

ETHANOL PRODUCTION IN OKLAHOMA

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INTRODUCTION

Ethanol is being explored as an additive to gasoline that will boost its octane and decrease the pollution output. Currently the possibility of ethanol production is being discussed in Oklahoma due to its vast farmland and variety of crops. The objective of this project is to determine the feasibility of producing ethanol in the state of Oklahoma. The main approach used to solve this problem is the implementation of a mathematical model that uses mathematical optimization to determine the optimal feed stock, location, net present worth, and many other aspects of the process. The data needed for this model was capital investment, operating costs, feed stock availability, transportation costs, and storage costs.

One of the main reasons for the need of ethanol is due to Methyl Tertiary Butyl Ether (MTBE) phase-out. The United States has been using MTBE as an additive in gasoline to boost the octane level of gasoline since the 1970s. Unfortunately, the accelerated use of MTBE has had adverse effects on the environment. Many hailed MTBE as a solution for cleaner air in the United States, but adequate studies were not done on its usage before it was implemented. One of the problems with MTBE is that it can be easily absorbed into the bloodstream of whoever comes in contact with it. MTBE can also contaminate groundwater because it takes a long time to degrade. This longer degradation time will allow MTBE to contaminate groundwater supplies over large areas of land very easily.

The Oklahoma government has realized that ethanol is the additive of the future and has passed legislation that will make it easier to pursue ethanol production in state. The Oklahoma House Energy and Utility Regulation Committee approved 2 bills that would help pave the way for an ethanol industry. One of the bills establishes an Oklahoma Ethanol Board that consists of 11 members appointed by the governor. The bill states that, "The board would consist of five members engaged in farming, one would represent labor interests, four would represent state petroleum marketers, and one member would be involved in trade and marketing." The other bill that was passed would simply create a panel that would study the possibility of economic ramifications of producing an ethanol industry in the state.

MARKET

Currently there are 68 ethanol production plants in the United States. The bulk of these plants are concentrated in the mid-west, mainly in the states of Minnesota, Iowa, and Nebraska. In 2002 the United States produced a record of 2.13 billion gallons of ethanol.

Locally, Oklahoma is expected to have a high demand for ethanol. The Oklahoma State Department of Commerce has conducted a study to determine how much ethanol would be needed for the different districts of the state. These numbers are summarized in Figure 1.

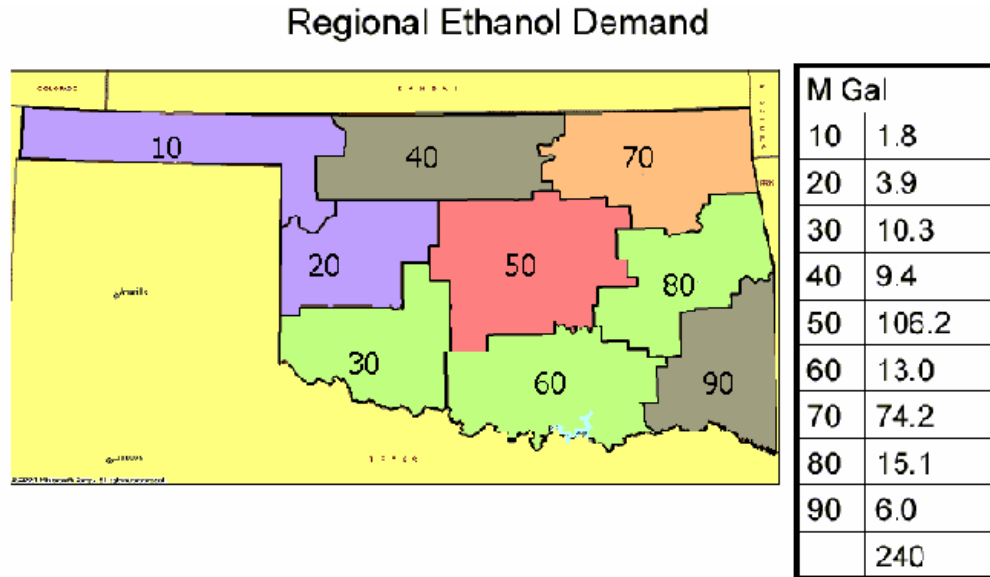


Figure 1 – Regional Ethanol Demand

The figure shows us that most of the ethanol demand will be concentrated in the Central (50) and Northeast (70) districts. The demand shown above is not our targeted demand however. The ethanol that is produced will be sold anywhere where it will make a profit. It is also important to note that should the production plant(s) exceed the state's demand in ethanol, the ethanol could also be sold in the neighboring states where ethanol production has yet to begin (Texas, Louisiana, New Mexico, and Colorado).

RAW MATERIAL

With over 44 million acres of land and 11 million acres dedicated to agriculture, Oklahoma is an ideal location for feedstock. The major crops include barley, grain sorghum, pecans, wheat, switchgrass, bermuda grass, and corn. The state produces several of these crops in large quantities making it a prime location for an ethanol production plant.

The cost of producing ethanol is highly sensitive to the cost of feed stock delivered to the plant, the volume, and the composition of the crop. Thus, the profitability of the ethanol plant is dependent on the selection of the appropriate crops, locations, and

production processes. Some of the selection criteria are: harvesting time, content of starch/cellulose of harvested feed, current crop production levels, transportation and storage costs, production of marketable by-products, and cost of converting the biomass yield to ethanol. Based on the factors listed above, the crops selected by our procedure for the production of ethanol are wheat, switchgrass, and grain sorghum.

Covering over 6 million acres of land, which is nearly half the state's cropland, wheat is the highest selling cash crop in Oklahoma. It also is ranked 3rd in the nation in production. Most of the wheat planted in Oklahoma is winter wheat, which is planted from November to March, and harvested from April to October. It goes through a vernalization period, (a period of cold required for the plant to change from vegetative to reproductive growth), and produces grain for the following spring. It is estimated that about 165 million bushels of wheat will be harvested in 2003 and the cost is estimated at about \$3.20 per bushel. Furthermore, about of 2.5 gallons of ethanol can be produced from each bushel of wheat.

Over 14 million bushels of grain sorghum is pre-estimated to be produced in the 2003/2004 season, making it the 2nd most consumed starch source for ethanol in the nation. Over 70% of grain sorghum produced in Oklahoma last season was used to feed livestock, which is due to the high protein concentration present in the crop. Because of this fact, grain sorghum ensures the production of wet distillers grain as a by-product during processing.

About 3 million acres of switchgrass will be harvested in the 2003/2004 season in Oklahoma. It is estimated that East Central Oklahoma is going to harvest about a million acres, making it the leading switchgrass producing district in the state. Although, switchgrass is not as abundant in Oklahoma as the other selected crops, it has a high conversion to ethanol during processing (about 100 gallons of ethanol produced per ton). The cost of switchgrass was found to be about \$34 per ton.

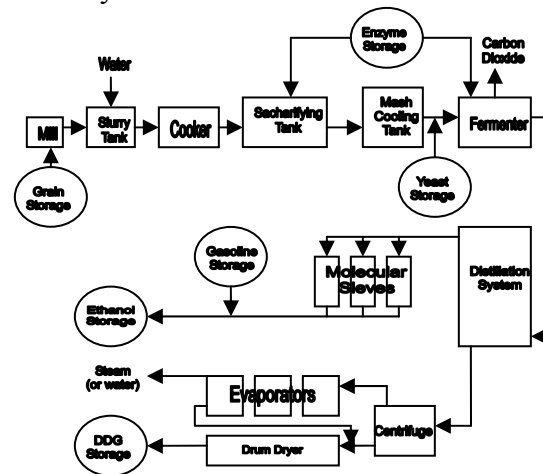
All of the crops mentioned above, except switchgrass, produce distillers grain as a by-product during processing. This distillers grain can be sold to farmers as feed for cattle. Distillers grain can either be in the wet or dry form. The dry form can be stored for up to 2 months and transported over long distances. Wet distillers grain can only be stored for 2 days and it must be transported within 50 miles of the source in order to avoid spoilage. Since Oklahoma has a cattle population of 5.25 million, it is believed that wet distillers grain would be a better investment, because dry distillers grain requires expensive dryers and it must be stored for a long time. Wet distillers grain is also very popular among farmers because of its' high amounts of fat and protein. Due to these high concentrations of fat and protein, it is the quickest and easiest way for cattle to put on weight. Wet distillers grain will also be in high demand because a milk cow can eat from 15-20 pounds of wet distillers grain a day, and steer cows can eat from 30-40 pounds a day.

PROCESSING TECHNOLOGIES:

Three processing technologies were considered for ethanol production: traditional grain fermentation, dilute acid hydrolysis, and gasification.

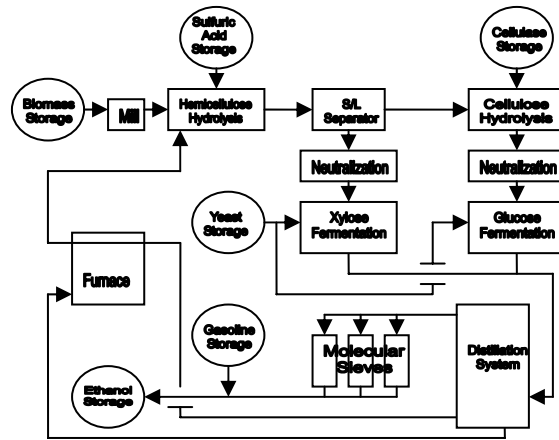
Traditional Grain Fermentation:

In traditional grain fermentation, starch based grains are converted into glucose through enzymatic catalysis using alpha and beta amylase. The glucose formed is converted into ethanol by fermentation through *Sacromyces cerevisiae* yeast consumption. The fermented stream is passed through a distillation section to separate the ethanol from the water and unfermented grain. The separated, protein rich unfermented grain is centrifuged and evaporated to form wet distillers grain, a byproduct used as cattle feed. The distilled ethanol/water mixture is then passed through a dehydration unit where the remaining water is removed. The 200 proof ethanol is then denatured through the addition of gasoline and is ready to be sold.



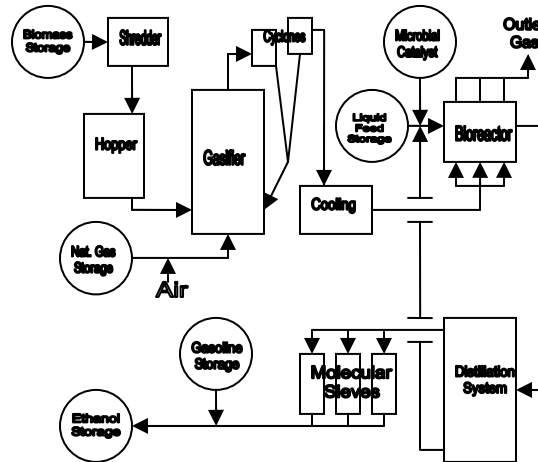
Dilute Acid Hydrolysis and Fermentation:

In the dilute acid hydrolysis process, biomass feedstocks consisting mostly of cellulosic material are broken down into fermentable sugars. Dilute sulfuric acid (1.1%) is added to the feed. This results in the hydrolysis of the hemicellulose component, creating xylose sugars and exposing the cellulose component. The cellulose solids can then be separated and hydrolyzed to form sugars by cellulase enzymes that are derived from *T. reesei*, a filamentous fungus. The acid in both streams is neutralized by lime. This process allows the separation of the glucose and xylose sugar solution streams and makes a parallel fermentation possible. The sugar solutions are fermented using two yeast species: the glucose is fermented by brewer's yeast (*Sacromyces cerevisiae*) and the xylose is fermented by yeast such as *Pachysolen tannophilus*. The product stream is then purified in the same technique as traditional fermentation.



Fluidized Bed Gasification and Fermentation:

The third process considered was the gasification of biomass to produce a syngas followed by fermentation. The first step in the process is the gasification of the biomass to form a syngas composed of carbon monoxide, carbon dioxide and hydrogen. The syngas is then cooled and bubbled through a bioreactor. It is converted into ethanol by an anaerobic microorganism. The final step is the separation of the ethanol from the bioreactor product stream.



Technology Comparison:

Table 1 displays the total capital investment and the annual operating cost for each processing technology for a capacity of 20 MGY. The capital cost was determined by rigorously sizing and pricing each piece of equipment within the plant; the remainder of the capital costs were found using statistical information from ethanol plants currently in operation, along with using local land and construction costs. The operating cost was determined by directly calculating the amount of utilities, raw material, and labor necessary for each technology.

Table 1 Technology Cost Comparison

Plant Type	TCI (\$)	Operating Costs (\$/yr)
<i>Traditional Grain Fermentation</i>	35 M	10 M
<i>Dilute Acid</i>	50 M	20 M
<i>Gasification</i>	80 M	12 M

*Values calculated for 20MGY Plant Capacity

Table 2 compares the crop conversion efficiency for each processing technology. Traditional Fermentation and Dilute Acid Hydrolysis can both obtain high conversions of ethanol based on specific feedstocks. Wheat and sorghum possess the highest efficiency for Traditional Fermentation because of their high starch content. Switchgrass is the feedstock of choice for Dilute Acid Hydrolysis because of its high cellulose composition, resulting in its high conversion rate. Gasification results in the lowest conversion of all three technologies. This technology is still in its research phase, with its potential yet to be fully realized. However, it is the most flexible of all technologies, obtaining moderate conversion for all three feedstocks.

Table 2. Crop efficiency comparison

	Wheat	Sorghum	Switchgrass
<i>Traditional Grain Fermentation</i>	0.277	0.286	0.023
<i>Dilute Acid</i>	0.043	0.038	0.299
<i>Gasification</i>	0.169	0.166	0.171

BUSINESS PLANNING MODEL

The model is designed to choose a processing technology, the raw materials, and their sources (counties) at different times of the year that would produce the highest NPW. The feedstocks selected are wheat, sorghum, and switchgrass. It is necessary for the plant to be able to process any one of these feeds. Using this data the model determines how many plants could be built and the location of these plants. It also determines the amount of feed bought from each supply point and the capacity of each plant. When determining the objective function it is assumed that the discount factor is constant for the duration of the plant life. It is also assumed initially that the plant will have a life span of 10 years. With all the constraints for the process, the main objective function can be maximized using a defined solver.

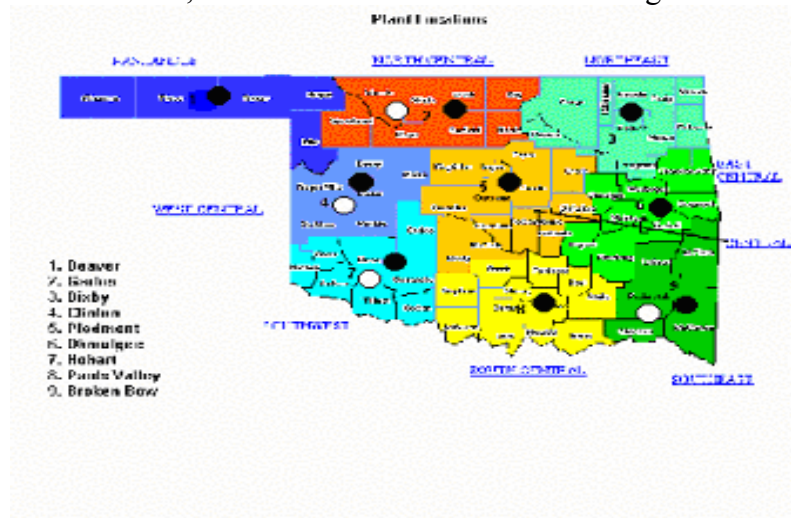
The equation below describes the net present worth.

$$NPW = dft * Duration \left[\sum_{jgt} r * q_{jgt} + \sum_{ijkt} dg * mb_k * bht_{ijkt} - \sum_{ijkt} a_{ikt} * bht_{ijkt} - \sum_{ijkt} f * tc_{ijkt} - \sum_{jgt} op_{jgt} - \sum_{jkt} st * sto_{jkt} \right] - \sum_{jg} ci_{jg}$$

There are 6 terms that affect the profitability of the proposed plant. The 1st term is the revenue from the sales of ethanol, where r is the unit price of the ethanol per tons and q is the amount of ethanol produced in tons per month. The 2nd term is another revenue term, which can be obtained from the sales of the by-products of the ethanol plant. In this specific case the revenue is from the sale of the distillers grain. The parameter mb(k) is the conversion of feed to the amount of distillers grain and dg is the unit cost of the distillers grain per tons. The 3rd term is the cost of feed bought from different crop locations, a (i,k,t) is the unit cost for buying the different feeds at different crop locations and different harvesting periods. The 4th term is the cost for transporting the feed that is bought to the plant and f is the unit cost for transportation in tons*mile. The 5th term is the operating cost of the plant depending on the capacity of the plant and its processing type. The 6th term is the storage cost of the feed before processing.

All of the terms described above are then multiplied by discount factors for each year of the useful plant life, which is assumed to be 10 years initially and then further increased to 20 years. The discount factors are obtained from census data for different counties.

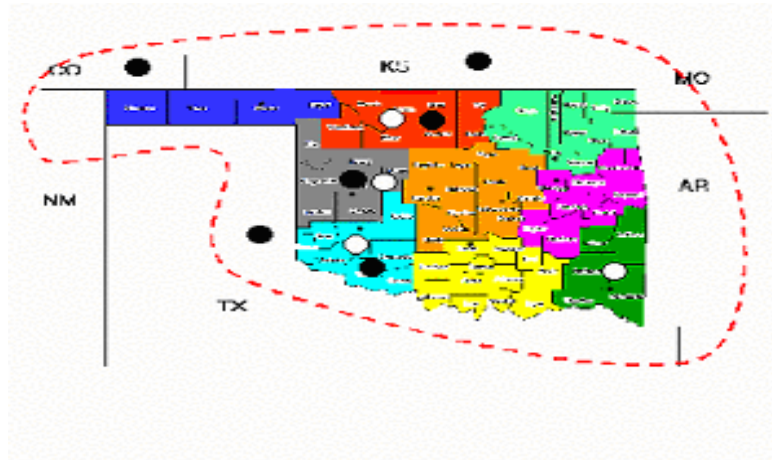
From the mathematical model the following results was obtained. The model proposed to build 4 plants, of each 200 million gallons capacity in Broken Bow, Hobart, Garber and Clinton. The feed source will come from most of the counties in Oklahoma mainly from North Central, West Central and the Southwest regions.



The capital investment of each plant is about \$20 to \$30 million and it produced ethanol from sorghum as the feed. Next, we did a sensitivity analysis on the model. The maximum size of the plant was varied and it is found that the NPW increases with the

maximum size, but the plant locations still remain the same. However, when different sizes were chosen for different plants the model picked the plant with the largest size, thus picking a new plant location.

Next, the feed source locations were expanded to include neighboring states such as Texas, Arkansas, Kansas, Missouri, Colorado, and New Mexico. The result obtained from this scenario is that some feed was taken from Texas, Kansas, and Colorado. These states have a significant feed supply and certain counties are closer in proximity to the proposed plants than to other feed supply points in Oklahoma.



The model concluded that in order for ethanol production to be profitable in Oklahoma, it is required that:

1. A maximum storage cost of \$2.00/tons of feed cannot be exceeded
2. The minimum selling price for ethanol is \$0.60/gallon.
3. Regarding the operating cost, the NPW will be zero for any cost higher than a factor of 3.2 from the initial costs estimates.

The figures below show the NPW and ethanol price generated from the model with 5 scenarios. It shows that the NPW will depend on the fluctuation of the ethanol price, harvested amount and cost. Therefore this will also effect the plant location and the feed souce as it is shown in the map above. A stochastic analysis reveals the following NPW distribution

