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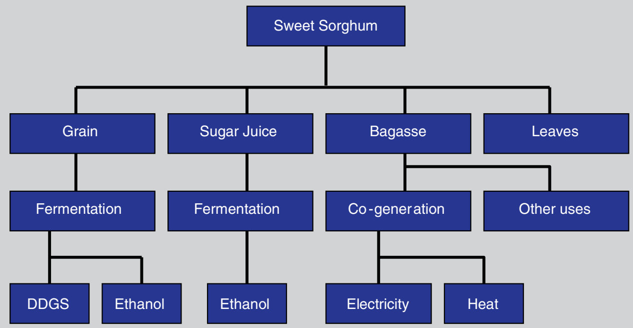

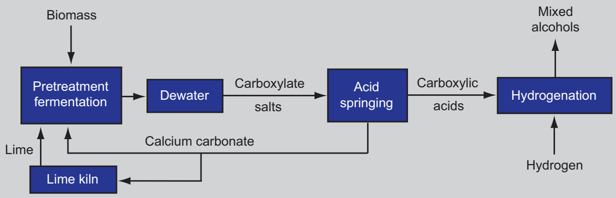

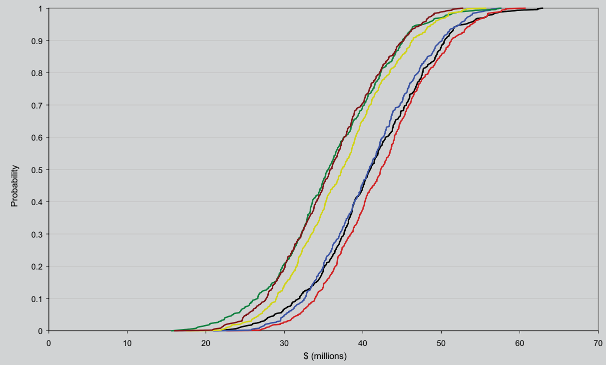

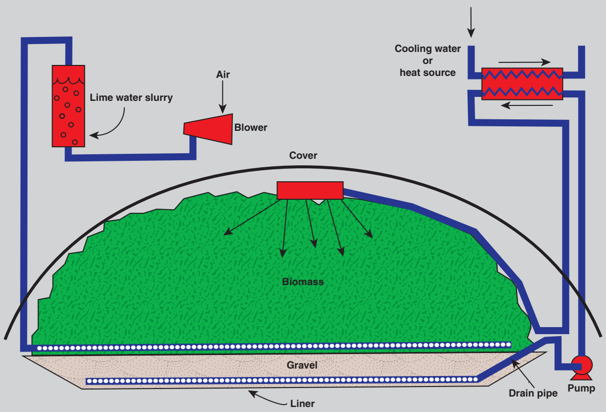

Agricultural and Food Policy Center
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The United States is becoming more dependent on ethanol production as a renewable fuel source to decrease dependency on foreign oil. The increase in demand for renewable fuels, due in part to the *Energy Policy Act of 2005*, has led to increased research on alternative renewable fuels from biomass. One such avenue of research has been the conversion of biomass to renewable fuels, and specifically sweet sorghum, as an ethanol fuel stock.

Biomass Energy

Biomass is used to describe any organic matter from plants that derives energy from photosynthetic conversion. It is a unique resource which is the only renewable source of carbon. Biomass is a versatile energy source that can be easily stored and transformed into liquid fuel, electricity, and heat through various processes (World Energy Council, 1994). Biogas, biodiesel, ethanol, methanol, diesel, and hydrogen are examples of energy carriers that can be produced from biomass (Bassam).

Traditional sources of biomass include fuel wood, charcoal, and animal manure. Modern sources of biomass are energy crops, agriculture residue, and municipal solid waste (ACRE). Biomass fuels are produced mainly in countries that have surplus of agriculture commodities (Shapouri, 2003). Biomass can be divided into three categories; sugar feedstock (sugarcane), starchy feedstock (grains), and cellulose feedstock (fibrous plant material) (Badger, 2002). Estimates show 512 million dry tons of biomass residues is potentially available in the United States for use as energy production (Mazza).

It has been estimated that biomass could supply all current demands for oil and gas if 6 percent of contiguous U.S. land area was put into cultivation of biomass feedstocks (Osburn, 1993). No net carbon dioxide would be added to the environment if biomass energy replaced fossil fuels (Osburn, 1993). Fuels derived from biomass are renewable and are sufficiently similar to fossil fuels to provide direct replacement (Bassam). The U.S. Department of Energy believes that biomass could replace 10 percent of transportation fuels by 2010 and 50 percent by 2030 (Sterling Planet).

Figure 1: Sweet Sorghum and Grain Sorghum Trials near Amarillo.
Source: Travis Miller.

Biomass has the potential to provide a sustainable supply of energy. It has the following advantages over fossil fuels:

- Renewable source of energy that does not contribute to global warming as it has a neutral effect on carbon dioxide emissions;
- Biomass fuels have low sulfur content and do not contribute to sulfur dioxide emissions;
- Effective use of residual and waste material for conversion to energy;
- Biomass is a domestic source that is not subject to world price fluctuations or uncertainties in imported fuels.

However, an important consideration with biomass energy systems is that biomass contains less energy per pound than fossil fuels (Sterling Planet). Dried biomass has a heating value of 5,000-8,000 British thermal units (BTU) per pound with virtually no ash or sulfur produced during combustion (Osburn, 1993). Other estimates show the energy content of agricultural residues in the 4,300 to 7,300 BTU per pound due to moisture content (http://bioenergy.ornl.gov/index.html). Incomplete combustion of biomass produces organic matter and carbon monoxide pollution. There is also a social debate over the use of land and water for food production versus energy production (ACRE, Mazza). Biomass could have an important impact on the socio-economic development of rural populations and the diversification of the energy supply (Renewable Energy World, 2000).

Combustion, gasification, liquefaction, and biochemical are the primary ways of converting biomass into energy. Combustion burns biomass to produce heat. Gasification produces gas that can be combustible in a turbine. Liquefaction produces an oxygenated liquid that can substitute for heating oil. The biochemical process converts biomass to liquid fuel through a fermentation process (Veringa, ACRE). Biodiesel and ethanol are an example of this process.

Ethanol from cellulose biomass material is still in the research and development phase (Mazza). There is currently only one commercial cellulose ethanol facility in operation (Canada) with another plant under development in Spain. The lack of real-world experience with cellulose biomass to ethanol production has limited investment in the first production facilities (California Energy Commission, 1999). Ethanol from cellulose has the advantage of a faster rate of reaction than the traditional fermentation process. However, ethanol production using cellulose is costly due to the need for acid hydrolysis of the biomass pricing it above expected long-run gasoline prices (Badger, 2002). MixAlco, a process developed at Texas A&M University, has the advantage of no extra processing of the biomass is needed for fuel conversion.

Sweet Sorghum

Sorghum (Figures 1 and 2) has been identified as a preferred biomass crop for fermentation into methanol and ethanol fuel (Miller and Creelman, 1980; Creelman *et al.*, 1981). Sorghum is among the most widely adaptable cereal grasses potentially useful for biomass and fuel production (Hons, *et al.*, 1986). The adaptation of sorghum to sub-humid and semiarid climates has extended sorghum production into larger regions than other warm-cereal grains.

Sorghum is relatively inexpensive to grow with high yields and can be used to produce a range of high value added products like ethanol, energy, and distillers dried grains (Chiaramonti, *et al.*). Sorghum can produce approximately 30 dry tons/ha per year of biomass on low quality soils with low inputs of fertilizer and limited water per dry ton of crop, half of that required by sugar beet and a third of the requirement for sugar cane or corn. (Renewable Energy World, 2000).

Figure 2: Texas A&M University Crop Scientist with Hybrid Sorghum.
Source: Travis Miller.

Most stover or crop residue is plowed back into the ground to replenish nutrients and used to reduce soil erosion. Small amounts are harvested for livestock feed. Studies to estimate sorghum residue yield for biomass production averages approximately 1.75 tons/acre (Franzluebbers, *et al.*,1995; Gallagher, *et al.*; Hons, *et al*, 1986; Powell, *et al.*, 1991).

Figure 3 shows a simplified diagram of alternative processes to convert sweet sorghum to energy fuel. Corn processing is very similar as the two crops are interchangeable. Sorghum production can be separated into grains (for consumption, livestock feed, ethanol production), sugar juice (extracted from the cane and used for ethanol production), and stover (used for energy production, plastics) (Chiaramonti, *et al.*). Sorghum easily converts to other value added products making it a versatile input.

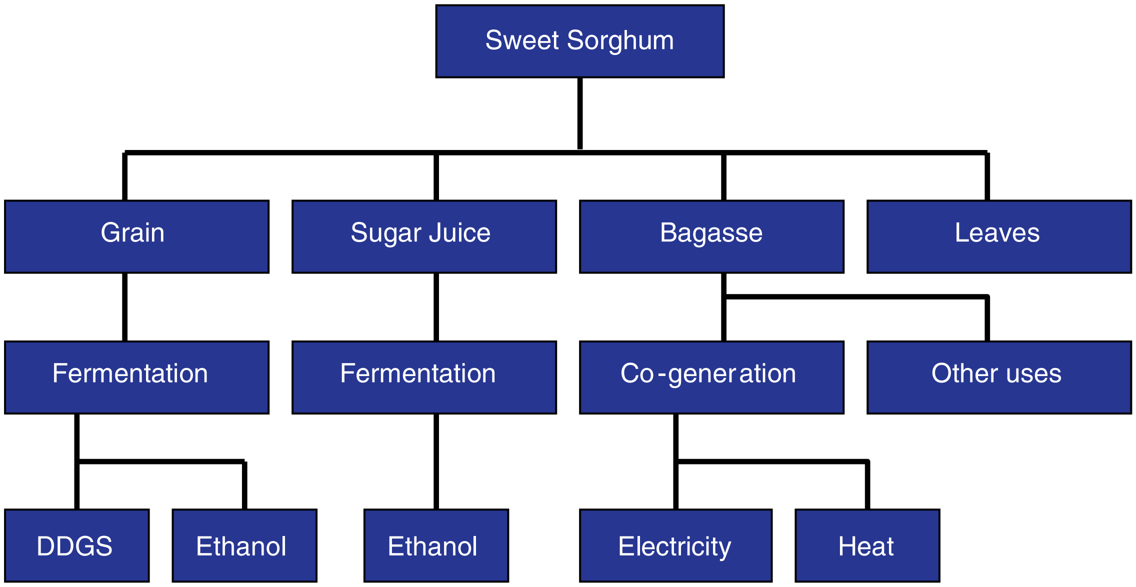

Figure 3: Simplified Diagram of Alternative Processes to Convert Sweet Sorghum to Energy Fuel.

Source: Chiaramonti, *et al.*

Although studies (Gallagher, *et al.*; Wiedenfeld, 1984; Committee on Biobased Industrial Products, 2000; Miller and Creelman, 1980; Creelman *et al.*, 1981) show sorghum stover is a good potential candidate for cellulose energy production, no historical values are available for residue costs and yields. Agriculture residue price for energy production is based on the opportunity cost for the grower plus harvesting and baling cost.

Residues are desirable raw materials for energy production because utilizing them does not require covering land cost which are included in the grain enterprise. Residue supply depends on opportunity costs at the farm level and the assumption that reasonable soil conservation practices will be followed. The amount of residue supplied is an approximation for acquisition cost by processing facilities. Growth is expected to occur in crop residue resource due to increase crop yields and declining livestock demand for forage (Gallagher).

MixAlco Process

While the MixAlco process has not been tested at a commercial scale, the technology appears to hold a tremendous amount of promise. The MixAlco process can convert a wide variety of biomass material such as sewer sludge, manure, agriculture residues, agriculture crops, into acids and alcohol fuels using microorganisms, water, steam, lime and hydrogen through an anaerobic process (Holtzapple, 2004). Two different versions of the MixAlco process are available. Version one is the original process which produces mixed alcohol fuels. Version

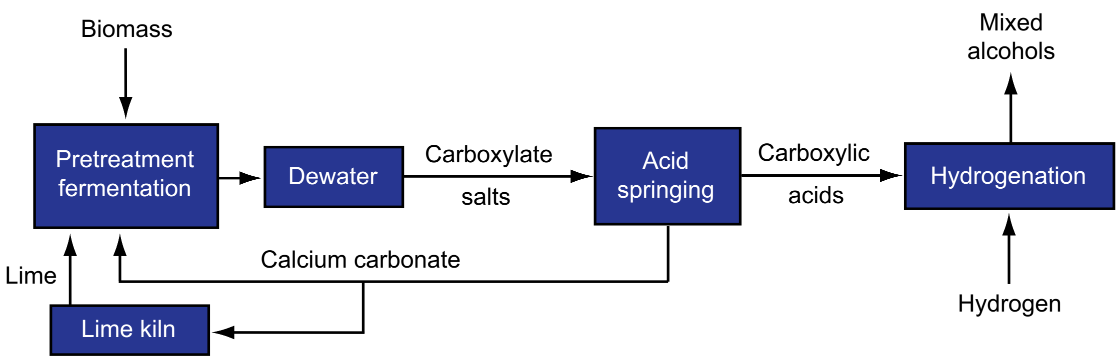

Figure 4: Schematic of the MixAlco Process

Source: Holtzapple, 2004.

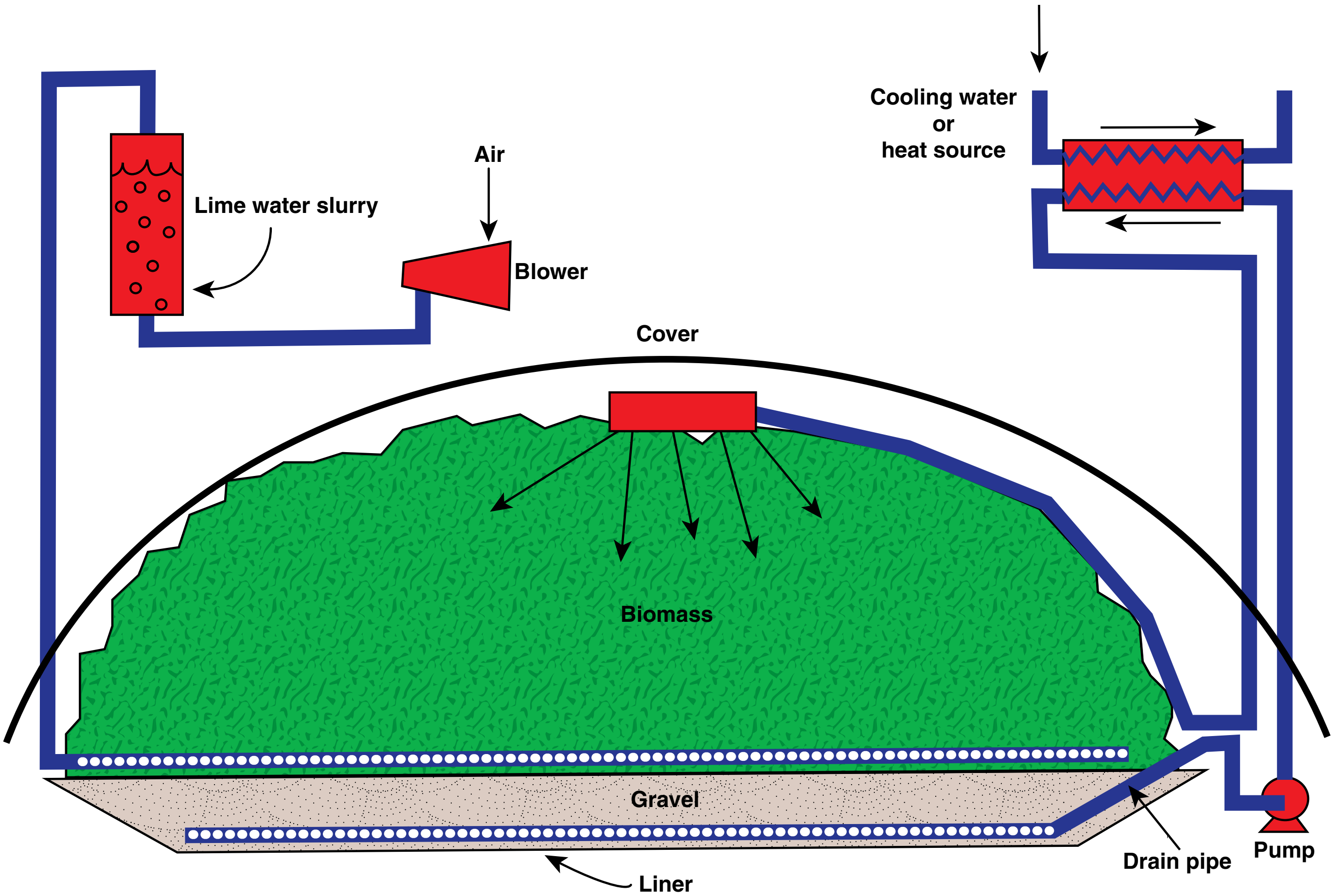

Figure 5: Schematic of the MixAlco Pretreatment Process

Source: Holtzapple, 2004.

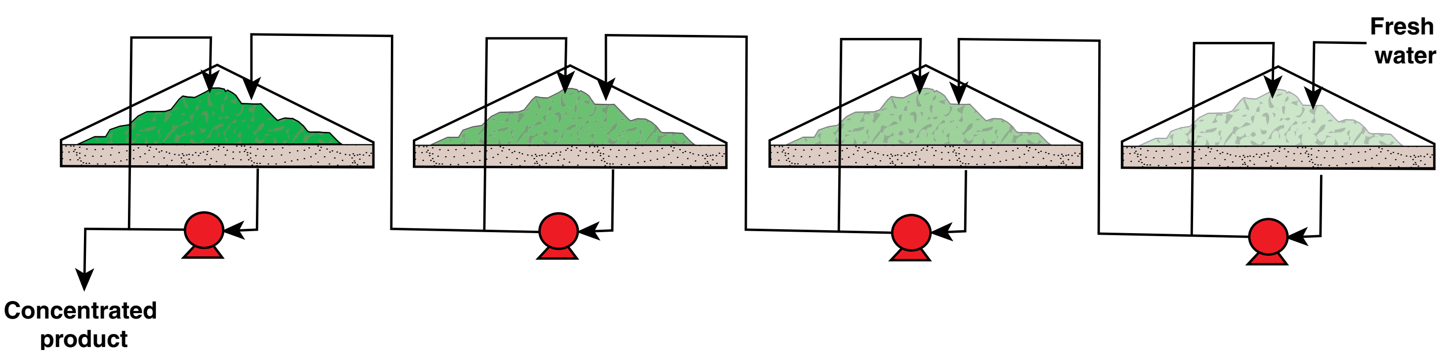

Figure 6: Schematic of the Fermentation Facility.

Source: Holtzapple, 2004.

two produces carboxylate acids and primary alcohols (ethanol).

Figure 4 summarizes the MixAlco process. This process differs from the use of acid hydrolysis of biomass material to produce ethanol. The MixAlco process calls for mixing biomass with a nutrient source such as manure or sewage sludge at a ratio of 80 percent to 20 percent. There are four phases to the process: pretreatment and fermentation, dewatering, acid springing, and hydrogenation.

During the pretreatment phase, biomass, lime, and calcium carbonate are blended and stored in a large pile. Air is blown up through the pile while water is trickled down through the pile. The combination of air and lime removes lignin from the biomass reducing the pH and rendering the bio-matter digestible. The pile is then inoculated with anaerobic microorganisms from saline environments. The microorganisms digest the biomass forming carboxylic acids commonly known as volatile fatty acids (VFAs) such as acetic, propionic,

Figure 7: MixAlco Pilot Plant Photos.
Source: Martk T. Holtzapple.

and butyric acids. The VFAs combine with calcium carbonate to form carboxylate salts, which are extracted from the pile with water.

Four reactor piles are created of equal volume. Figure 5 and Figure 6 show the schematic of the pretreatment and fermentation facility. Each reactor is shaped like a cone to minimize material use. For a 44 ton/hour facility, each reactor has a base diameter of 397 feet and is 115 feet high. The fuel pile is covered with a geomembrane to resist the weather, wind, and sun. The base consists of a one-meter-thick layer of gravel that is divided by bermed walls to collect the VFA solution.

From fermentation, the VFA solution is concentrated using a vapor compression evaporator during the dewatering phase. The fermentation broth containing the VFAs are heated to 100°C and mixed with high-molecular-weight acid (e.g., heptanoic) to acidify the fermentation broth. Steam and lime are than used to remove non-condensable gases and calcium carbonate. The treated fermentation broth is heated to 212°C and water is evaporated from the solution concentrating the salts.

Acid springing converts the carboxylate salts into carboxylate acid and calcium carbonate. The concentrated broth is blended with carbon dioxide and a low-molecular-weight tertiary amine (triethyl) to form insoluble calcium carbonates and amine carboxylates. Approximately 75% of the calcium carbonate removed can be used in the pretreatment and fermentation phase and the remaining 25 percent is converted to lime using a special lime kiln. Most of the water is then removed leaving a concentrated amine carboxylate.

The carboxylate acids are blended with high-molecular-weight alcohols to form esters and water. The water is evaporated and remaining esters are mixed with high-pressure hydrogen to form alcohols. The resulting ethanol fuel is cooled and stored for transportation to be mixed with gasoline fuel. Large storage tanks are used to hold the ethanol fuel until shipping.

Byproducts

MixAlco produces water, heat, carbon dioxide, calcium carbonate, and residual biomass as byproducts. The MixAlco facility can be almost self-sufficient after the first year of operation if the necessary equipment for lime production, water recycling, and steam capture, and boilers, are in place. Water can be reused for the pretreatment and fermentation phase. Calcium carbonate can be manufactured into lime and used in the pretreatment and fermentation phase. The heat generated can be transferred to dryers to aid in the evaporation during the dewatering phase.

The MixAlco structure is completely sealed from the outside environment and all carbon dioxide gas produced can be collected. The carbon dioxide can be released once it is "scrubbed" to remove odor or sold to oil refineries to be pumped into oil wells and aid in the collection of oil. However, the carbon dioxide market is very limited.

Residual biomass is the largest byproduct produced. MixAlco differs from corn-based ethanol production that produces distiller dried grains with solubles (DDGS) that be can be sold to livestock operations for feed. Approximately 20 percent of the biomass feedstock is residual biomass when the MixAlco process is complete. The residual biomass can be used internally to generate power and steam for the facility or it can be sold to coal-fired power plants as a fuel source to reduce sulfur emissions.

Net Energy Balance of MixAlco

The net energy balance of MixAlco alcohol fuel is dependent upon which feedstock is used as a fuel source. Initial testing has shown ethanol produced from MixAlco has a slightly higher energy content than corn-based ethanol. A gallon of gasoline contains approximately 125,000 BTU/gallon and corn-based ethanol contains 84,000 BTU/gallon (Holtzapple, 2004). The energy content of MixAlco produced ethanol is approximately 95,000 BTU/gallon. The energy content for the residual biomass byproduct is similar to coal. It is substitutable for coal in co-firing energy production facilities and can reduce sulfur emissions.

MixAlco Feedstock Requirements

Initial research into MixAlco used sugarcane bagasse as feedstock as it is widely available around the world. However, the supply of sugarcane in the United States is limited to the four states producing sugarcane and is not large enough to support large-scale MixAlco production. The amount of feedstock required is dependent on the desired output size for the facility. The feedstock is decomposed at the same rate for all crops and all plant sizes. The efficiency of the MixAlco process is also still under experimentation. Version two of the MixAlco process has increased alcohol yield per ton of biomass from approximately 90 to 100 gallons/ton in version one to 130 to 140 gallons/ton. However, the ethanol produced from version two has a lower energy content than the alcohol produced in version one.

MixAlco feedstock demand differs from ethanol feedstock demand as year-round supply is not necessary. The MixAlco process only requires feedstock input once a year to build the fuel pile. This is advantageous when compared to other forms of biomass energy production. Biomass can be used for other types of energy production (burning, digesting) but again, have not found commercial success.

Economic Analysis

A simulation model was developed for two alternative MixAlco plant sizes (44 ton/hour and 176 ton/hour) using sweet sorghum as feedstock. For both plants, economic feasibility was examined for two initial investment amounts (Base – representing the expected costs and BasePlus 30 percent – representing Base costs plus 30 percent); with and without incentives; and three alternative regions in Texas (Panhandle, Central Texas, and Coastal Bend). A simplified diagram of the model and the

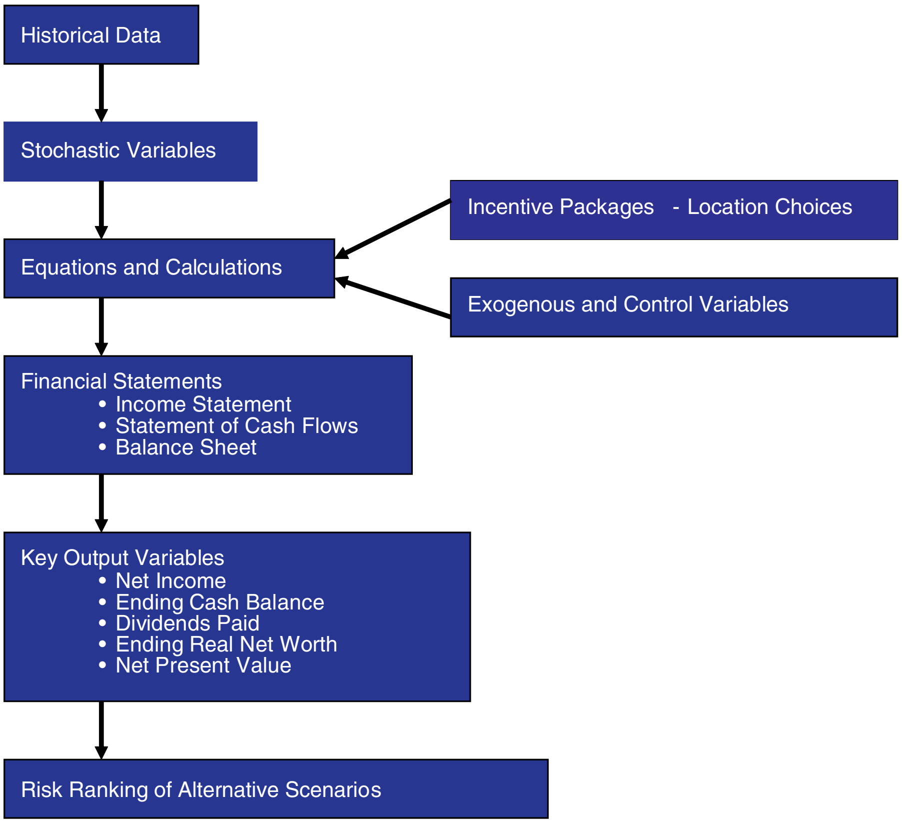

Figure 8: Diagram of the Simulation Model.

alternative scenarios are presented in Figures 8 and 9.

Common financial statements for each alternative scenario were developed. Stochastic variables were incorporated into the model to capture risk. Specific key output variables were calculated and compared for each alternative scenario from the financial statements.

Results

Key Output Variables

For all the scenarios analyzed, the projected financial feasibility results show a positive net present value (NPV) over the 16 year planning horizon with only a small probability of being negative.

Net income is expected to remain positive and increase slightly for all scenarios. The probability of negative net income is less than 30 percent in the first year for all scenarios and only 1 percent thereafter years 2006 to 2019. As expected, net income for the Base Plus 30 initial investment scenario is lower in all cases due to higher depreciation costs and higher capital improvement costs.

Because net income remains positive, ending cash balance increases annually. The probability of negative ending cash balance is less than five percent in 2005 and less than one percent from 2006 to 2019 for all scenarios. Also, annual dividends paid are positive for all scenarios. Real net worth increases to 2014 and than flattens out for all scenarios because of the increasing deflation factor. Real net worth is highest in the Panhandle Region for the 44 ton/hour and 176 ton/hour production facilities because of the additional initial investment costs needed for wells and water rights. For the Plus 30 initial investment scenario, real net worth is higher for all scenarios as expected. The probability of real net worth being negative is less than one percent for all scenarios

Community Impacts

The economic impacts of locating a MixAlco production facility in the Panhandle, Central Texas, and Coastal Bend Regions were analyzed using the Regional Industry Multiplier System (RIMS) and the summation of the simulated discounted wages, hauling costs, property tax, and additional farmer income from 2005 to 2019 for each region. The RIMS method presents the direct and indirect benefits to the community. The simulation results represent direct impacts from the MixAlco production facility.

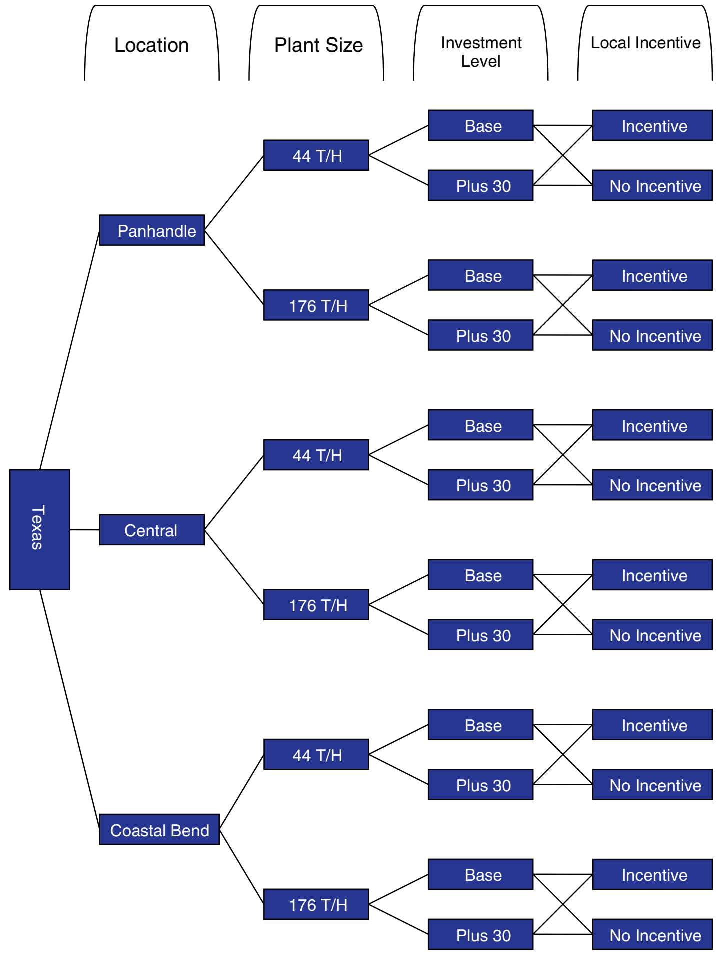

Figure 9: Flow Chart of Alternative Scenarios.

The estimated additional capital spending was $50 million to $65 million for the 44 ton/hour facility with an additional household income of $124 million to $133 million. For the 176 ton/hour production facility, the local economy would benefit from $407 million to $440 million in additional spending and $72 million to $78 million in additional household income. These economic gains for the local economy are quite large and indicate locating a MixAlco production facility in the region would have a substantial and positive impact on the local economy.

For the direct impacts, hauling revenues were the largest direct contributor to the region ranging from $42 million for a 44 ton/hour production facility to $190 million for a 176 ton/hour facility.

The summed discounted wages were $12 million for a 44 ton/hour facility and $27.5 million for a 176 ton/hour facility. Farmers receive a substantial increase in additional revenue with a high of $20 million for the 44 ton/hour production facility to $65 million for a 176 ton/hour production facility. Property tax revenue for the local community varies and is dependent on the offer of tax abatements.

Sensitivity Analysis

Elasticities for key input variables were estimated to determine which variables had the greatest effect on feasibility in terms of NPV. From the analysis, ethanol price, ethanol yield, and hydrogen price are the three variables with the highest elasticities. A one percent annual increase in ethanol price or yield would increase NPV by six to seven percent depending on the plant size. In terms of cost, if hydrogen price increases one percent each year, NPV would decrease by 2.5 to 3 percent for the production facility. The calculated elasticities for all other input cost variables were less than 0.25 percent.

Conclusions

The promising results for production of ethanol from the MixAlco process should be viewed with caution. The analysis uses the Energy Information Administration's long-term forecast for wholesale gasoline price where prices are expected to continually increase from 2005 to 2019. The uncertainty in the world oil market caused by the current war in the Middle East could dramatically affect the feasibility of a production facility. These outside factors cannot be controlled.

Also, the MixAlco process is still being refined and the production data used in this analysis are primarily derived from small-scale pilot plants. These numbers, such as ethanol yield per ton of feedstock, could vary in commercial conditions. More than likely, MixAlco will follow an adoption curve for new technology where the process is fine tuned over the first few years before full efficiency can be reached.

The results indicate that either size plant will be profitable given current assumptions. A positive NPV is forecasted with increasing net worth for a 44 ton/hour and 176 ton/hour production facility in the Panhandle, Central Texas, and Coastal Bend regions of Texas. Potential investors can use the results to determine the location, plant size, and key variables in deciding if a production facility should be constructed.

Furthermore, the results of this study provide useful information to compare the risk and benefits between the alternative plant sizes and locations. Investing substantial amounts of money in a new technology is a risky decision. Understanding and incorporating variability into the model allows for a probabilistic analysis where a probability range can be assigned for each outcome. The probabilistic framework gives decision makers much more information than a deterministic estimate.

The results also show the additional business activity associated with a MixAlco production facility would increase capital spending and household income boosting the local economy. MixAlco has the potentially to be a feasible alternative to corn-based ethanol production offering substantial economic gains for the community.

Study Limitations

There are several limitations to this study. First, silage yields and silage prices were interpolated from historical grain yields and budgets. These numbers are only best estimates of what the expected forage yield and price would be. Actual data from experimental plots collected from individual farmers would give a better representation of the expected yield and cost for sorghum silage. Yield is heavily dependent on weather, especially for dry-land farming in the Panhandle, Central Texas, and Coastal Bend regions of Texas.

Second, this study assumed specifically growing silage for energy production. Sorghum silage is used as feedstock because of its high yield characteristics, low costs of production, and adaptability to be grown in different climates. A 20 percent premium was included in the price to entice farmers to harvest sorghum for silage rather than for grain which may or many not be necessary. However, MixAlco would directly compete with the dairy industry for sorghum silage which may raise prices higher than expected. The higher sorghum silage price could dampen the financial outlook for MixAlco.

Residual biomass, such as tree clippings and farming residues, are not considered in this study. Agricultural residues could offer a low cost alternative to growing crops specifically for energy conversion. Studies show sorghum produces one ton of residual matter for every ton of grain produced. Harvesting the sorghum for grain and collecting the residual biomass could be a viable alternative. The ability of MixAlco to convert any biomass material to alcohol fuel makes it an attractive alternative for ethanol production. Large amounts of available residual biomass represent a low cost feedstock source that can be used for energy production (Gallagher, *et al.*).

Third, electricity prices, natural gas prices, steam prices, and lime prices were not separated by region. The differences in price between regions may be small, but for completeness, a separate price should be used in each region. Also, the prices are average prices for Texas. Better prices may be obtained from negotiations with providers in each region.

Fourth, location incentives may be available. The location incentives used in this study were generalized for each region after discussion with the local Chamber of Commerce and Economic Development Corporations. Each stated that the incentives are project specific and negotiated on an individual basis. They could not provide a complete and specific incentive package for a production facility without the proper information to evaluate.

Lastly, this study considers the production of ethanol on premise and shipping the finished fuel to refineries for blending. Smaller acid production facilities could ship acid to a centrally located, large hydration facility. There may be cost advantages to shipping acids to a central hydration facility located close to a large hydrogen production facility. This would reduce the cost of hydrogen and negate the problems associated with shipping ethanol. However, little data is available on the pricing and shipping cost for acids as well as the costs for large-scale production of hydrogen.

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