Production of Sustainable Butanol Biofuel from Lignocellulosic Biomass

The Subsidization of Corn for Ethanol Product and its Impact on Agricultural Communities

A Thesis Prospectus
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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:

Agricultural communities have been foundational to the development of the United States, providing food and energy security for hundreds of years. Until the twentieth century, these communities worked in a relatively laissez-faire environment (Angelo, 2010). However, the environmental and economic disasters of the 1920's and 1930's, namely the Dust Bowl and the Great Depression, led to the implementation of government policy that shaped the agricultural frontier moving forward. The mindset of policymakers had changed with the belief that agricultural communities were in a constant state of emergency, and without permanent help would result in a "collapse of the farming system" (Angelo, p. 30, 2010). One such emergency involved federal legislators responding to the oil crisis of the 1970s. According to Duffield et al., (2008), "[p]olicymakers began to look at the U.S. agricultural sector as a source of energy supply, which had the ability to turn corn…into renewable fuels", facilitating the creation of "a new market for farmers who suffered from persistently low commodity prices caused by crop surpluses" (p. 426). In response to the oil crisis, legislators instituted laws creating and necessitating the use of ethanol-based gasoline additives. Lawmakers also designed mandates requiring that up to 15 billion gallons of bioethanol must come from corn, more than one-third of nationwide corn use (McPhail & Babcock, 2012). To achieve this large scale technological and environmental objective, many subsidies were written into law. Subsidies allowed the federal government to aid farmers via various methods including direct payments to farmers to bolster or suppress crop production (Angelo, 2010), or support programs that acted as crop insurance based on crop yield and market price (Orden & Zulauf, 2015).

Angelo (2010) states that "[f]rom 1995-2006, the United States government paid out 177.6 billion dollars in agricultural subsidies", where the largest percentage of "commodity subsidies were for corn, with 1,568,095 recipients receiving $56,170,875,257 dollars" (p. 5). However, according to Bruckner (2016), "only three out of 10 farms with less than $100,000 in sales, but seven out of 10 farms with $500,000 or more in sales received government subsidies" (p. 632). Subsequently, Bruckner (2016) claims that "[g]iven this artificial competitive disadvantage, smaller and more diversified farms and beginning farmers are unable to compete with the largest farms for highly coveted cropland to rent or purchase" (p. 633). These authors seem to bring two opposing viewpoints on the impact of subsidization, therefore demonstrating the importance of understanding the effect that government policy had on agricultural communities. The technical portion of the thesis will discuss the use of lignocellulosic corn stover as a second-generation feedstock for the creation of biobutanol, an innovative, and environmentally optimal fuel additive alternative over ethanol. The STS analytical framework of the Sociotechnical Imaginary in the reading "Selling Smartness: Corporate Narratives and the Smart City as a Sociotechnical Imaginary" by Sadowski and Bendor (2019) will be used throughout the STS portion of the thesis to highlight the research question in a unique way.

Technical Portion:

Emissions from internal combustion engines have driven the world's air pollution, a significant concern in the global warming phenomenon (Manzetti & Andersen, 2015). The pollution from these emissions is attributed to the extensive burning of fossil fuels, which are non-renewable fuels (EPA, 2023, *The sources and solutions: Fossil fuels*). To help mitigate this problem, the United States federal government has implemented the addition of alcohol-based fuel additives to gasoline, which reduces the carbon emissions from internal combustion engines and partially replaces a finite fuel resource (i.e. petroleum) with a sustainable, renewable fuel source (EPA, 2023, *Economics of biofuels*). Ethanol is commonly added into gasoline for this purpose, as well as to better oxygenate the fuel. Research has shown that butanol, a longer chain alcohol, has a higher heating value, lower volatility, increased ignition performance, and higher energy density, making it a more promising fuel additive alternative (Trindade & Santos, 2017). First generation feedstocks such as corn, sugarcane, oil palm, wheat, and soy are commonly used in ethanol production today (Tomei & Helliwell, 2016). Like ethanol, butanol can be produced from this type of feedstock. Controversies arise concerning the use of these food crops for biofuel production because such use drives increases in food prices, with some regions seeing food prices rise up to 83% in recent years (Tenenbaum, 2008). Second generation feedstocks are lignocellulosic agricultural residues such as corn stover. These byproducts have been presented as an innovative, low-cost way to repurpose waste into usable biofuel and prevent food price hikes (Bušić et al., 2018; Tomei & Helliwell, 2016). One impediment with this material is the requirement of advanced pretreatment technologies for successful fermentation since microorganisms cannot digest cellulose as easily as sugars and starches (Taha et al., 2016). This poses obstacles for large-scale commercialization; however, the team is optimistic in this regard due to recent research that has proposed cheaper, innovative pretreatment methods, such as the use of alkali as a hydrolyzing agent (Baral et al., 2016; Chen et al., 2021). This technical project aims to answer the following research question: How can the team simulate a technically optimized production process of butanol, a more energy dense, sustainable biofuel additive, from a cellulosic feedstock, corn stover, in an economically viable manner?

This project is intended to examine the production of biobutanol from a corn stover feedstock using an acetone-butanol-ethanol (ABE) fermentation process (Buehler, 2016). Fuel-additive grade butanol is the primary product, with byproducts of acetone and ethanol to be used as is most economically viable. Conversion of corn stover to butanol will be accomplished through pretreatment of the feedstock, followed by biological fermentation using the bacteria *Clostridium Acetobutylicum ATCC 824* (Buehler, 2016; Rao et al., 2016), and separation steps. The unit operations that will likely be used and designed in this process include reactors and washers for the pretreatment hydrolysis; a reactor for the fermentation reactions; and interconnected distillation columns to separate components and break aqueous ABE azeotropes (Pudjiastuti et al., 2021). A block flow diagram below depicts the general process to be designed by the team (Figure 1).

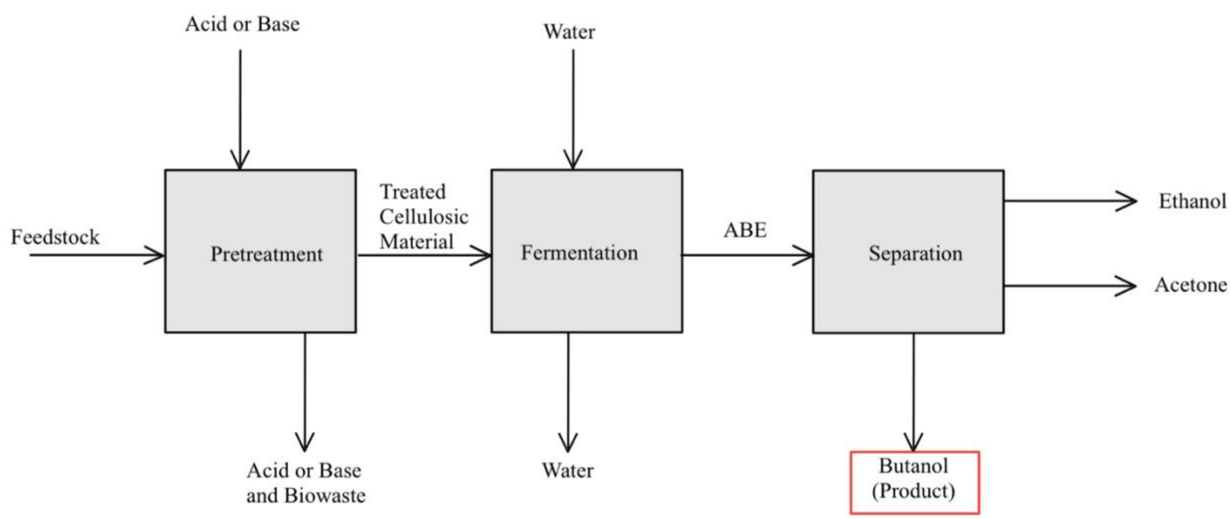

Figure 1. Butanol from ABE fermentation block flow diagram

The team will use Aspen Plus Simulation software to design a plant for the economical and sustainable production of butanol from ABE fermentation. This software allows the user to construct a process model and simulate its function using complex equations, mathematical computations, sensitivity analyses, and regressions. To begin construction, design data such as fermentation cell growth kinetics, methods of separation (e.g. azeotropic distillation, extraction, successive distillation columns), various feedstock viabilities, and economic analyses of the process, will be collected from peer-reviewed journal research and industrial data. Consultation with UVA Professor Ronald Unnerstall, who has 34 years of experience in the Oil and Gas industry and further experience writing BP's company directive for biofuel use in 2001, will also help direct the team's efforts in designing a process fit for an industrial scale application. This project will take place in the Fall 2023 and Spring 2024 semester as a part of the CHE 4474 and CHE 4476 senior design courses. The team will divide work based on preliminary research focus and relative familiarity of plant unit operation. They will complete the final design report in April of 2024.

STS Portion:

According to Duffield et al. (2008), "[t]he early development of the U.S. ethanol industry was sparked by government policy", where "[t]he three primary motivations behind government support for ethanol are environmental, energy independence, and rural development" (p. 425). The commodity price of corn became tethered to ethanol production numbers, where an increase in ethanol generated heightened demand for corn (Fortenberry, 2008). Legislative intervention began as a temporary bandage to help farmers out of debt and to keep farms operational even when farming wasn't economically viable. However, government aid began a positive feedback loop that has exponentially increased over time. Instead of keeping every small farm working various crops afloat, the large swaths of government aid allowed large farms to run smaller ones out of business and created the rise of corn monocultures that made farmers more dependent upon government subsidies and digging farmers deeper into debt. The characteristics of traditional farming communities were altered with the advent of legislative agricultural aid. This situation prompts the question, how has the subsidization of corn for ethanol product affected agricultural communities?

The impacts from federal subsidies like those in Farm Bills, and mandates like the Department of Energy's Renewable Fuel Standard (RFS) will be examined. This topic will utilize the theme of the "smart city", a type of sociotechnical imaginary framework discussed by Sadowski and Bendor (2019). This thesis will analyze how the United States federal government aiding agricultural communities via legislation is equivalent to "smart services" provided by IBM and Cisco to alleviate issues arisen in the smart city. Journals, discussion papers, and law reviews will be the main source of information for the thesis. This research question will be broken into three subsections: modifications of type of crop grown, shifts in farming techniques and methods, and changes in farming community number and makeup.

In response to the federal government's policy directive on corn and bioethanol production, agricultural communities have shifted the balance of crops grown across the United States. The Department of Energy's 2007 RFS mandate set a quota of 15 billion gallons of biofuel blended into gasoline, which was recently increased to 36 billion gallons by 2022 (*Renewable fuel standard*). From 2000 to 2009, nationwide ethanol production scaled from 1.6 billion gallons to 10.8 billion gallons, requiring "U.S. corn production [to] increas[e] from 9.9 billion bushels to 13.1 billion bushels" (Wallander et al., p. 1, 2011). Specific areas in the United States, including the Corn Belt and Lake State regions, demonstrated strong trends of converting soybean and hay acreage to cropland deemed only for corn (Wallander et al., 2011). According to Wimberly et al. (2017), one of the primary reasons for expanding cropland for corn production was based on difference in potential income. This subsection will connect the four elements of strategy from IBM and Cisco to the federal government instituting legislation that provides aid for agricultural communities (Sadowski and Bendor, p. 548, 2019).

Agricultural communities have deviated from traditional farming techniques as a result of federal government policy. According to Power and Follett (1987), "[t]he driving force behind a farmer's choice of production techniques is usually the net economic return" (p. 86). To keep up with increasing ethanol production quotas, farmers have attempted to supply enough corn via methods like monoculture farming. However, monocultures pose a significant economic threat to farmers because of dependency on a single market and specific set of economic conditions, with crops at risk of succumbing to severe weather or blight (Power & Follett, 1987). In the past two decades, almost 10% of corn in the Central United States was grown as a quadruple, or four-year, monoculture, representing around 7 million acres of land (Plourde et al., 2013). Monocultures tend to degrade the environment, having a deleterious effect on future crops and economically impacting farmers (Power & Follett, 1987). This subsection will use the quote, "the entire urban 'system of systems'… must eventually be redesigned and made smart(er) so that it can sustain growth" (Sadowski & Bendor, p. 549, 2019). Agricultural "systems" have also been redesigned, with farming technique being a prime example.

The size and number of agricultural communities can be linked to the institution of government agriculture policy. When considering farm size, from 1982 to 2007 "the midpoint farm size…almost doubled from 589 to 1105 acres" (Key, p. 186, 2019). Larger farms receive an artificial competitive advantage, allowing larger farms to outcompete smaller ones for purchasable land and production technology (Bruckner, 2016; Key, 2019). The number of farmers has steadily decreased from 32.5 million people to 4.5 million in 2017, which could be attributed to farms getting larger and needing less labor to function (Pardey & Alston, 2021).

This subsection will contrast the goal of smart city projects as “the belief that all the world’s problems…can be solved technologically” to agricultural communities (Sadowski & Bendor, p. 553, 2019). Farms are scaling to larger operations or are selling to other operations. The federal government’s original objective was to save agricultural communities from economic or environmental emergencies via legislation. If agricultural subsidies are equivalent to “smart city projects”, the ultimate shrinking of agricultural communities may signify that the purpose of this aid failed, in direct opposition to Sadowski and Bendor’s message.

Conclusion:

The United States has relied upon agricultural communities for hundreds of years for food and energy security. Original fuel additives took food grade corn away from humans to produce lesser energetically dense product. Designing a butanol production process creates a more energetically dense fuel additive from corn stover, a type of corn waste. This allows corn farms to still be utilized as a feedstock option, and yet separates food security concerns from energy ones. Corn is a valuable energy and food product. Therefore, research on government policy and subsidization of the agriculture industry will be invaluable in understanding the impact of government intervention and to better help agricultural communities in the future.

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