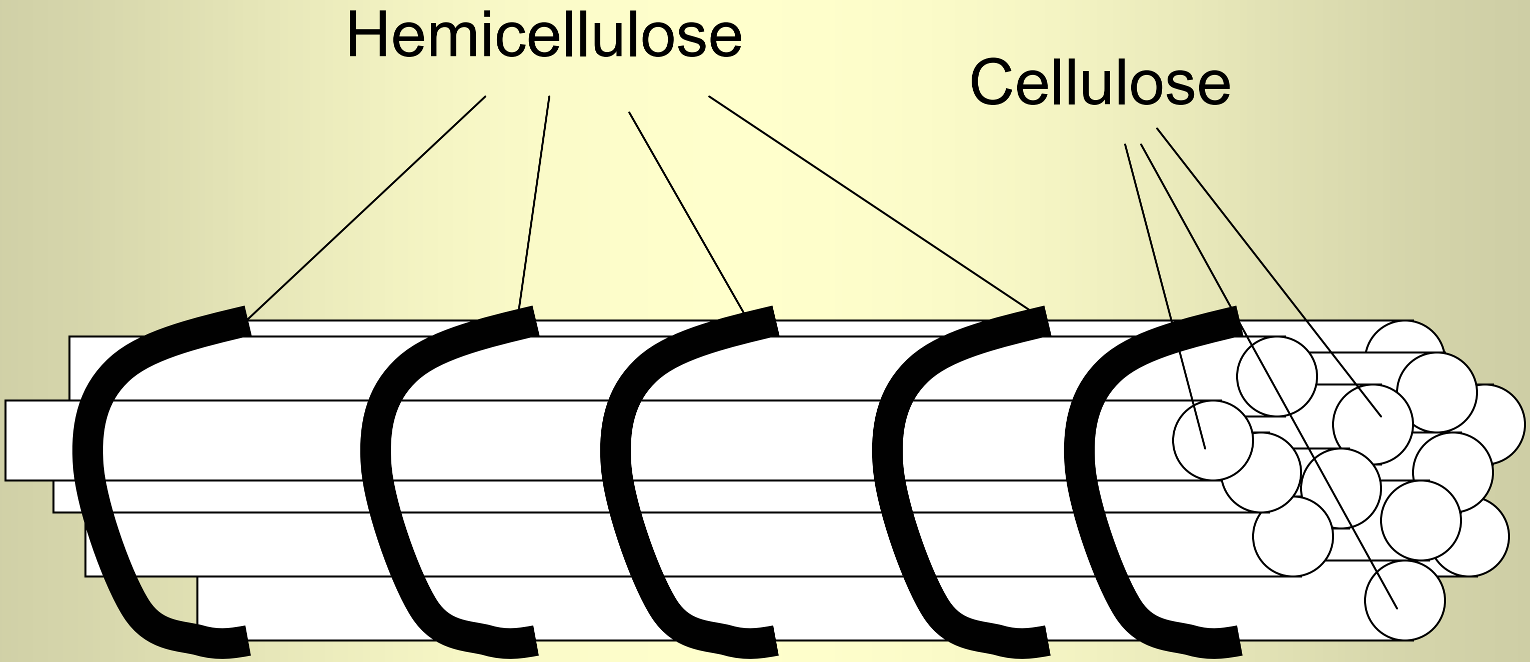


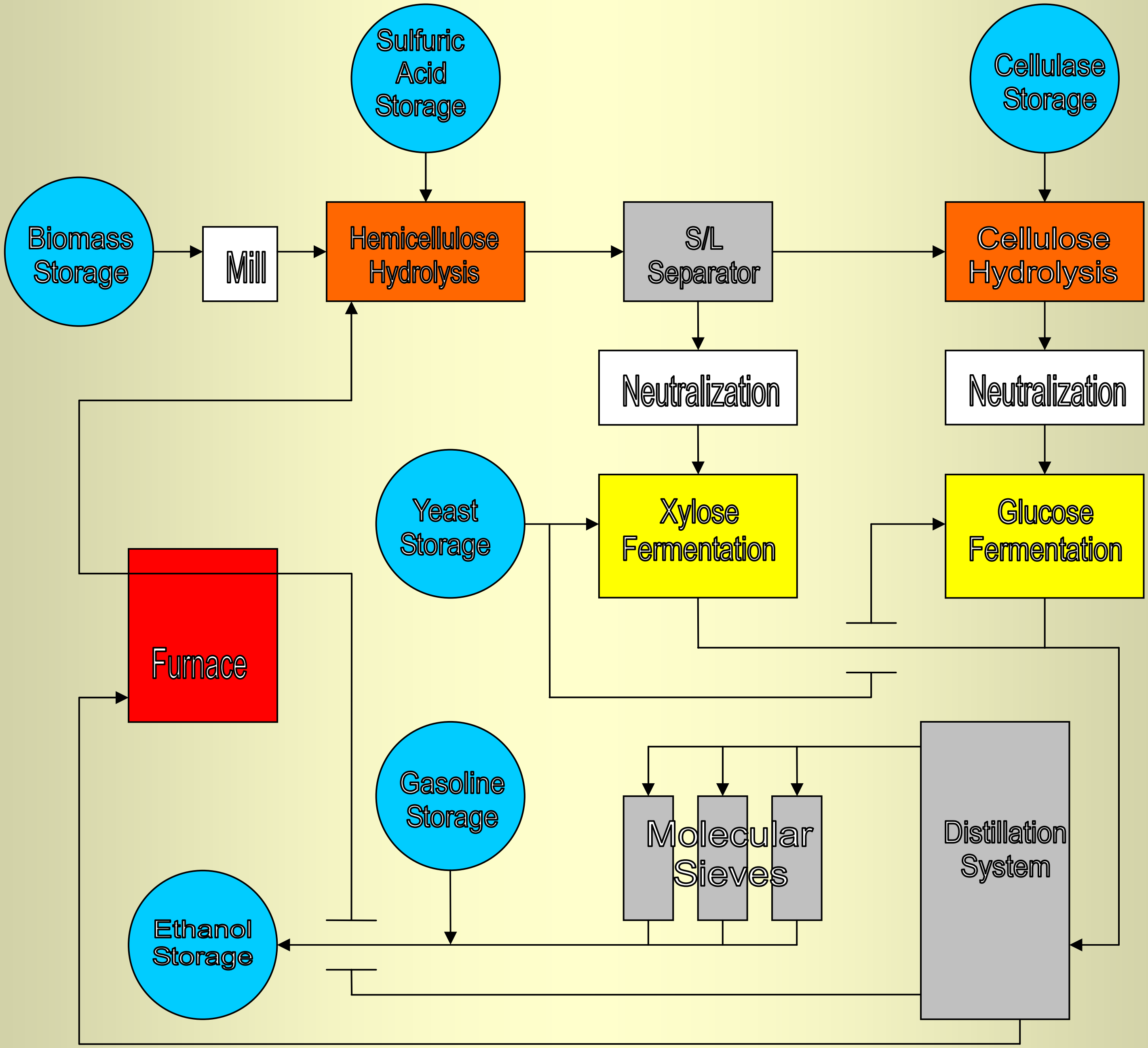
20 MGY Plant:

TCI = $35 million

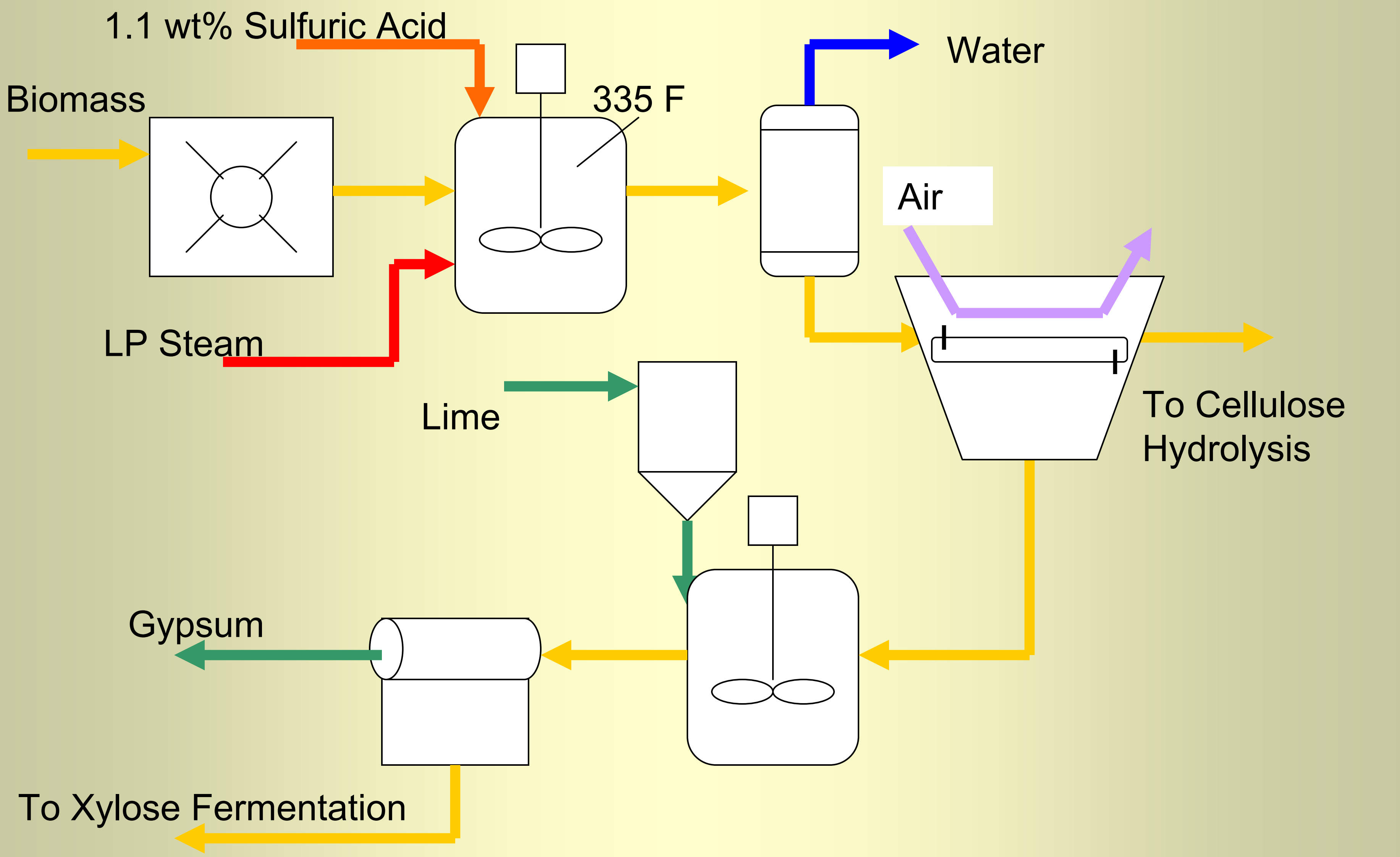
Operating Cost = $10 million

Processes for Lignocellulosic Crops

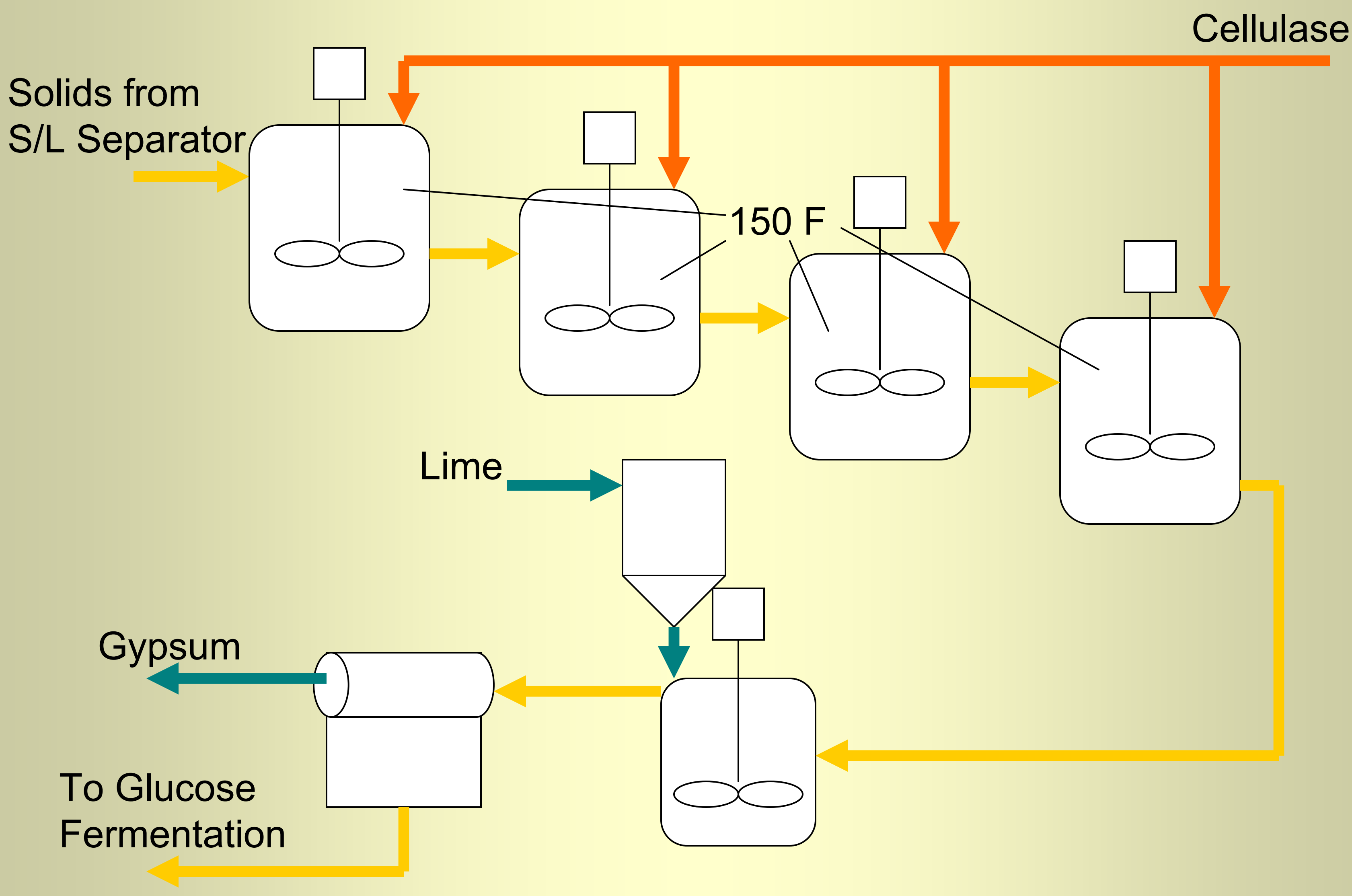



Sulfuric Acid Storage
Cellulase Storage
Biomass Storage
Mill
Hemicellulose Hydrolysis
S/L Separator
Cellulose Hydrolysis
Neutralization
Neutralization
Yeast Storage
Xylose Fermentation
Glucose Fermentation
Furnace
Gasoline Storage
Molecular Sieves
Distillation System
Ethanol Storage

Hemicellulose Hydrolysis



Cellulose Hydrolysis



Fermenters in Parallel

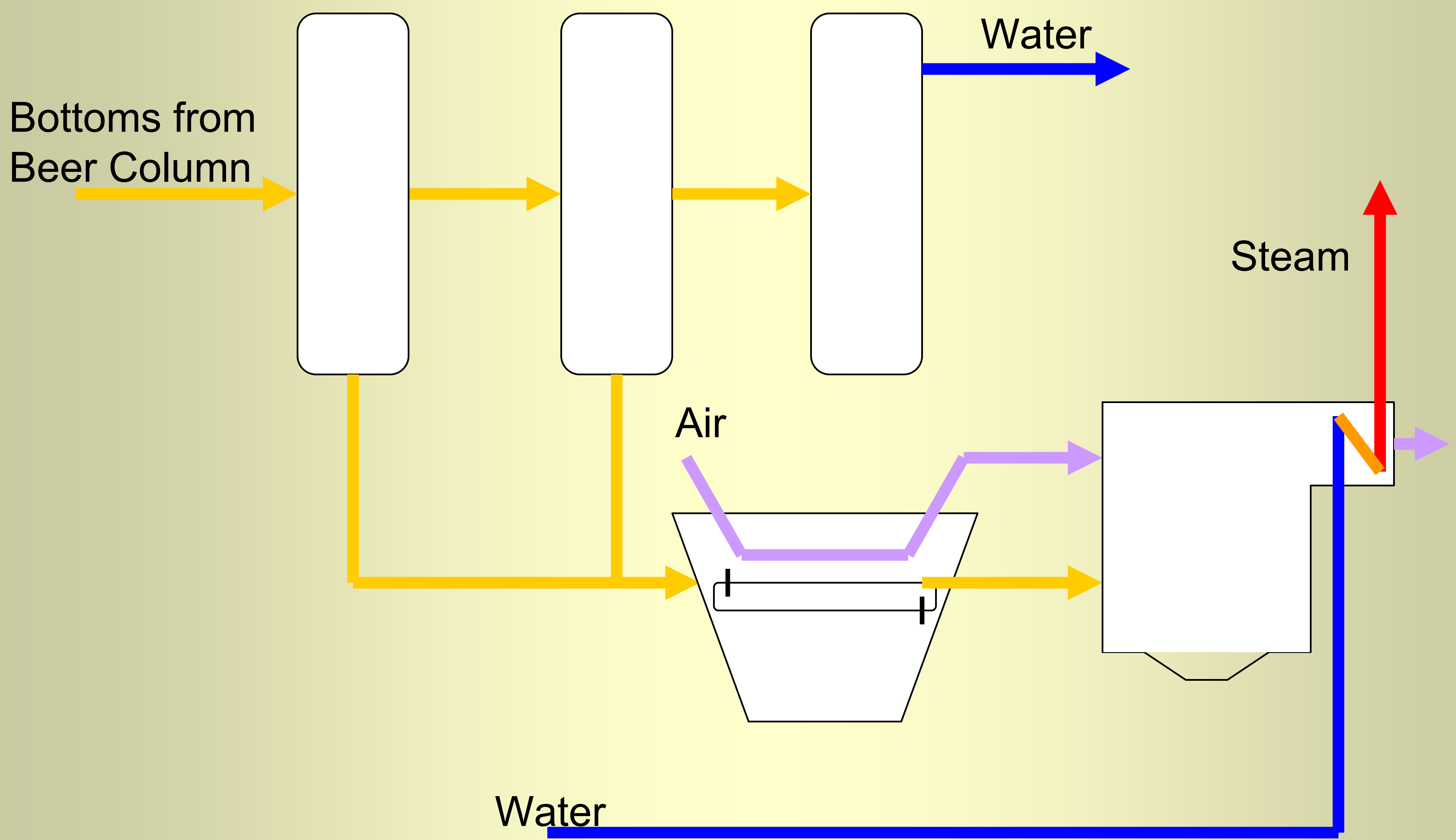
Xylose Fermenters

- Ferment 5 carbon sugars
- Use the yeast *Pachysolen tannophilus*

Glucose Fermenters

- Ferment 6 carbon sugars
- Use the yeast *Sacromyces cerevisiae*

Lignin Fueled Furnace

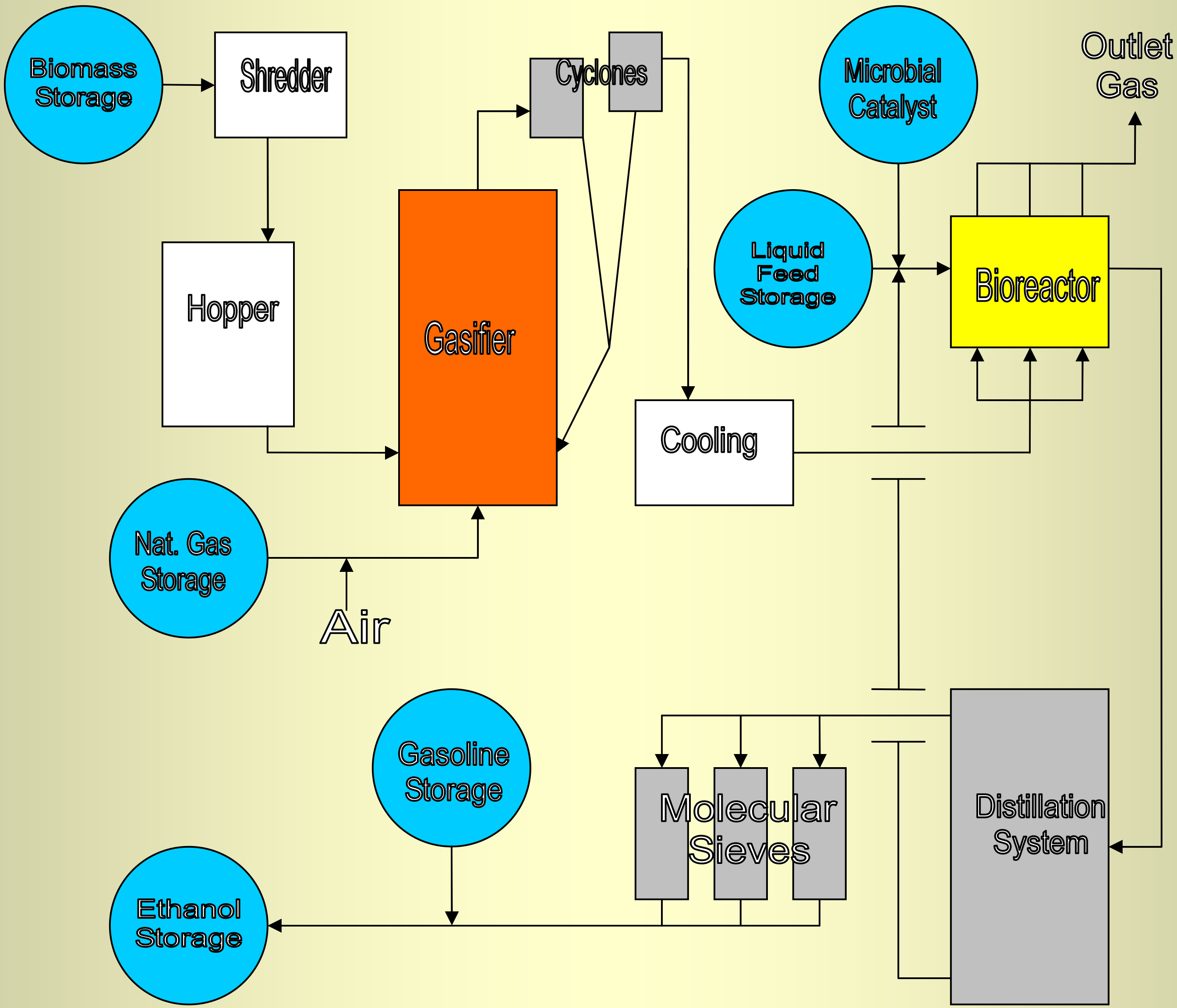


Dilute Acid Economics

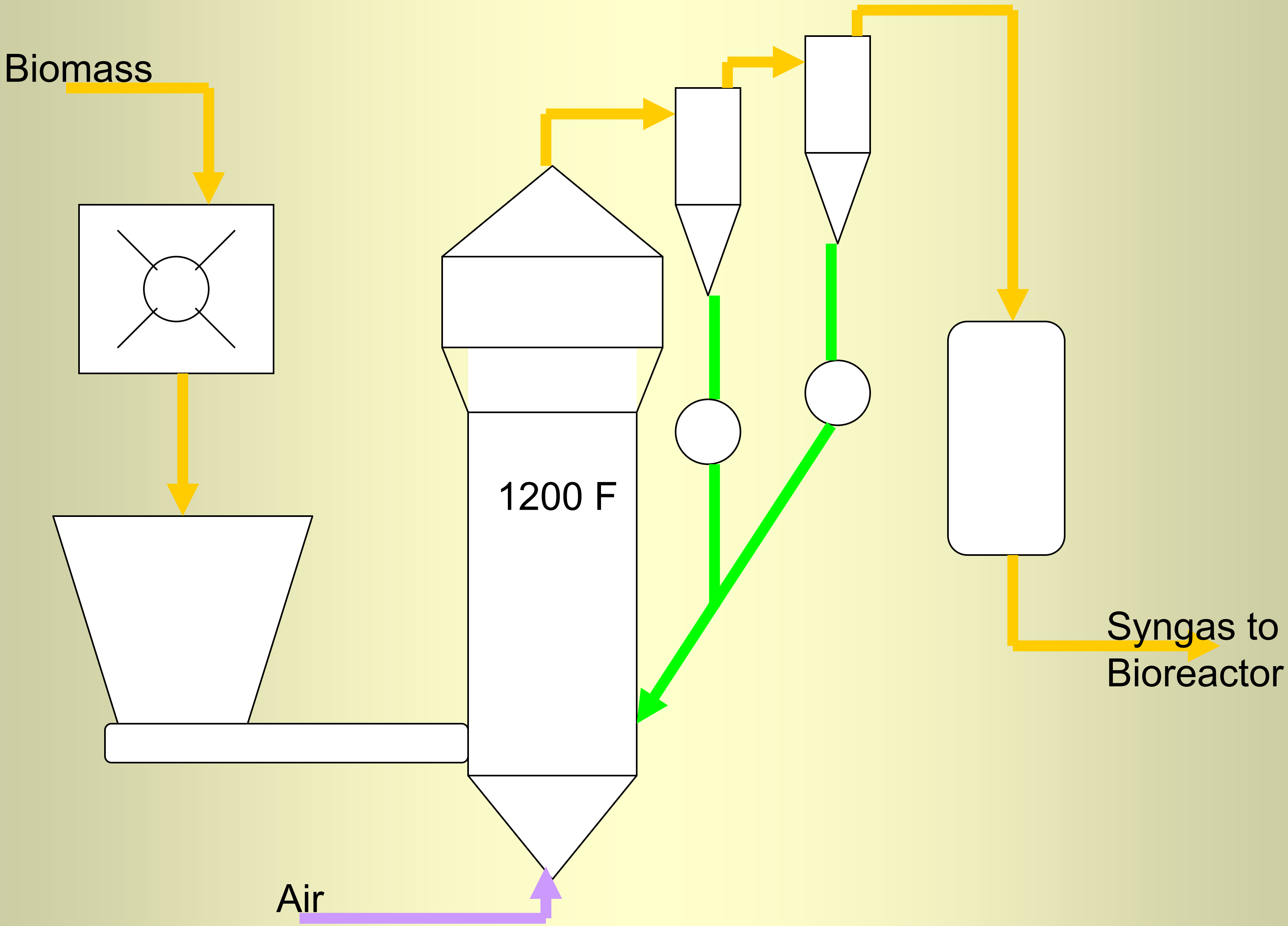
20 million gallon plant:

TCI = $50 million

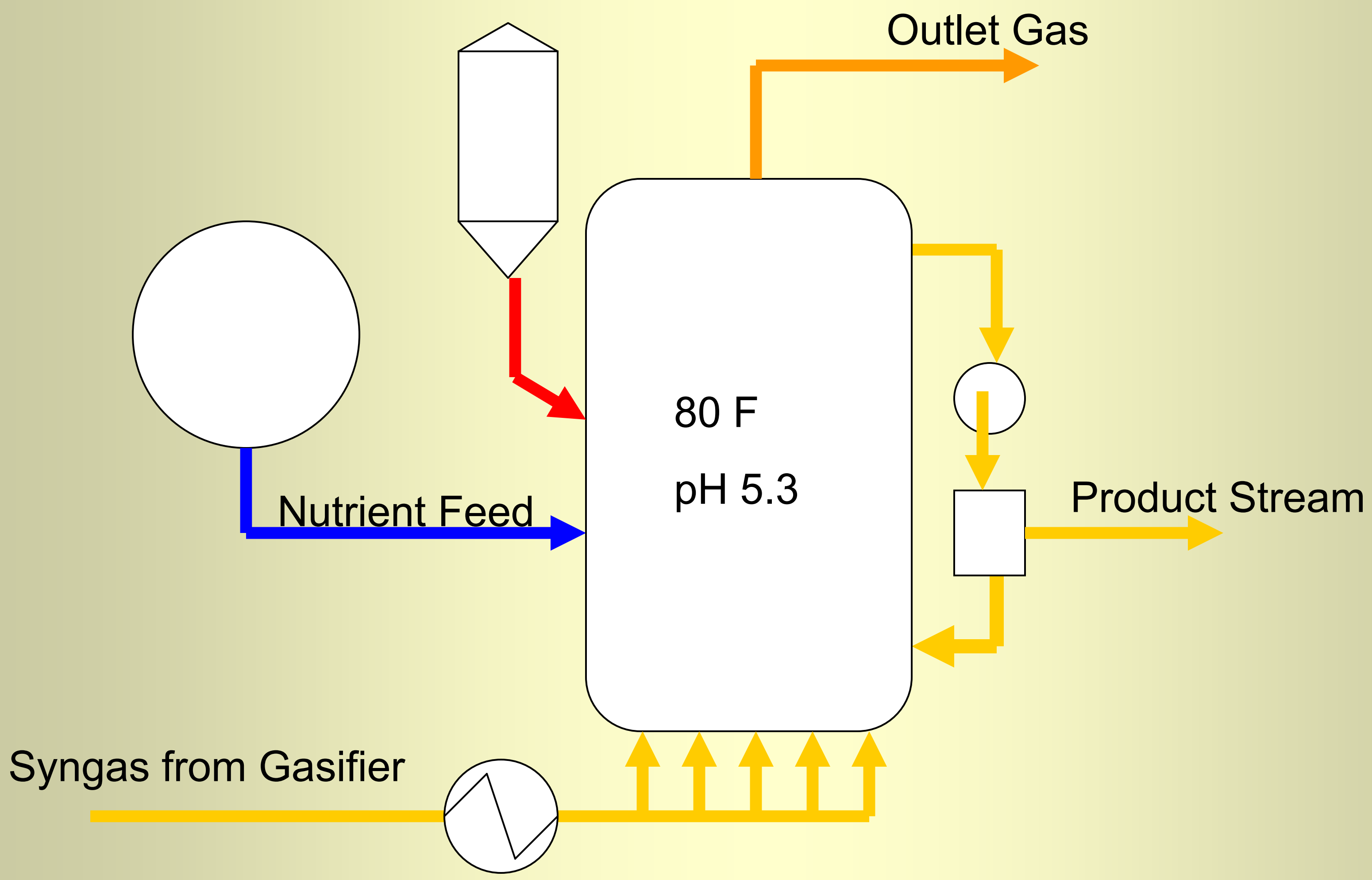
Operating Cost = $20 million


Biomass Storage
Shredder
Cyclones
Microbial Catalyst
Outlet Gas
Hopper
Gasifier
Liquid Feed Storage
Bioreactor
Cooling
Nat. Gas Storage
Air
Gasoline Storage
Molecular Sieves
Distillation System
Ethanol Storage

Gasifier



Fermentation



Gasification Economics

20 million gallon plant:

TCI = $80 million

Operating Cost = $12 million

Technology Comparison

Capital and Operating Costs
20 Mgal/yr Ethanol Plant

Plant Type	**TCI ($)**	**Operating Costs ($/yr)**
Fermentation	35 M	10 M
Dilute Acid	50 M	20 M
Gasification	80 M	12 M

Technology Comparison (cont.)

Feedstock to Ethanol Conversions

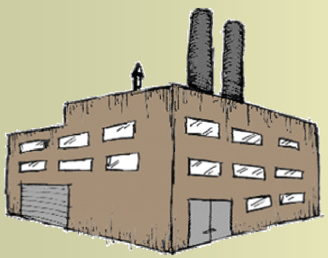
(tons ethanol / ton feed)

	Wheat	**Sorghum**	**Switchgrass**
Fermentation	0.277	0.286	0.023
Dilute Acid	0.043	0.038	0.299
Gasification	0.169	0.168	0.171

Decision to make when building a plant

Feed Source

Feed Type



Location

Technology

- Can this be done manually?
- How do we calculate all the variables and decide the optimal solution?

Relationship between feed supply and plant

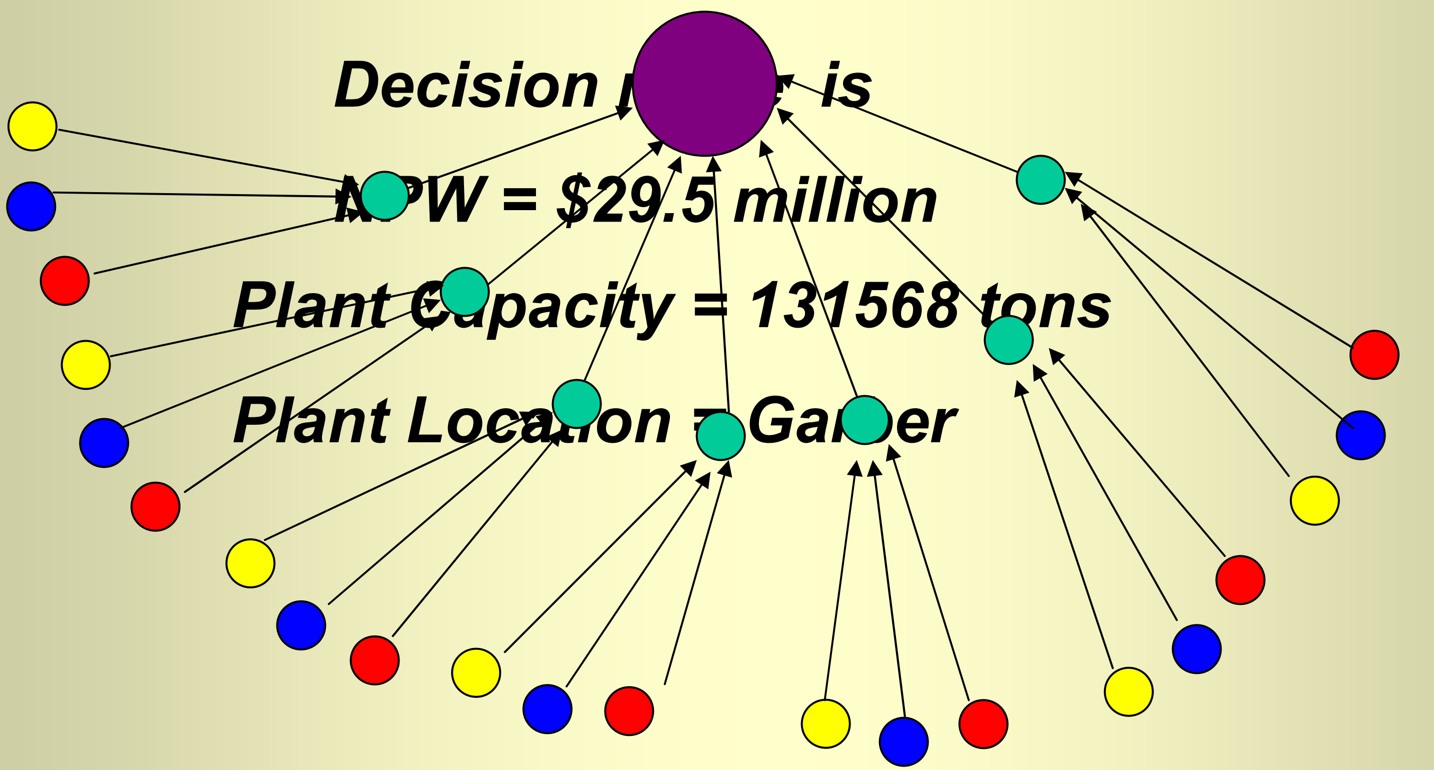
Feed Supply = 7 points

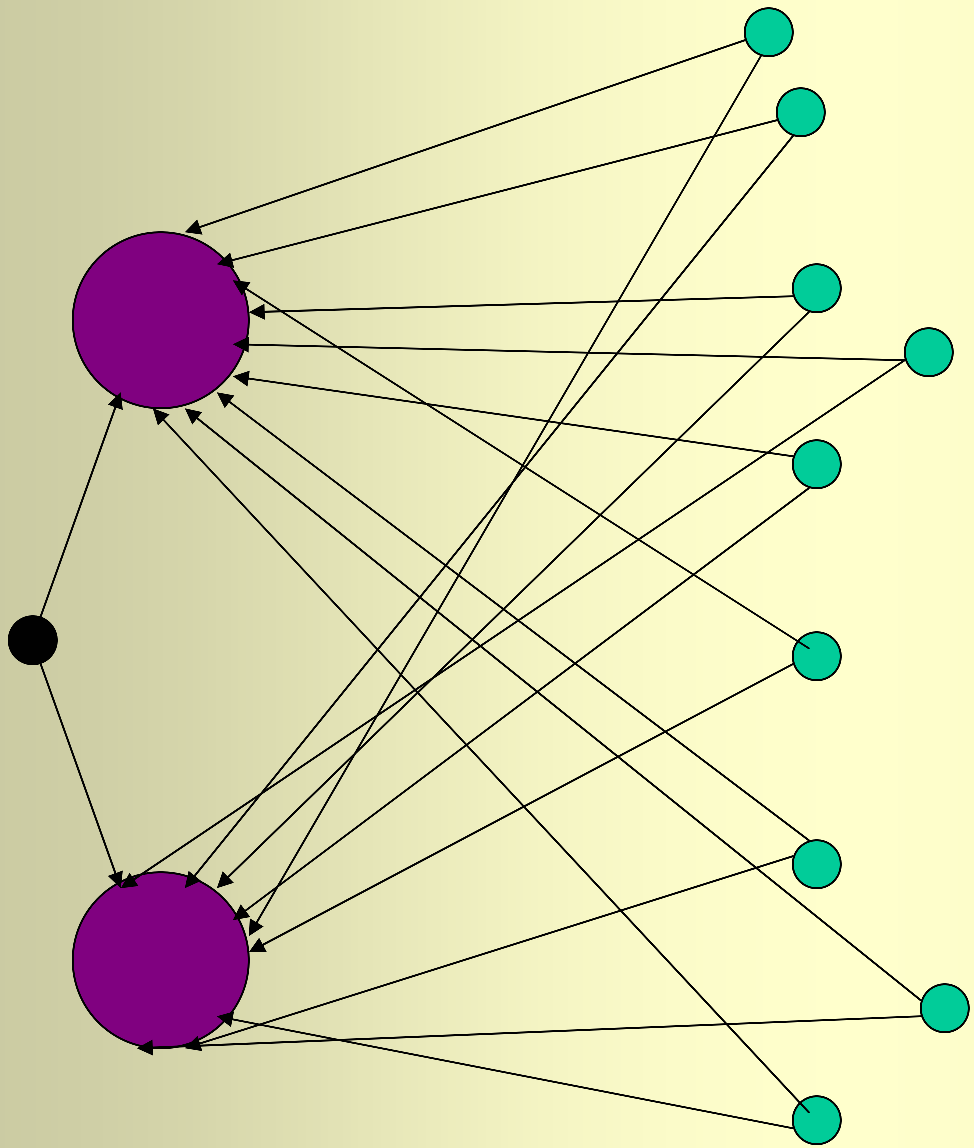
Plant Location = Garber

Wheat =

Sorghum =

Switchgrass =





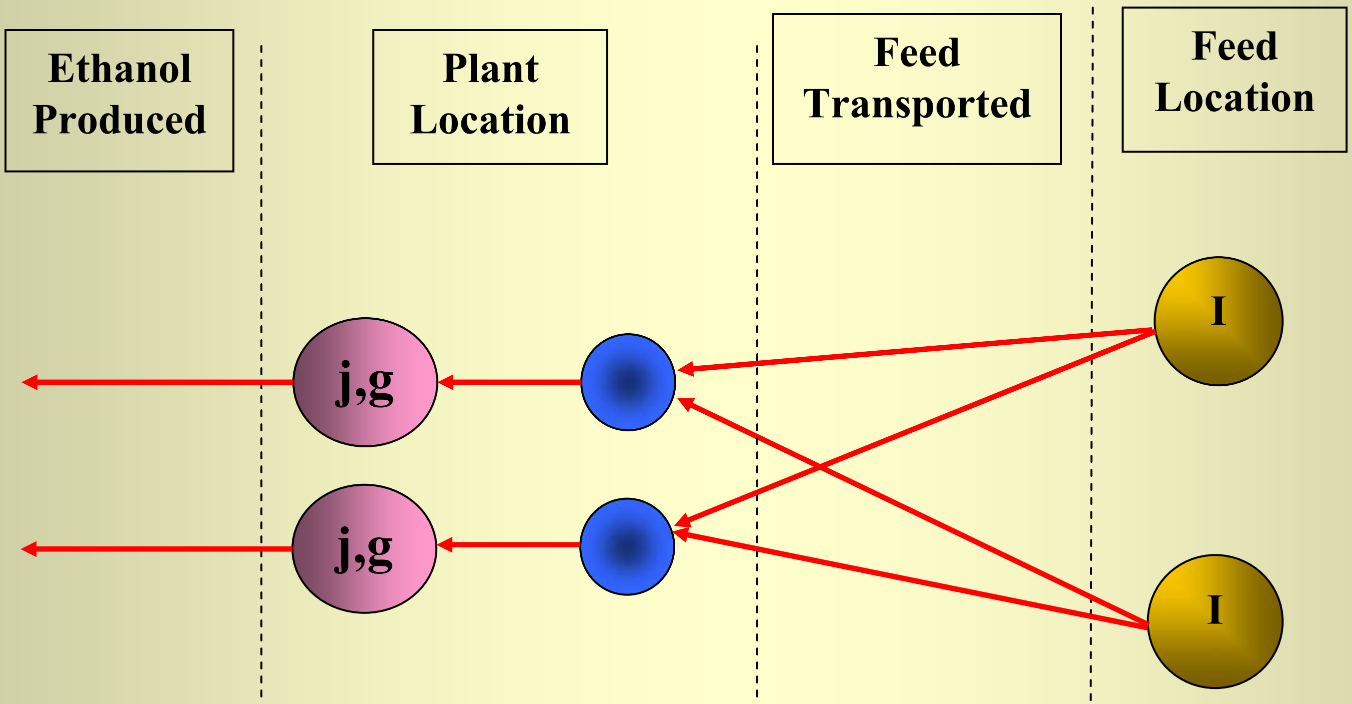
What if there is more than 1 plant and many feed sources?

Feed Supply = 78 points

Plant Location = 9 points

Therefore using a model would make the calculations possible

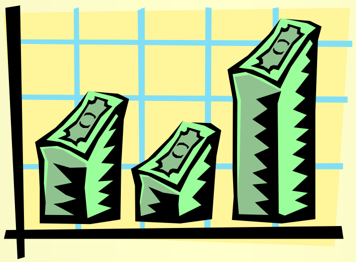
Mathematical Model Flow



Decision for building an Ethanol plant based on

$$NPW = \left(Dft * Life\right)\left[\sum\left(Sales\right) - \sum\begin{pmatrix}Bought\\ Feed\end{pmatrix} - \sum\begin{pmatrix}Transportation\\ Cost\end{pmatrix} - \sum\begin{pmatrix}Storage\\ Cost\end{pmatrix} - \sum\begin{pmatrix}Operating\\ Cost\end{pmatrix}\right] - \sum\begin{pmatrix}Capital\\ Investment\end{pmatrix}$$

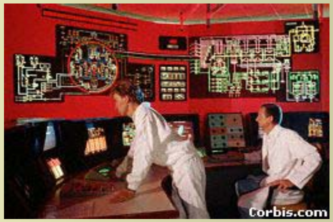
The plant is chosen based on **MAXIMIZING** the NPW



Transported Feed

Storage

Bought Feed



Operating Cost

Variables which affect the profitability of the Ethanol plant

Plant Throughput

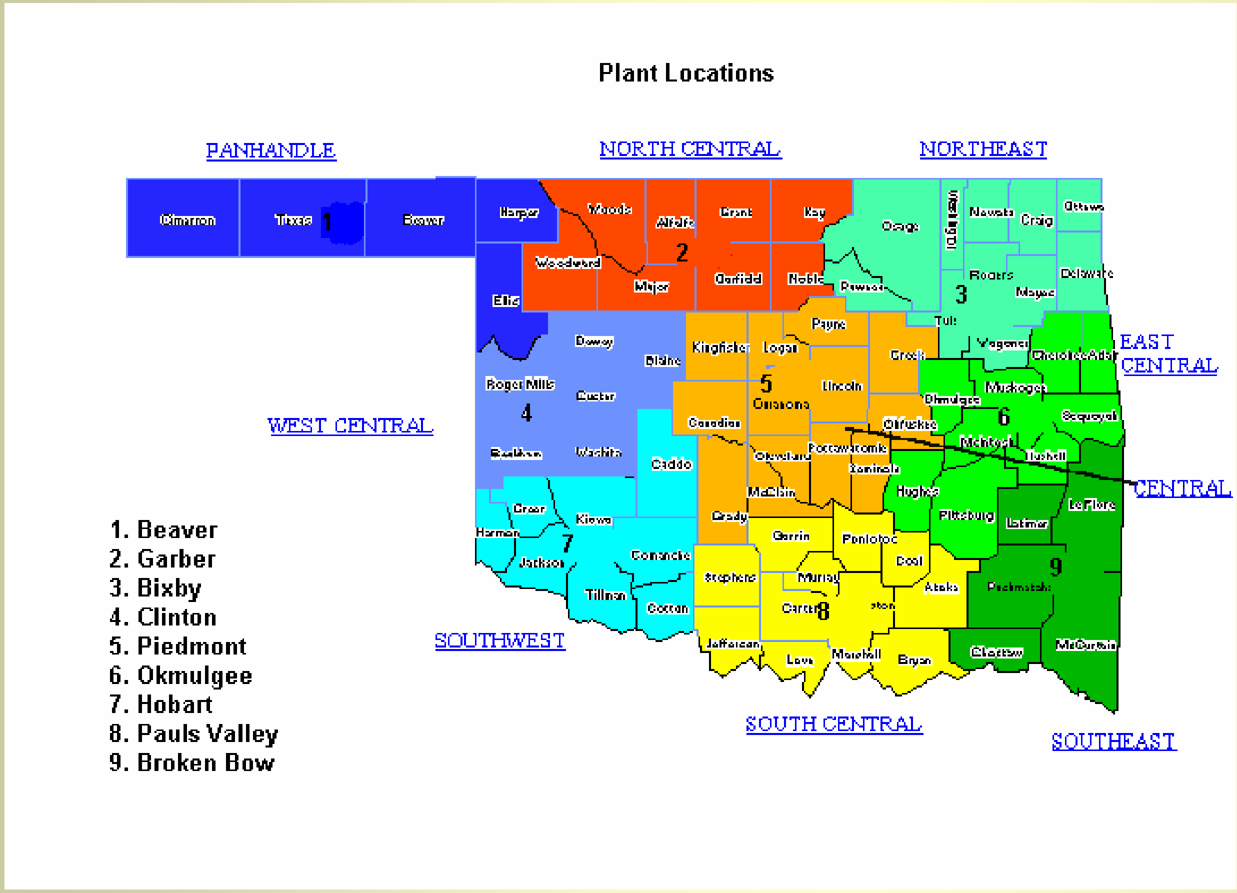
Ethanol Produced

Capital Investment

Variables which affect the profitability of the Ethanol plant

Feed

$$\sum\begin{pmatrix} Bought \\ Feed \end{pmatrix} \leq \sum\begin{pmatrix} Harvested \\ Feed \end{pmatrix}$$



9-plant locations

78-feed locations

3-types of feed

Plant Throughput

$$\begin{pmatrix} Yearly \\ Trhoughput \end{pmatrix} \leq \begin{pmatrix} Max \\ Size \end{pmatrix}$$

$$\begin{pmatrix} Yearly \\ Trhoughput \end{pmatrix} \geq \begin{pmatrix} Minimum \\ Throughput \end{pmatrix}$$

$$\begin{pmatrix} Ethanol \\ Produced \end{pmatrix} \leq \frac{(Yearly\,Throughput)}{12}$$

Capital Investment

$$\begin{pmatrix} Capital \\ Investment \end{pmatrix} = \begin{pmatrix} FCI \\ Slope \end{pmatrix} \begin{pmatrix} Plant \\ Throughput \end{pmatrix} + \begin{pmatrix} FCI \\ Intercept \end{pmatrix}$$

$$\begin{pmatrix} Capital \\ Investment \end{pmatrix} \leq \begin{pmatrix} Maximum \\ FCI \end{pmatrix}$$

Storage

1st Month Storage

$$storage_{t1} = \sum_i \begin{pmatrix} Bought \\ Feed \end{pmatrix}_{t1} - \sum_g \begin{pmatrix} Feed \\ \Pr ocess \end{pmatrix}_{t1}$$

Subsequent Month Storage

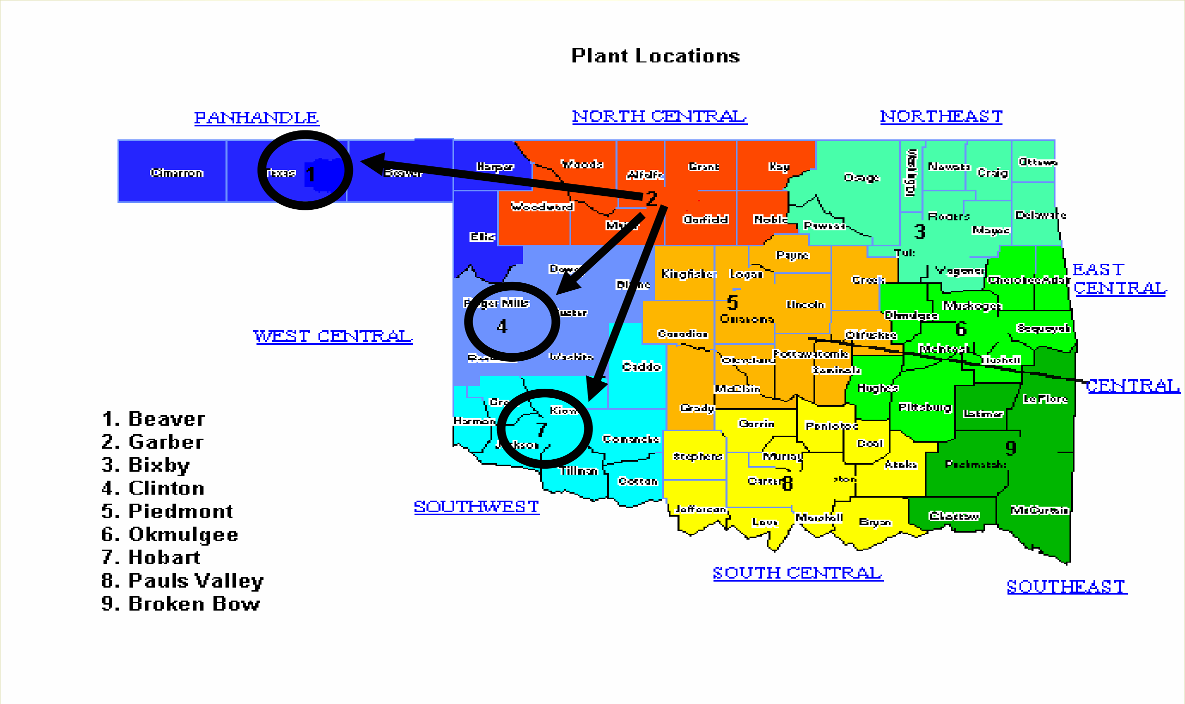
$$\sum (Storage_t) \le \sum (Storage_{t-1}) + \sum \begin{pmatrix} Bought \\ Feed_t \end{pmatrix} - \sum \begin{pmatrix} Feed \\ \Pr ocessed_t \end{pmatrix}$$

Operating Cost

$$\begin{pmatrix} Operating \\ Cost \end{pmatrix} = \begin{pmatrix} OP \\ Slope \end{pmatrix} \begin{pmatrix} Ethanol \\ \Pr oduced \end{pmatrix}$$

Transportation of Feed

$$\begin{pmatrix} Transported \\ Feed \end{pmatrix} = \begin{pmatrix} Bought \\ Feed \end{pmatrix} * \begin{pmatrix} Distance\ of \\ Source\ to\ plant \end{pmatrix}$$



Ethanol Produced

$$\sum\left(\begin{matrix} Ethanol \\ \Pr oduced \end{matrix}\right) = \sum\left(\begin{matrix} \Pr ocess \\ Effeciency \end{matrix}\right) * \sum\left(\begin{matrix} Feed \\ \Pr ocessed \end{matrix}\right)$$

$$\left(\begin{matrix} Ethanol \\ \Pr oduced \end{matrix}\right) \le \frac{1.2*(Max\ Size)}{12}$$

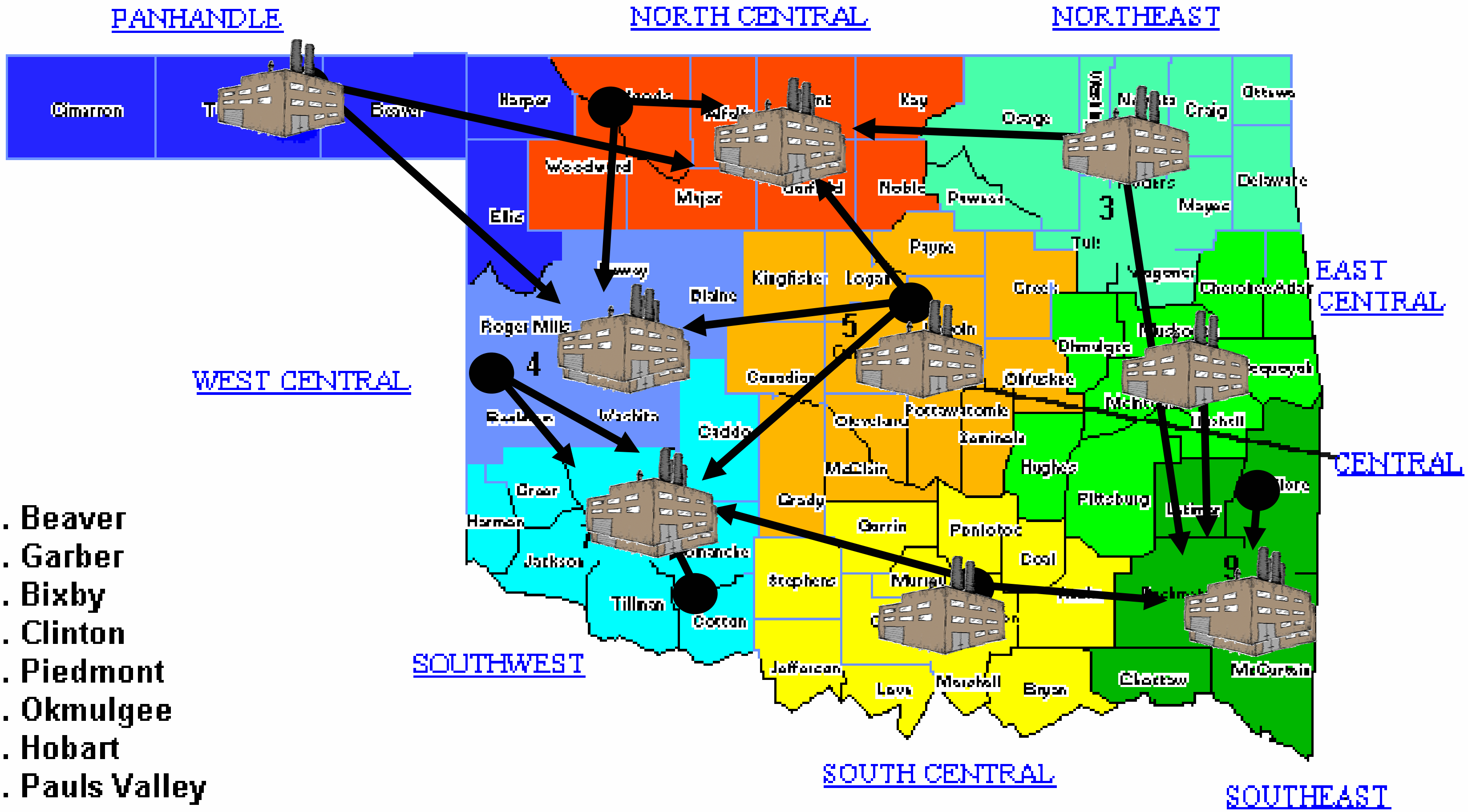
Generalized Model

- 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

					Total Feed Bought per month	
Capacity (million tons)	**NPW($ million)**	**Ethanol produced (tons/month)**	**Plants**	**Capital investment ($)**	**Wheat**	**Sorghum**
0.658	$2,508	54822	garber	$22,504,130	391.58	8839.26
			clinton	$21,736,270	391.58	8839.26
			hobart	$22,808,630	391.58	8839.26
			broken_bow	$20,554,580	391.58	8839.26

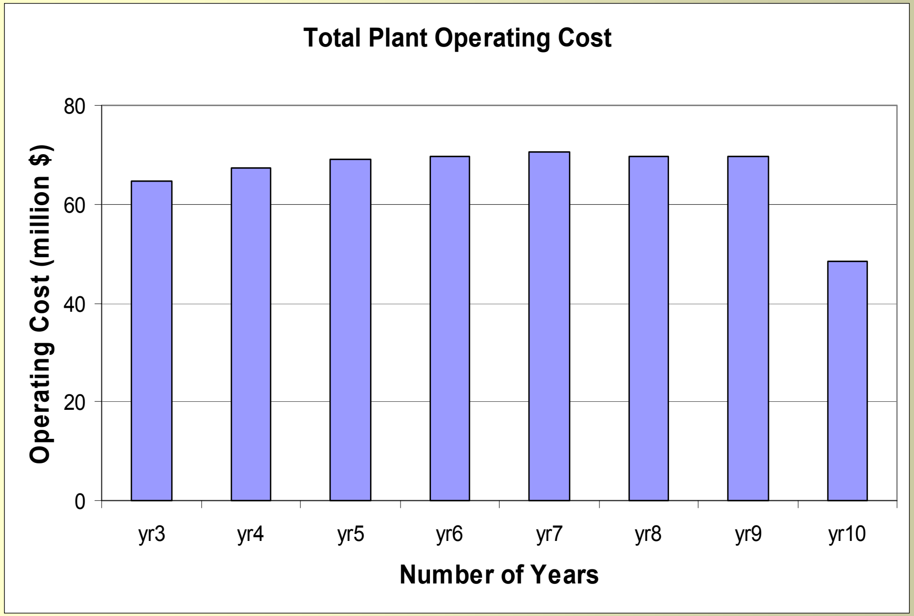
Plant Locations



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

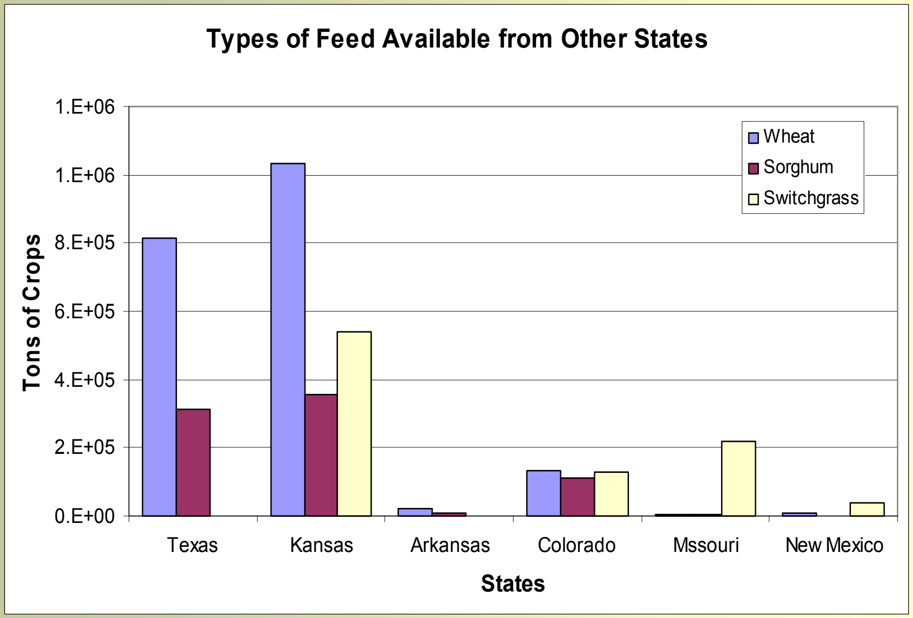
• Operating Cost

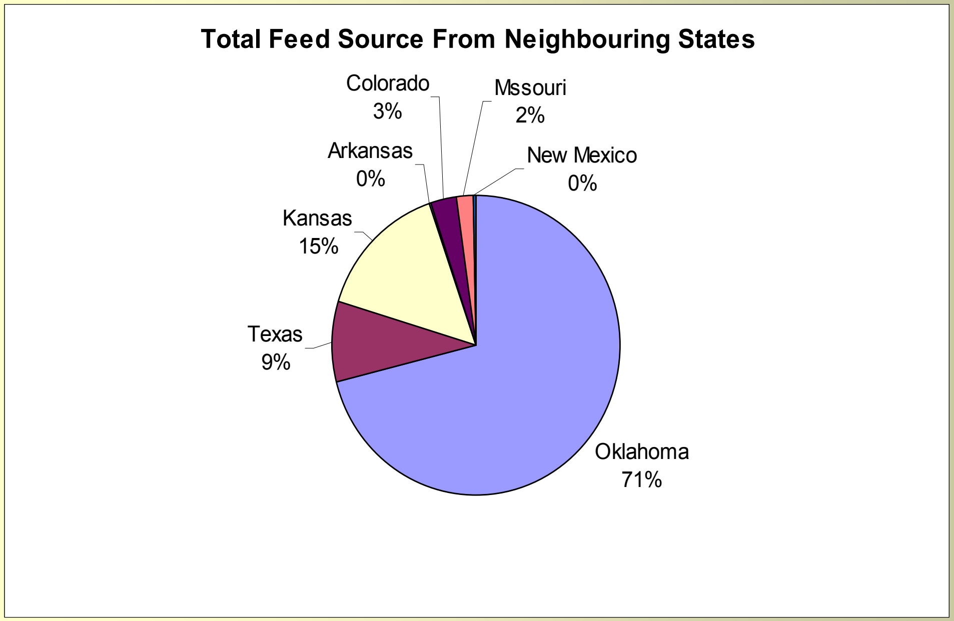
- All plants were built in the first 2 years.
- Start producing Ethanol in the 3rd year.
- Each plant capacity produces 55,000 tons of ethanol per month



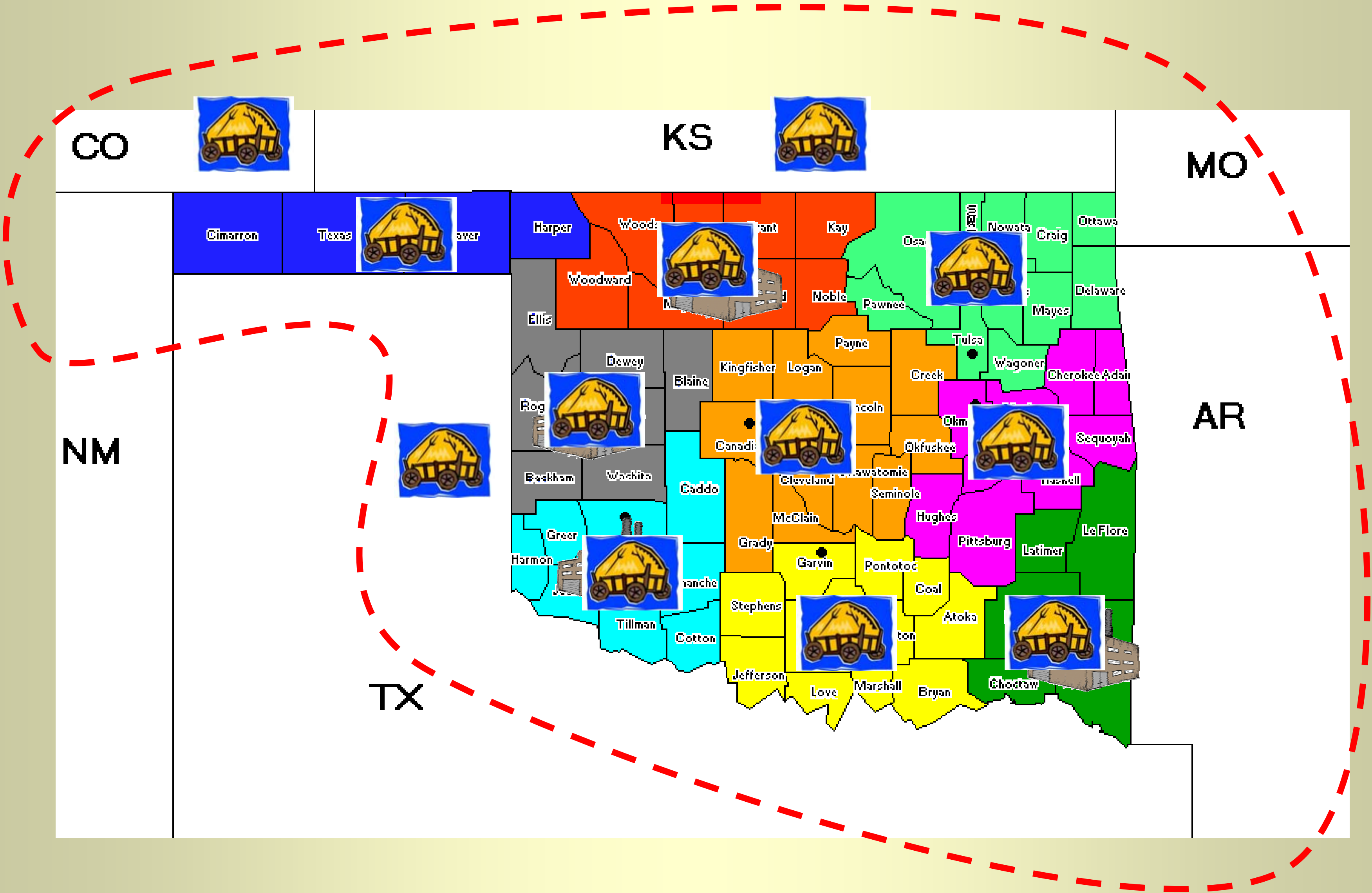
- Economic and Sensitivity Analysis based on
  - Feed Source Variation
  - Capacity Variation
  - Cost Variation
- Deterministic and Stochastic Analysis
- Conclusion

Feed Source From Bordering States





- Majority feed comes from Texas, Kansas and Colorado.

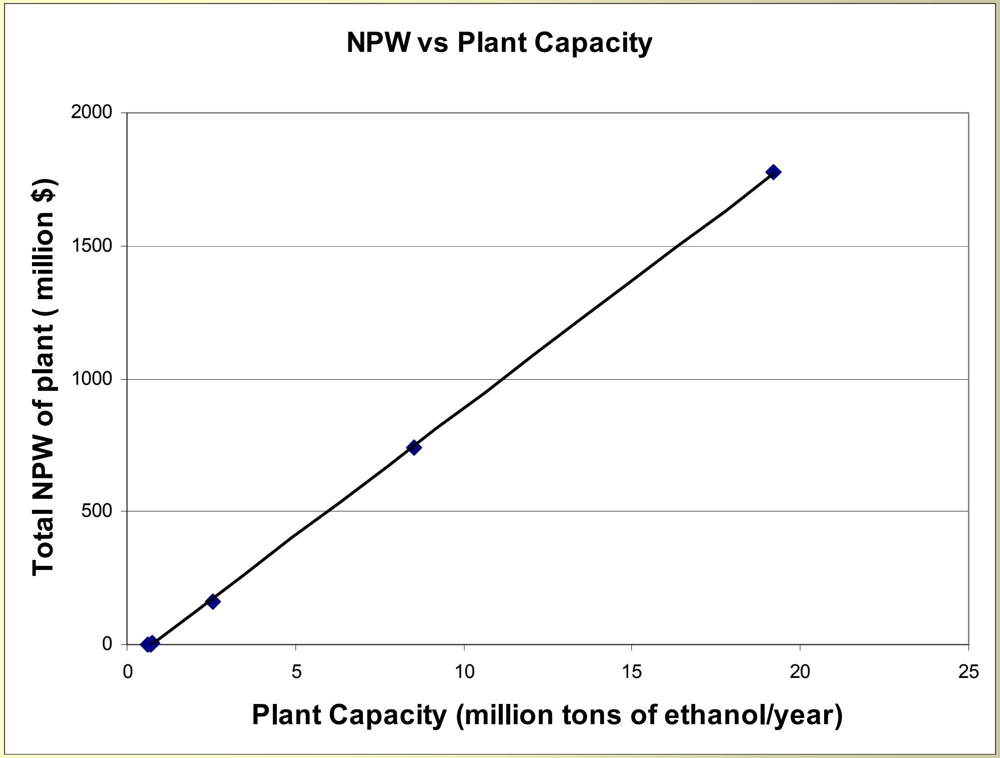


CO
KS
MO
NM
AR
TX
Cimarron
Texas
Harper
Woods
Kay
Nowata
Craig
Ottawa
Woodward
Noble
Pawnee
Delaware
Mayes
Ellis
Dewey
Payne
Tulsa
Blaine
Kingfisher
Logan
Creek
Wagoner
Cherokee
Adair
Sequoyah
Okfuskee
Beckham
Washita
Caddo
Cleveland
Seminole
McClain
Hughes
Greer
Harmon
Grady
Garvin
Pontotoc
Pittsburg
Latimer
Le Flore
Coal
Stephens
Atoka
Tillman
Cotton
Jefferson
Love
Marshall
Bryan
Choctaw

- Capacity Variation

•NPW increase linearly with plant capacity

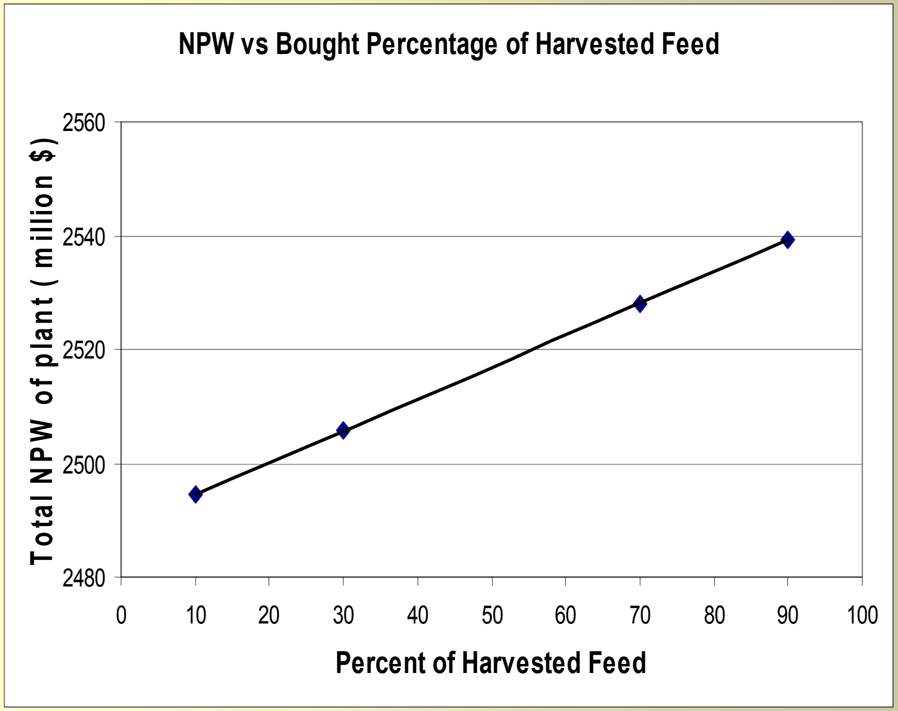
•Linearity is because the capacity is also a linear function of the operating cost and capital investment



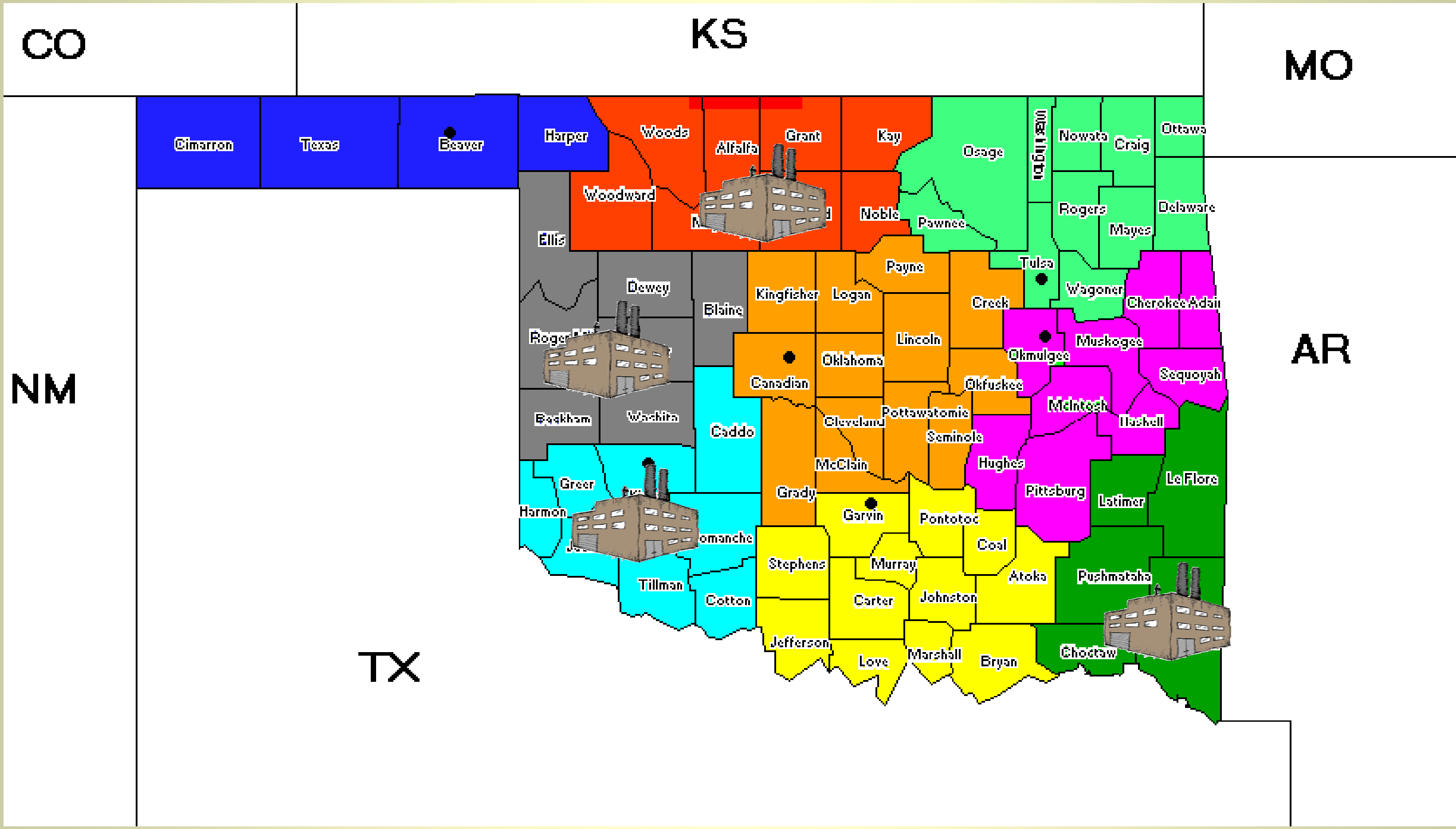
- Percent Variation of Bought Feed

•NPW increases with the availability of harvested feed

•Increment is linear because its a function of bought feed



When Bought Feed < 10% of Total Feed Harvested



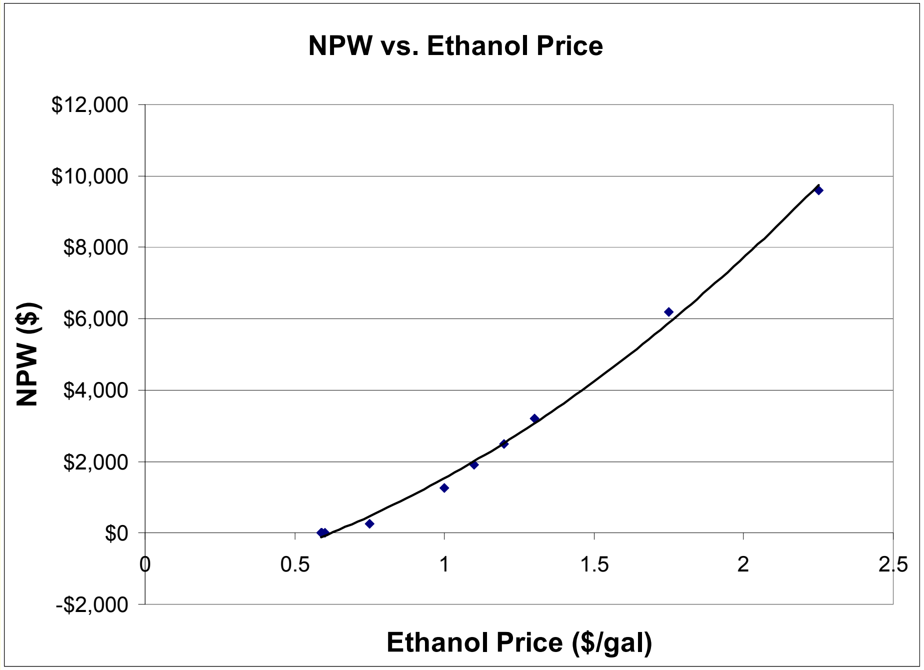
NO PLANTS BUILT

- # 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

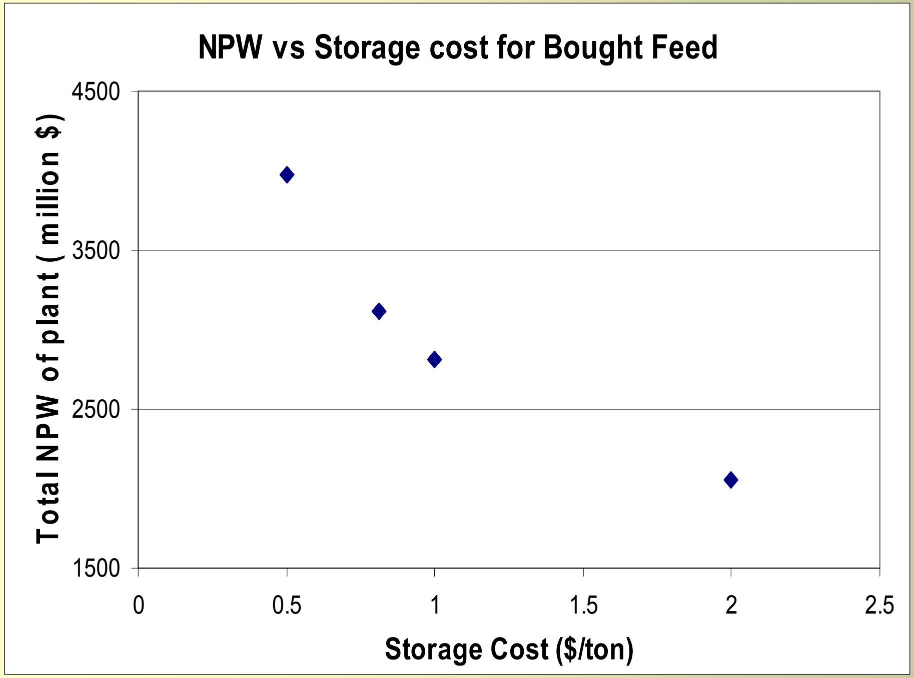
<table>
<tr><th>Ethanol Price ($/gal)</th><th>Number of Plants</th><th>Location</th><th>Capacity (tons)</th><th>Technology</th><th>Cap. Investment ($)</th><th>NPW ($ million)</th></tr>
<tr><td>$0.59</td><td>0</td><td>0</td><td>0</td><td>0</td><td>$0</td><td>$0</td></tr>
<tr><td>$0.60</td><td>1</td><td>Broken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

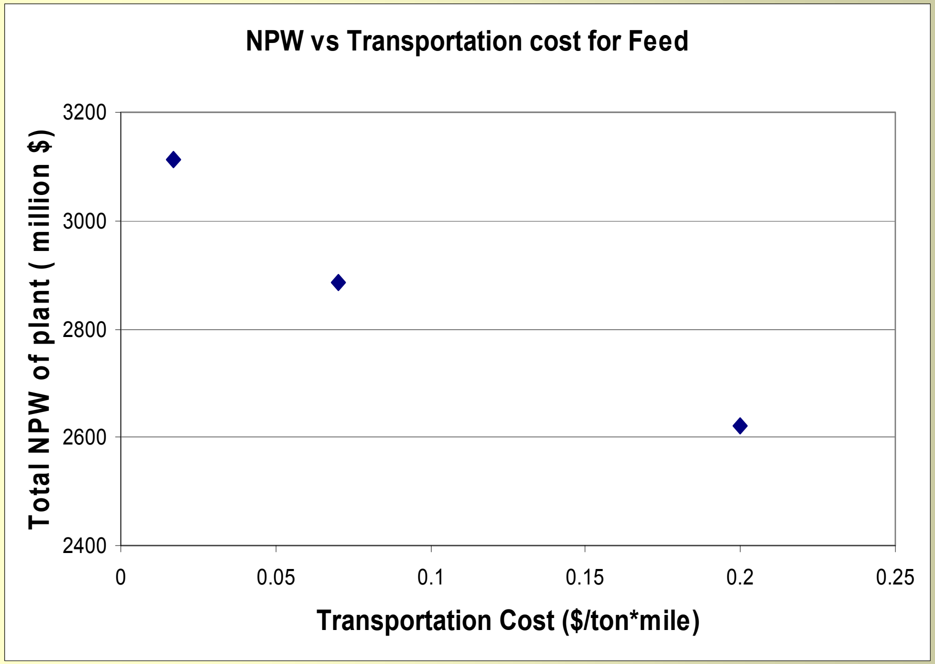


Result From Storage Cost Variation

		Feed Bought (million tons)			
Stoage Cost ($/ton)	Plants	Wheat	Sorghum	NPW ($ million)	Capacity (tons)
$0.50	garber clinton hobart broken_bow	4.70	45.85	$3,970	657860
$0.81	garber clinton hobart broken_bow	1.57	35.36	$3,111	657860
$1.00	garber clinton hobart broken_bow	2.94	35.36	$2,814	657860
$2.00	garber clinton hobart broken_bow	0.00	9.42	$2,053	657860

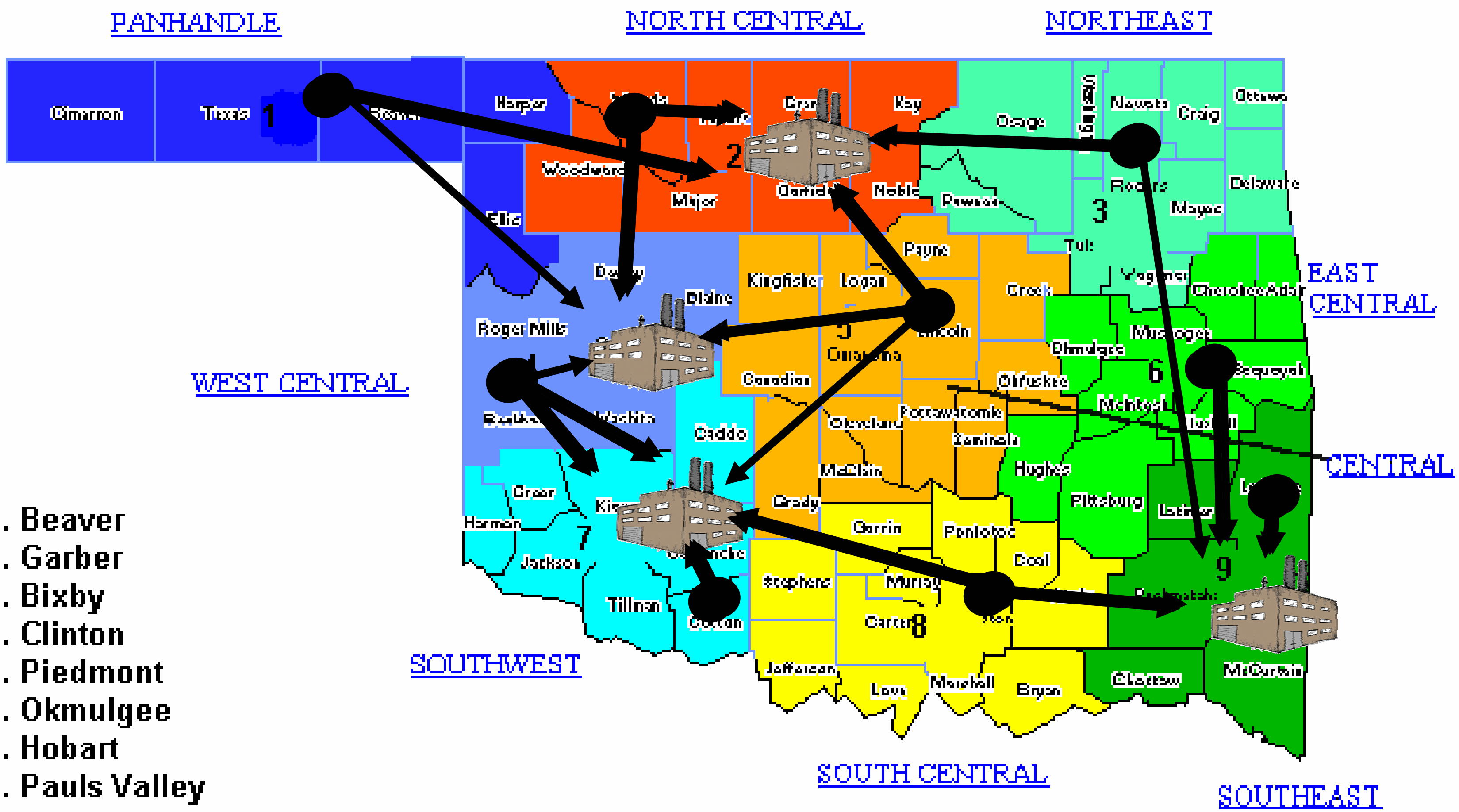
Transportation Cost Variation

- 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.



Transportation Cost = $0.0468/ton

Plant Locations



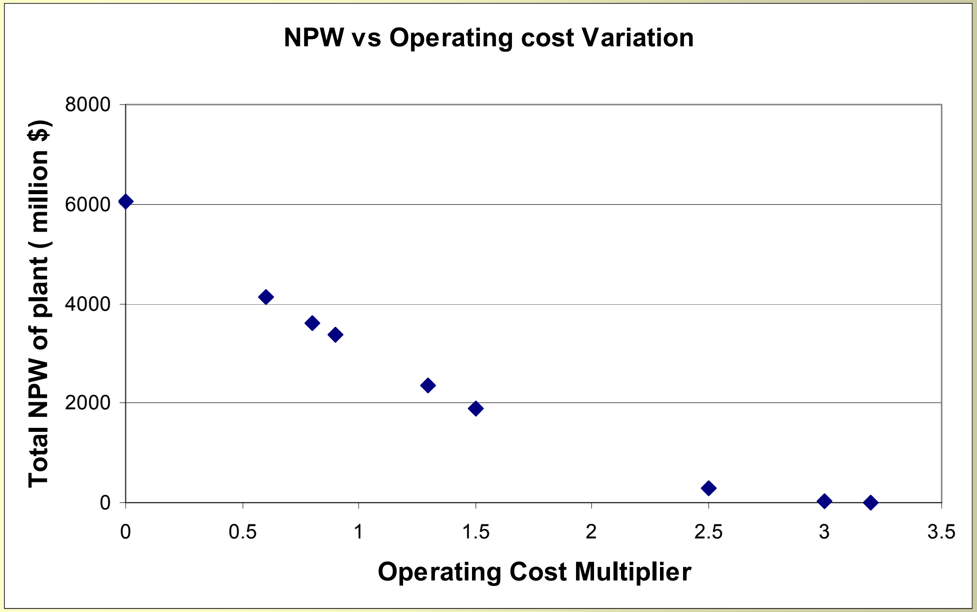
1. Beaver
2. Garber
3. Bixby
4. Clinton
5. Piedmont
6. Okmulgee
7. Hobart
8. Pauls Valley
9. Broken Bow

• 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:

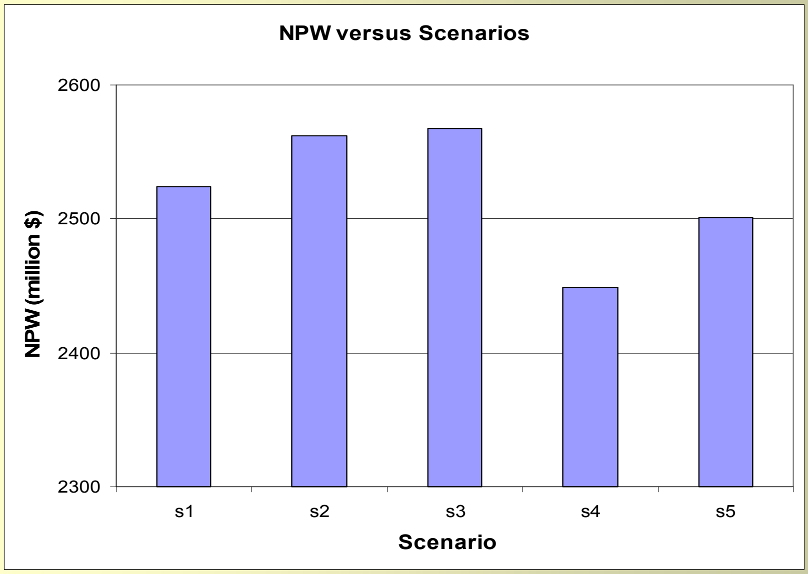
$$\begin{pmatrix} Ethanol \\ \mathrm{Pr}\,ice \end{pmatrix}_s = normal\left(\begin{pmatrix} Ethanol \\ Mean\ \mathrm{Pr}\,ice \end{pmatrix}, Sdt\right)$$

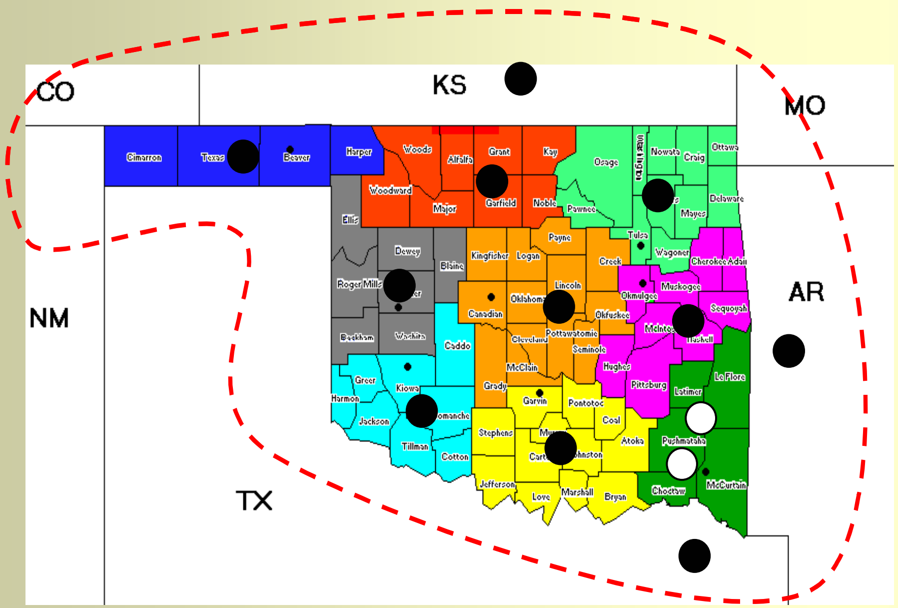
$$\begin{pmatrix} Harvested \\ Amount \end{pmatrix}_s = normal\left(\begin{pmatrix} Harvested \\ Mean \end{pmatrix}, Sdt\right)$$

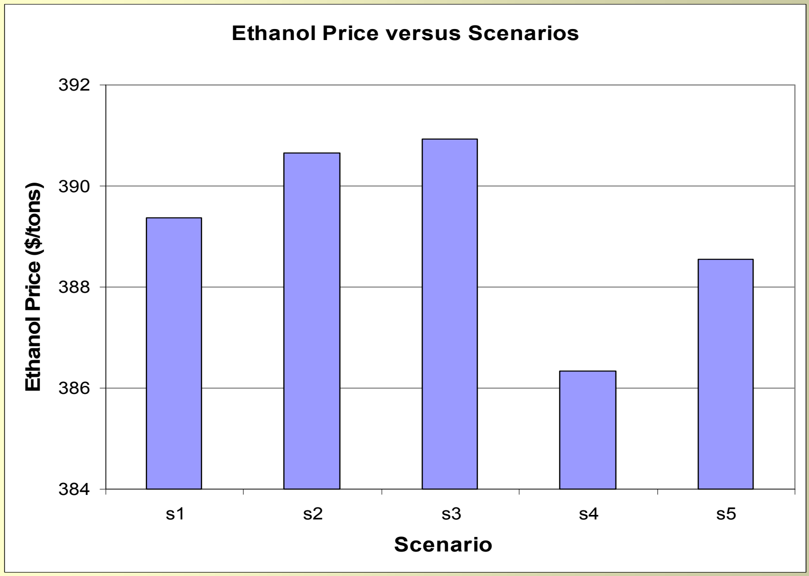
$$\begin{pmatrix} Operating \\ Cost \end{pmatrix}_s = normal\left(\begin{pmatrix} Operating \\ Cost\ Mean \end{pmatrix}, Sdt\right)$$

Stochastic Model Results with 5 scenarios

		Capital Investment for year plant is built (in million dollars)	
Plant Location	**Technology**	**yr1**	**yr2**
broken_bow	FER	$20.55	
broken_bow	HYD		$30.83







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