Acetone Butanol Ethanol (ABE) Fermentation from Corn

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Current industrial activities around the world have led to an extensive amount of need for energy which in turn requires a greater need for environmental protection. According to the IEA, fossil fuels make up about 80% of the world's energy source. Fossil fuels are a direct contributor to toxic carbon dioxide emission and climate change. Because it's a nonrenewable resource, the dependency on fossil fuels could lead to energy insecurity in the future due to potential shortages of petroleum and oil. Because of these issues, biofuels are being researched extensively to find an inexpensive and efficient alternative to traditional fuel. Biobutanol is a fuel that can be made from cellulosic biomass. Butanol is better than ethanol because it has 33% more energy capacity on a gallon basis as well as many suitable gasoline blending properties. Bio-butanol can be made from multiple sources but many research efforts focus on corn stover for the source. Corn stover consists of the leaves, stalks, and cobs of the plant, thus it would not be competing with food supply. The process that makes biobutanol is known as Acetone-Butanol-Ethanol fermentation. The glucose and xylose in the corn is utilized by certain *Clostridium* species of bacteria during fermentation. It is then converted into acetone, butanol, and ethanol. The product then goes through downstream processing and purification. The final product for biobutanol is a liquid fuel similar to gasoline. Similar to other fuels, the final product will be loaded in trucks or piped to distributors.

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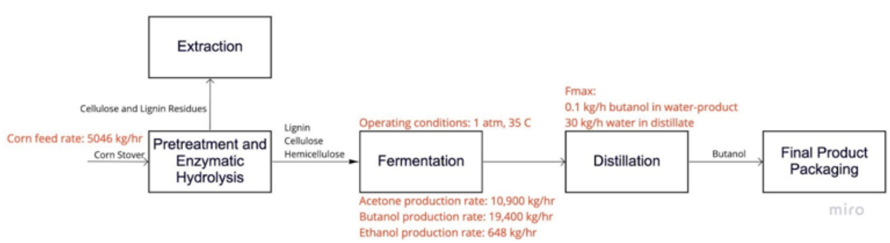
Product, Market, and Scope

The global market for biofuel butanol is evaluated at 3000 million gallons in 2020 and is projected at a compound annual growth rate of 8.5% for 2021-2026. A large part of biobutanol is used to blend in gasoline, which explains the fact there is a great demand for such fuel. The biobutanol market is segmented by region, by type, and by application. The biobutanol production costs ranged between $1.8 and 1.5 per liter without and with byproducts. It is estimated that 8% of the total butanol market (50000 metric tons per year) is consumed in direct solvent applications in the US. The quantity of biobutanol from corn sold in the US is estimated at 10500 megaliters which is 3.7 million tons.

Process

This process looks into the production of corn-based biobutanol. The aim of this process is an efficient production that will yield highest purity biobutanol, while minimizing the overall cost; to do this, several factors must be considered such as temperature, run time, pressure, and number of equipment used. The process begins by harvesting corn stovers sourced from a supplier. The corn stovers undergo a pretreatment process of steam explosion to soften its fibers. Then, it goes through enzymatic hydrolysis which utilizes sulfuric acid to break down the corn stovers into its three main components: cellulose, hemicellulose, and lignin. Hemicellulose consists of 5 carbon sugars and is the primary carbon source used in the fermentation process. Cellulose and lignin is extracted for other uses. Hemicellulose is fermented under anaerobic conditions using the bacteria *Clostridium acetobutylicum* to yield three products, acetone, butanol, and ethanol (ABE). The products then go through four distillation tanks to purify and separate butanol from the fermentation broth. Finally, the purified butanol is transported in its liquid form for distribution.



Equipment

For this process a total of 24 different pieces of major equipment are used to produce acetone, butanol, and ethanol. There are 11 holding tanks for the main process and for solution storage. This process represents single reactor fermentation and with a single, 2.6 million liter vessel. To save costs, vessel size could be divided by a factor of 4 and increase the amount of reactor vessels by the same factor. There are 5 distillation towers needed to distill furfural and other waste from the three products, as well as each other. 6 heat exchangers are used in the process, with 1 heat exchanger operating as a condenser. The last piece of equipment that is required is a straw crusher to process corn stover. Total equipment cost under a single reactor design is estimated to be 6.2 million dollars. A full list of major equipment is shown below:

Major Equipment					
Equipment #	**Equipment Name**	**Quantity**	**Type**	**Size**	**Cost**
T-101	Corn Storage Silo	1	Stainless Steel Silo	18540000 L	$470,000[1]
T-102	Steam Explosion Tank	1	Carbon Steel	8770 L	$112,000[1]
T-103	Acid Treatment Tank	1	Polyethylene	7500L	$64,000[2]
T-104	Neutralization Tank	1	304-grade stainless steel	7500L	$48,300[1]
T-105	Enzymatic Saccharification Tank	1	304-Stainless steel with thermal insulation	15000L	$50,200[1]
T-106	Agitation Tank	1	304-grade stainless steel	7500L	$123,000[1]
T-111	Waste Storage Tank	1	304-grade stainless steel	7500 L	$10,900[1]
R-101	Fermentation Reactor	1	316-grade stainless-steel	2.6 million L	$4,150,000[1]
DT-101	Furfural Distillation Tower	1	Carbon - Steel	760 L	$29,700[1]
DT-102	Differential Distillation Tower	1	Carbon Steel	760 L	$29,700[1]

DT-103	Butanol Distillation Tower	1	Carbon Steel	760 L	$29,700[1]
DT-104	Acetone Distillation Tower	1	Carbon Steel	760 L	$29,700[1]
DT-105	Ethanol Distillation Tower	1	Carbon Steel	760 L	$29,700[1]
H-101	Shell and Tube Heat Exchanger	1	Stainless-steel	333 m^2	$261,000[1]
H-102	Shell and Tube Heat Exchanger	1	Stainless-steel	158 m^2	$209,000[1]

Major Equipment					
Equipment #	**Equipment Name**	**Quantity**	**Type**	**Size**	**Cost**
H-103	Shell and Tube Heat Exchanger	1	Stainless-steel	121 m^2	$198,000[1]
H-104	Shell and Tube Heat Exchanger	1	Stainless-steel	35.4 m^2	$80,400[1]
H-105	Shell and Tube Heat Exchanger	1	Stainless-steel	10.2 m^2	$72,600[1]
H-106	Shell and Tube Heat Exchanger	1	Stainless-steel	95 m^2	$107,000[1]
G-101	Straw Crusher	1	Carbon steel	15,000 kg/hr	$65,300[1]
Total Equipment Cost: $6,180,000					

Economic Analysis

When calculating the profitability of a major plant that will produce a large amount of biobutanol many things must be taken into consideration. Among these includes capital costs, manufacturing/operating costs, raw materials, and etc. A major factor outside the scope of calculated profitability includes impacts from severe weather which may affect the supply of corn stover. The supply of corn may be limited and the price will be driven up which can affect our profitability. If this becomes a major problem, our team of engineers can work to retrofit this plant to be able to process rice or a similar grain in order to maintain profits. Another potential external factor that can impact profitability is the cost of labor and/or labor shortages. If this becomes more of a problem for the company, a potential solution could be to invest in technology that would automate more parts of the process. This would require less people to be at the facility at one time. Engineers could be on call instead if anything goes wrong instead of paying multiple employees to be there at once.

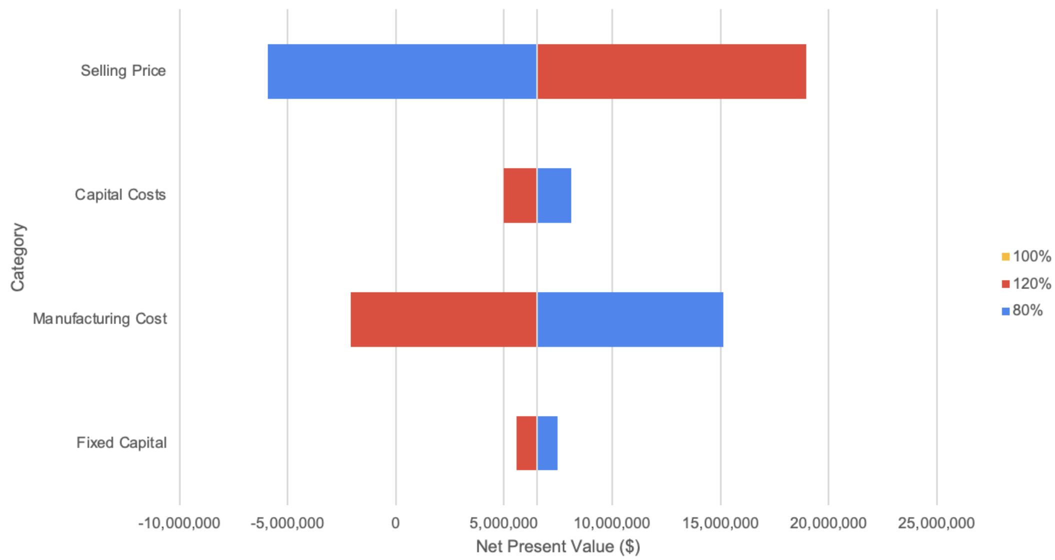


Figure 1: Tornado plot uses an example plant to determine the sensitivity of selling price, capital cost, manufacturing cost, and fixed capital on the net present value.

Regulatory Conditions

Biobutanol is the main product in this process with acetone and ethanol as side products. These products aren't heavily monitored by the FDA because they don't qualify as a food or drug. The EPA is the organization that regulates fuel more closely. The biobutanol production produces carbon dioxide through two sources, the fermentation process and the generation of electricity and heat. The fermentation process releases carbon dioxide through the growth of Clostridium acetobutylicum. Due to its biogenic nature, the release of carbon dioxide through the fermentation process does not require an environmental permit and thus can be disregarded. On the other hand, the generation of electricity through the use of fossil fuels does require adherence to the state imposed limits for air pollution. Through Title V of the 1990 Federal Clean Air Act, the maximum limit of carbon dioxide release is dependent on the location of the plant. Another important consideration in regards to environmental permitting is the release of unrecoverable ABE arising from the distillation process. As such, release of ABE to the environment falls under the hazardous waste permitting of the Resource Conservation and Recovery Act.

Production biobutanol uses and produces products that can be harmful if haled, ingested, or contact with skin. Especially materials like ammonia, acetone, ethanol, and butanol can cause irritation, respiratory damage, and other issues if inhaled, so personal protective equipment (PPE) should be worn by plant workers. PPE like hard hat, googles, gloves, clothing must cover the body to ensure safety of the plant workers. The materials like ammonia, acetone, ethanol, and butanol are flammable materials, especially dangerous when operating in a high pressure and high temperature environment. Meaning these materials should be stored in a cool, well ventilated, and place away from heat source to reduce the risk of fire or explosions. The bacteria used in the ABE fermentation, Clostridia, is not hazardous at all. Clostridia is a common bacteria that reside in the gastrointestinal tract of humans. Therefore clostridia can't produce any dangerous toxin or any harmful enzymes. Most of the equipment in the plant is safe to operate except for the distillation column. PPE like hardhat, long pants, close toed shoes, and safety glasses must be worn at all times when working with distillation columns. It is important to know the normal still heating medium temperature and the maximum temperature that it can reach as this is normally the maximum temperature that the distillate and residues can be exposed to. Prevention is the best appropriate basis for safety, therefore safer operation should be considered. Actions such as heating medium temperature below the decomposition temperature, continuous distillation to reduce inventory, vacuum distillation to reduce batch temperature. Care needs to be taken to maintain adequate size to cover temperature probes to ensure no loss of control.