THE CREATION AND PURIFICATION OF ETHANOL FOR USE AS A BIOFUEL

THE IMPACT OF CORN ETHANOL PRODUCTION ON THE ENVIROMENT, FARMERS, AND CONSUMERS

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By
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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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Corn derived ethanol makes up 95% of all ethanol produced in the United States. It is primarily used as a fuel blend with traditional gasoline, with current fuels mandated to be a blend of ethanol and gasoline, with a minimum threshold of 10% ethanol by volume, commonly called E10 (Economic Research Service, 2021). The purpose of fuel ethanol is to both improve the performance of engines and reduce tailpipe emissions that negatively impact the environment. Ethanol inclusion in fuel is also meant to reduce the United States dependence on foreign energy providers, and since the passage of the Energy Policy Act in 2005, foreign oil imports have decreased 36% from 2005 until 2019 (Energy Information Administration, 2019). The increased demand for corn also serves to provide farmers with continuous revenue streams, as they are able to guarantee the sale of their corn reserves. The ethanol production process provides several useful co-products, including distillers dried grains with solubles (DDGS), which can be sold as livestock feed, and carbon dioxide, which can be captured and used as energy (Shad et. all, 2021). 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 focus of the technical report will be on designing a corn-to-ethanol production facility. The report will include an analysis of feed products, fermentation methods, separation techniques, material and equipment costs, energy requirements, and wholesale value, as well as other variables in plant construction and operations. This extremely detailed theoretical assembly will entail the creation of an ethanol production facility that is viable for long-term commercial use, specifically minimizing the costs per barrel of oil equivalent, which is the amount of ethanol needed to provide the same energy as a barrel of oil. The STS paper will use the Actor-Network Theory framework to examine the impact of corn ethanol production on the environment, corn producers, and corn suppliers. The paper will explore the interconnection between corn subsidies, food security, and ethanol energy mandates, and how these factors compete for a finite corn supply. These two projects are tightly coupled as the corn-to-ethanol production facility project will focus on the commercial and industrial side of the corn ethanol industry, while the STS project will focus on the actors impacted by the corn ethanol industry, specifically the environment, the producers of corn, and those who use corn for purposes other than ethanol production (Callon, 1999). The technical project will be completed by graduation and will require the assistance of the entire technical team members to complete, while the STS project will have a similar timeline, but require only one author. Please refer to the Gnatt chart below in regards to the timeline, which shows a breakdown of both projects and their components.

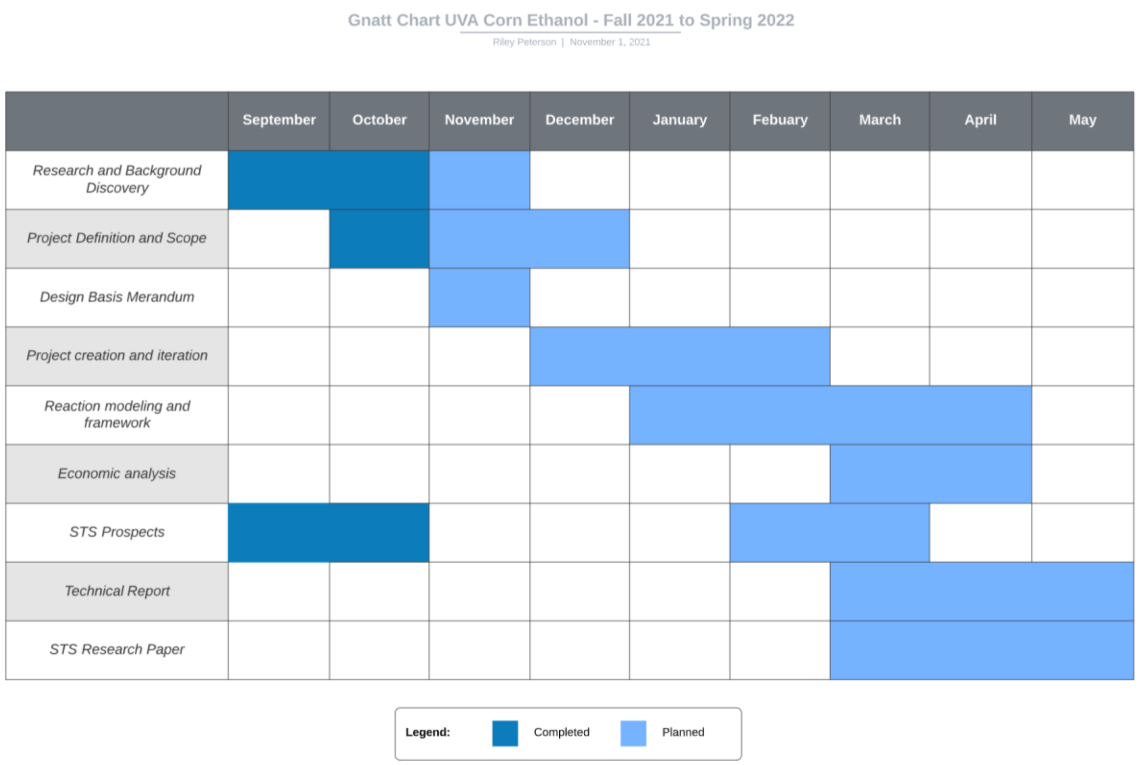

Figure 1: Gantt chart, UVA corn ethanol capstone. This figure visualizes the timeline for the technical project and STS project. (Peterson, 2021).

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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 (Karuppiah, 2008).

The value of this project is particularly important given the world's ongoing 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 (Hettingaa et all, 2008). Bioethanol currently provides a drop-in renewable energy alternative that integrates well into the 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, as shown in Figure 1. Corn is first taken from the stalk, cleaned, and then milled into a blend that contains cellulose, hemicellulose, and lignin. A hammer mill 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. The 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 into fermentable sugars. These sugars are added to a fermenter, where yeast is added and the sugars are converted into ethanol and CO2. 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. This process allows for raw corn to be converted to fuel-grade ethanol, as well as purifying the byproducts for sale (Kwiatkowski, 2005).

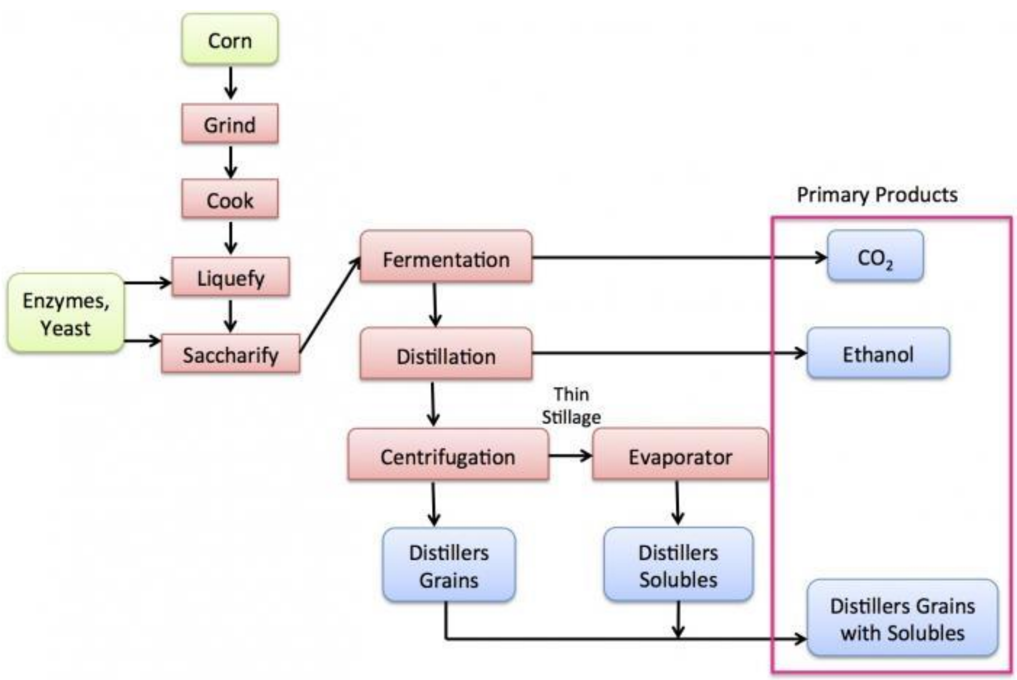

Figure 2: Schematic of Ethanol Dry Milling Process, Adapted by Riley Peterson (2021), from Penn State College of Earth and Mineral Science.

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 (Pimentel, 2005). 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 (Economic Research Service, 2021). By evaluating the economics of the process and input requirements, we will determine the profitability of ethanol production at this scale. This is a two-semester team project that will be completed under the guidance of Professor Anderson, a professor of chemical engineering in the Department of Chemical Engineering at the University of Virginia, structured through the classes ChE 4474 and ChE 4476. The team members on this project include Christian Benedict, Emily Beyer, Gregg Gardner, Riley Peterson, and William Mosburg. Each team member is an undergraduate student studying chemical engineering in their fourth year at the University of Virginia School of Engineering and Applied Science.

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, see references. ASPEN Plus will be used to simulate and evaluate the distillation-based separations, and this computer model will be used to further estimate production capabilities. 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 (McCabe et all, 2005). Microsoft Excel will be used to manipulate and represent data and results, as well as conduct the plant financial analysis. 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 fuel at this production scale (Karuppiah, 2008).

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

THE IMPACT OF CORN ETHANOL PRODUCTION ON THE ENVIROMENT, FARMERS, AND CONSUMERS

In the United States, subsidies provide an incentive for farmers to grow corn, specifically providing a price floor for corn prices per acre of corn. These subsidies allow farmers to grow corn without fear of the volatility of the agriculture market causing them to lose money on their products. Corn is currently subsidized for $1.95 per bushel, which means that the minimum a farmer would receive for his bushel of corn would be $1.95 (Energy Information Administration, 2019). The idea behind these subsidies was to protect and help American Farmers and consumers who would be hurt by fluctuation in corn prices. In 2002, the passage of the Farm Bill Act re-enforced food security in the United States by setting these price floors for crop yields, with the intended purpose of reducing the United States' dependence on foreign aid for food. This policy of American food resilience led to $20 billion in aid being allocated for farm subsidies (Babcock & Fabiosa, 2001). The year-to-year volatility for corn is shown in table 3 on page 8,which demonstrates how seasonal variation and other variables can contribute to corn production per acre. The trends displayed in table 3 further illustrate the increase in corn yields starting in 1956, where technological development led to rapid growth in corn yield per acre. This increased corn production led to larger corn reserves, which then contributes to a decrease in corn price. The

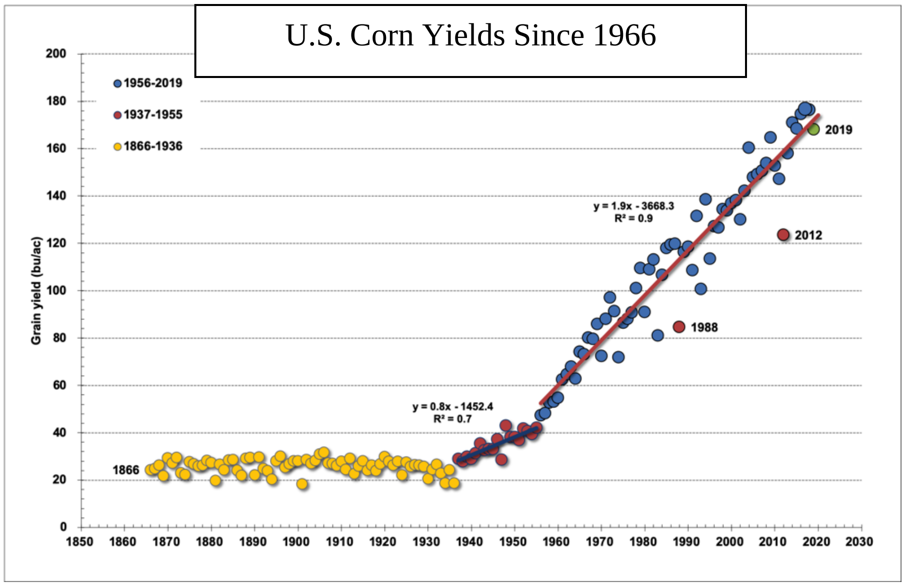

Table 3: Measure of Corn Yield in the United States from 1866 to 2015 in Bushel per Acre, Adapted by Riley Peterson (2021) from Colorado State University (2020).

problem with greater corn production is an increase in greenhouse gas emissions, GHG, specifically methane stemming from the production of corn ethanol (Dunn, 2013). The main cause of this methane is the farming techniques that led to the yields, but with the demand for corn as both food and fuel, these concerns are overlooked and overshadowed.

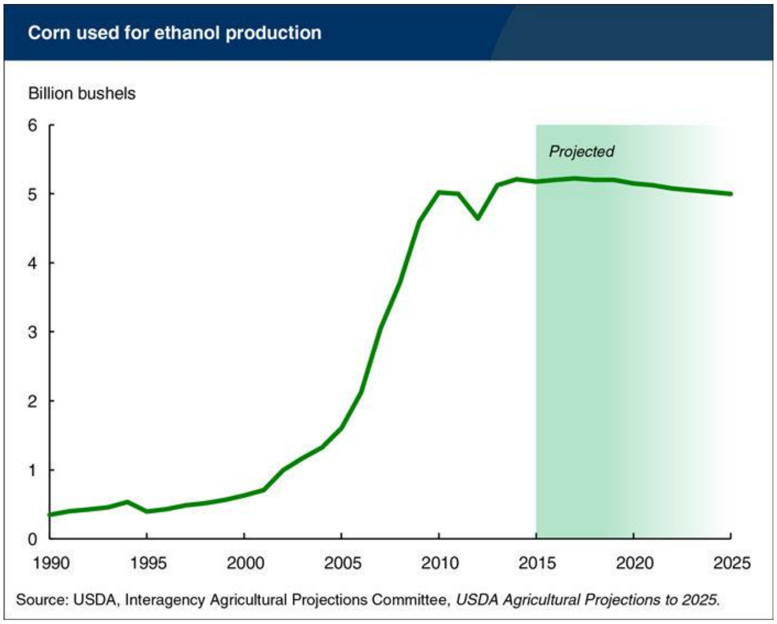

Table 4: Corn used in Ethanol production in billions of Bushels, from 1990 to 2025, projected based on current market trends, adapted by Riley Peterson (2021), from USDA (2015).

The decrease of domestic energy prpoduction and rising oil prices led to the passage of the Energy Policy Act of 2005, which mandated that billions of gallons of ethanol are to be added to the American fuel supply to guarantee demand for ethanol. This has led to a sharp increase in corn use in ethanol since 2005, as shown in table 4 on page 8. Before the passage of the Act, the corn used in ethanol production hovered around 1 billion bushels per year, but it quickly jumped to over 5 billion in under 5 years. This massive spike in corn usage for ethanol after 2005 has led to a constant demand for the existing corn reserves, however, this

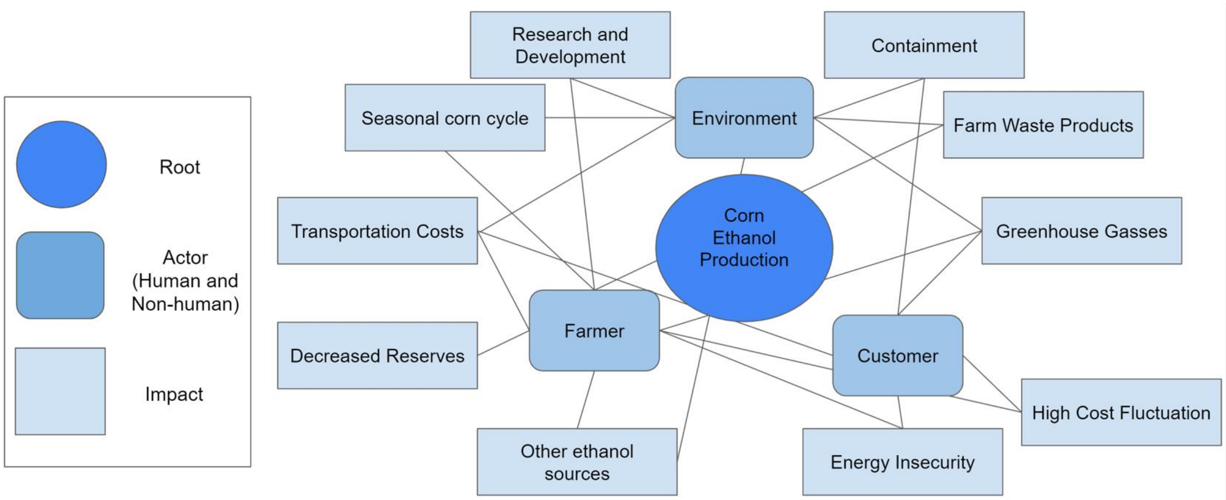

Figure 5: Actor Network Framework for corn ethanol production. Identifies the impact of corn ethanol production on both human and non-human actors. (Peterson, 2021)

drastic spike in ethanol usage has led to unforeseen consequences (Vo, 2020). Ethanol consumption has spiked as well, and this rapid production and consumption of ethanol have led to significant greenhouse gas emissions, specifically producing methane and carbon dioxide (ICF, 2018). The argument has long been that ethanol combustion produces less GHG, and this is true for out of tailpipe emissions, but for ethanol, the majority of emissions stems from the production, not consumption.

The purpose of the STS research project is to examine the actor-networks impacted by the spike in corn ethanol production and to determine the consequences of increased production on farmers, the environment, and corn consumers as shown in Figure 5. This figure details the complex relationships between the actors in the corn ethanol industry and the impact that corn ethanol production has on these participants. This analysis will first examine the corn ethanol production in the environment, where the claim is that corn ethanol reduces tailpipe emissions, but in reality, corn ethanol production bears much of the emissions footprint for ethanol (Yang, 2012). The second actor examined will be small and commercial farms, examining how the corn ethanol subsidies have shifted the responsibility from producing quality grains to producing corn in volume. This shift from the quality of harvest to the yield of an acre has shifted the balance of agricultural power and impacted significantly the livelihood of small and family farms. In addition to examining the impact on family farms, the project will examine the product of corn on other subsidies crops, and how the corn ethanol mandates have caused an agricultural shift between crops produced (Ferris, 2004). The final actor examined will be consumers of corn, specifically how the supply chain for corn has been impacted by the Energy Policy Act, and how it has impacted corn consumers. The STS project will examine the cost of corn per bushel since 2005, and the markets for corn imports and exports. The demand for corn is continuously growing as more and more avenues for use become apparent, and the project will examine how these demands negotiate with the limited supply.

The STS project will detail the intricacies of corn ethanol subsidies on three actors in the network. The project will examine the environmental impact of ethanol production, the production demands on family farms, and the consumer impact of ethanol mandates. These three different actors are the actors that have been most impacted by the Energy Policy Act of 2005, and the unknown impact of this policy will be examined. The research paper will hope to detail the complex web of interactions between these actors and hope to bring awareness to how public policy can directly impact unforeseen players.

THE INTERCONNECTION OF ETHANOL AND FARMERS

The purpose of the STS project is to examine the impacts of corn ethanol subsidies on human and non-human actors, specifically how the increased industrialization of farms to meet production demands has impacted these segments. The technical report will examine the harvesting and transformation of corn into fuel-grade ethanol and will do so from an engineering, chemical, and financial perspective. These two reports should provide a look into the corn-to-ethanol industry, and the effects this industry has on other shareholders and consumers.

Corn based ethanol is a major economic drive in the United States, and as such there has been much research and development behind the industrial process. Despite this heavy technical research, environmental and consumer impact remain distant afterthoughts for the researchers (Karuppiah, 2008). The failure to evaluate the complex framework in which ethanol demand exists, as a relationship between consumers, producers, and the government, obscures much of the impact of corn ethanol. While many claim the benefits of corn ethanol, helping farmers sell more corn, reducing gasoline consumption, and reducing US dependencies on foreign oil, outweigh the costs, the STS paper will explore both (Ferris & Joshi, 2004). The aim is to explore the interconnection between identified actors, and determine both impact and control on the network. The technical paper will explore the production of corn ethanol from a mainly economic perspective, as the team seeks to find the operating conditions that minimize cost of barrel equivalent. The project will provide further information on how to examine the impact of corn ethanol production, as the factors that will be both examined and ignored by the technical team will be evaluated in the STS project. The hope is to examine the direct impact of the hypothetical plant to determine the conditions that industry leaders are placed in when examining the conditions to create their own production facilities.

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