THE CREATION AND PURIFICATION OF ETHANOL FOR USE AS A BIOFUEL
(Technical Paper)

THE ENVIRONMENTAL AND SOCIO-ECONOMIC CONSEQUENCES OF BIOETHANOL SCALE-UP
(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Climate change is encroaching upon a threshold from which it may not be able to recover, and it is swiftly moving to the forefront of pressing global challenges. The dependence of society on fossil-fuel based technologies has led to the rapid depletion of the ozone layer and caused massive climate ramifications on a global scale. Reallocation of resources into the development of alternative fuel sources is urgent in order to mitigate the planet's worsening environmental conditions. Bioethanol is a promising alternative to fossil-fuels due to the lower environmental strain associated with its production and consumption. Under current conditions, bioethanol is not an economically feasible substitute for conventional fossil-fuels; designing economically viable plant schematics is critical to addressing the climate change issue. By optimizing the production of corn-based bioethanol, it accelerates the ability of society to help mitigate the global climate crisis.

Technical Discussion

Corn ethanol makes up 95% of all ethanol produced in the United States. It is primarily used as a fuel blend with traditional gasoline. Fuel ethanol is used to both improve the performance of engines and reduce tailpipe emissions that negatively impact the environment. Current fuels are composed of 10% ethanol by volume. The inclusion of ethanol in fuels has contributed to the reduction of the United States' dependence on foreign petroleum from 60% to 28% **(**"Ethanol and Energy", n.d.**)**. This benefits the economy and provides employment to many Americans. The increased demand for corn also serves to provide farmers with continuous demand, thus supporting farming communities. The ethanol production process provides several useful co-products, including distillers dried grains with solubles (DDGS), which can be sold as livestock feed. In an effort to meet the ever-growing demand for efficient and cost-effective fuels, the corn ethanol process must be further optimized to produce fuel at the lowest possible cost.

The objective of this capstone project is to design a dry-mill corn ethanol production facility capable of producing the cheapest barrel of oil equivalent (BOE) of fuel grade ethanol. The scope of the project will entail determining the location of the plant, in regards to both local infrastructure and resources. Plant production costs and equipment required to produce profitable corn ethanol will also be determined. The project will require a cost analysis of both fixed start-up costs and variable production costs. The environmental impact of input fuel choices will also be examined to evaluate the sustainability of the end ethanol product. DDGS will be analyzed for profitability and cost of processing. These factors provide a comprehensive scope for the entire process, allowing the team to design a corn ethanol production facility that will take the corn from stalk to barrel.

The value of this project is particularly important given the world's on-going interest in transitioning away from fossil fuels in favor of renewable energy sources. Biofuels are highly regarded as a powerful way to reduce net emissions, particularly in the otherwise fossil-fuel reliant transportation sector. Bioethanol currently provides a drop-in renewable energy alternative that integrates well into current nationwide infrastructure. Identifying key improvements in the manufacturing process of corn bioethanol will serve to benefit an industry that will surely grow with time.

The corn ethanol production process can be separated into five stages: milling, liquefaction, saccharification, fermentation, and recovery (Figure I, Johansson, 2013). Corn is first taken from the stalk, cleaned, and then milled into a blend that contains cellulose, hemicellulose, and lignin. A hammermill or roller mill is used to mill the corn. A slurry is then formed by mixing the milled corn with hot water. The temperature is then increased to form a viscous slurry, where the longer carbohydrate chains will undergo partial hydrolysis to form smaller chains. Alpha-amylase enzyme is then added to the slurry as part of the liquefaction stage. The mixture is sterilized at high temperatures. The liquified starch is then cooled, and a secondary enzyme, glucoamylase, is added to transform the starch to fermentable sugars. These sugars are added to a fermentor, where yeast is added and the sugars are converted into ethanol and CO_2. The fermented mass is then fed to a system of distillation columns to separate the ethanol from the grain with solubles. At this point the ethanol contains about 5% wt. water that must be removed, and the DDGS must be further processed. The hydrous ethanol is passed through a series of ceramic beads that absorb the water, allowing the anhydrous ethanol vapor to pass through to the collection unit. The DDGS is centrifuged to separate the grain from the liquid, which is then taken to drying units, and sold as a co-product. This process produces pure, anhydrous ethanol that must be combined with a bittering agent to discourage inhalation or ingestion.

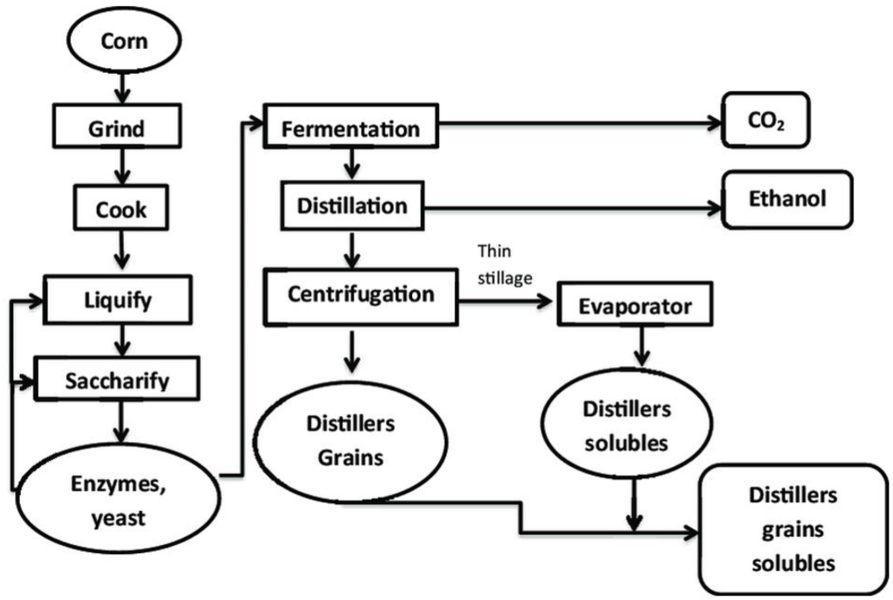

Figure I: Schematic of Ethanol Dry Milling Process

The high demand and applications for corn-based ethanol have driven research and process optimization within the field. Separation methods are of particular interest due to the disadvantages of thermal distillation-based separation for ethanol purification. Several alternatives have been evaluated, including ultrasonic irradiation distillation and the adsorption of impurities (Onuki, 2008). By studying the applicability of nontraditional ethanol separation techniques, the process can be improved to optimize profitability while improving the separation capability.

A gallon of ethanol currently sells for $2.22, which is the highest per gallon price since 2014 **(**“Ethanol Commodity”, n.d.**)**. By evaluating the economics of the process and input requirements, we will determine the profitability of ethanol production at this scale. As a team, we will discuss progress and more difficult tasks on a weekly basis. We intend to each be involved in all steps of the process and phases of the project. Based on each of our unique skills sets, we will break down each process step into tasks and split responsibilities among group members. Weekly check-ins will serve to keep the team moving forward at a reliable pace. This is a two-semester team project that will be completed under the guidance of Professor Anderson as part of ChE 4474 and ChE 4476.

Design data will be primarily supplied from public company databases and academic literature. Several datasets detailing the biomass starting material composition, reaction analysis of yeast, and economies of scale in ethanol production have already been identified for the potential application within this project. ASPEN Plus will be used to simulate and evaluate the distillation-based separations. The *Unit Operations of Chemical Engineering*, by McCabe, Smith, and Harriott, provides insight into the calculations relevant to solid handling, corn milling, and pre-distillation separations. Microsoft Excel will be used to manipulate and represent data and results. The application of these computation tools in conjunction with the available data will facilitate an in-depth analysis of the economic viability of corn-based ethanol as a fuel at this production scale.

In conclusion, through an iterative design process spanning 2 semesters, the group will research, design, and propose a large-scale corn bioethanol production facility that will ideally inform further developments in biofuels production, particularly as the nation becomes increasingly focused on emissions impacts.

STS Discussion

Steering the transportation industry towards the increased implementation of biofuels may lead to serious positive consequences in the global climate battle. Reduced emissions from ethanol fuels are a promising start to combatting rising temperatures, but it does not represent the full-scale of environmental or social impact of producing bioethanol. Sourcing a bioethanol operation is extremely land intensive, and it comes with associated environmental, social, and ethical considerations.

In order to produce corn on the scale necessary for feasible operation, natural conditions in the plant’s location are altered severely. Groundwater usage and soil erosion occur at significantly higher rates, and overall biodiversity is disrupted due to the reallocation of naturally occurring nutrients (De Oliveira, 2005). The gradual degradation of the land used for such intense corn production is a concern for both the ethanol manufacturer and the farmer alike. Abusing the soil ensures that either costly reparations need to be made in order to revitalize the growing conditions, or lose out on periods of production.

In order to accommodate the United States’ ever growing energy needs, the scale-up of ethanol production facilities requires the acquisition of more and more land. Projections indicate that to meet the demands of the entire automobile fleet in the United States, all available cropland would be required to produce enough usable bioethanol (De Oliveira, 2005). If such vast amounts of land are necessary for energy production, intense competition will arise between other industries fighting for land. This competition can lead to the deforestation of public forests on land that is purchased from the government, oftentimes impacting indigenous people and communities (Chatty, 2002). Because of the strong ties between indigenous communities and their land, the socio-economic ramifications of these land acquisitions can be intense. The Dakota Access Pipeline illustrated a similar situation under which native land was taken under government contract (Whyte, 2017). There was immense societal outrage pertaining to the ethics of the projects’ construction; the intense land requirements of biofuel production may encroach on similar issues.

In its current state, corn-based bioethanol production already impacts the corn supply chain and leads to higher prices for consumers (Gardebroek, 2013). Increasing the scope of bioethanol usage only serves to put more strain on existing infrastructure that will raise the prices higher. Government regulation is involved in this process to help harmonize the production of bioethanol and redistribution of corn supply with its price to the consumer (Michael, 2020). Subsidies into renewable energy markets can help to alleviate some of the price differences that prevent bioethanol from directly competing with conventional fossil-fuels. The increasing involvement of the government in energy regulation may have some short-term impacts on consumers as well. In order to promote the usage of ethanol-based fuels, the need for increased taxes on regular gasoline may make it more expensive for the average person to drive their car day-to-day. (Vedenov, 2008).

To adequately assess the feasibility of bioethanol production, it is integral to acknowledge the socio-economic consequences that its implementation will create. The environmental concerns with land acquisition and resource depletion are partnered with the economic and judicial aspects of pricing and regulation. In order to fulfill the goal of creating a more sustainable fuel for the future, a balance must be struck between the economic viability for the company and the environmental and economic benefit of the consumer.

Conclusion

Corn-based bioethanol production is a promising alternative to conventional fossil-fuels due its reduced environmental impact. The need for sustainable fuel alternatives is more important now than ever before. The continued optimization of bioethanol process design is paving the way towards economic viability. It is important to be cognizant of the bioethanol industry’s impact on the environment through its usage and acquisition of land. It is equally important to consider the possible negative socio-economic impact bioethanol can have on the people that it aims to benefit. The goal of this project is creating the most economically feasible ethanol plant possible, without compromising its ethical integrity.

Word Count: 1815

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