### ALTERNATIVE BIOFUEL: CORN STOVER TO BIOBUTANOL

# ETHANOL BIOFUEL IN THE CONTEXT OF TECHNOLOGICAL MOMENTUM

A Thesis Prospectus In STS 4500 Presented to The Faculty of the School of Engineering and Applied Science University of Virginia In Partial Fulfillment of the Requirements for the Degree Bachelor of Science in Chemical Engineering

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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. Isabella Powell

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#### Introduction

Since the industrial revolution, there has been a heavy societal dependence on fossil fuels like coal, oil, and gas (United Nations, 2023). Combustion of these fuel sources represents some of the largest contributions to the greenhouse gas (GHG) emissions responsible for climate change (United Nations, 2023). Despite the growing awareness of the link between fossil fuel usage and the damage to Earth, there has been little change in this reliance: as of 2022, 79% of all energy consumed in the United States was derived from fossil fuels. Internal combustion engines (ICEs) are significant contributors to the usage of fossil fuels and the subsequent environmental impacts as they produce roughly 25% of GHG emissions (NASA, 2023).

In an effort to reduce the impact that ICEs have on climate change, there have been extensive efforts to implement biologically derived alcohol fuels, so called "biofuels." Biofuels, whether used as a replacement for gasoline or as an additive, reduce GHG emissions during combustion while simultaneously decreasing the usage of nonrenewable fossil fuels. Currently, ethanol is the alcohol commonly added to gasoline, but research has indicated that there are other alcohols that may be better suited as fuel alternatives. Butanol is particularly promising given that it has a higher heating value, lower volatility, increased ignition performance, and higher energy density than ethanol (Trindade & Santos, 2017).

In addition to the opportunity to exceed current ethanol performance, there is also substantial room for improvement in alcohol fuel generation processes. Presently, ethanol biofuel is derived from the fermentation of corn, which results in over 45% of U.S. corn production going toward ethanol production (USDA, 2023). This represents a sustainability challenge in that farmland and corn that would otherwise have been a food are being redirected to the energy sector (Tenenbaum, 2008). A shift from corn to a biological waste stream is one possible way to

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address this issue. As such, I will propose a chemical process that converts corn stover, a biological waste feedstock, into butanol, resulting in an overall more sustainable process with a product better suited to a biofuel application.

While the technical component of overcoming the challenges associated with ethanol consumption is vital to the success of alcohol fuels, over the course of their existence there have been many societal factors involved in the production and implementation of the fuel. From the first application of ethanol in transportation fuel to the multi-billion dollar industry (USDA, 2023) that exists today, ethanol has progressively increased in societal prevalence while also becoming more resistant to changeover to better alternatives, such as butanol. In my STS project, I will draw on the framework of Technological Momentum to analyze this social shift over time and current reluctance to change. If butanol from the technical project is to be successfully implemented, it is paramount that the design team fully analyzes the interplay between society and ethanol, as well as the gradual transition of societal influence.

Thus, in order to fully address the shortcomings of current alcohol based biofuels, both technical and social factors must be accounted for. For the technical component, I will utilize chemical engineering knowledge in conjunction with modeling software and extensive research to design a process for the conversion of corn stover waste into butanol. Moreover, I will apply the Science, Technology, and Society (STS) concept of Technological Momentum (Hughes, 2009) to examine the social implications of ethanol fuel in the United States. The goal of this analysis will be to derive an understanding of how the consumption of ethanol in gasoline has shifted over time and how subsequent regulation, change in infrastructure, and economic factors resulted in the expansive influence that ethanol biofuel has on society today. I will also account for the resistance to change in ethanol fuel despite the growing rationale to do so and the

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presence of alternative biofuels. By studying these factors, I will be able to leverage my findings in the technical portion of this project to ensure that sustainable butanol implementation is successful.

### **Technical Proposal**

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, J., & Helliwell, R, 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). One impediment of this material is the

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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 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 Proposal

Ethanol produced from corn was initially used as a fuel source on a small scale, typically in household or experimental technology, but it was not until the 1970s that the widespread use of ethanol in automotive gasoline began (EIA, 2008). A combination of increasing petroleum prices and concerns regarding leaded gasoline generated the need for an alternative, octane-boosting fuel source (Gustafson, 2008). Capitalizing on the abundance of corn in the United States, corn-derived ethanol was touted as a solution to these problems. Today, ethanol can be found in almost all commercial automotive gasoline. Because of how pervasive ethanol as a fuel additive is in American society, it is easy to believe that ethanol has always existed in its current form. In actuality, ethanol fuel consumption in the U.S. has progressed over time due to social influences and has grown to a position of influence in society itself. For example, governmental efforts to reduce fossil fuel dependence pushed for biofuel initiatives. Changes in ethanol pricing and demand led to the creation of agricultural subsidies while gasoline additive mandates set minimum requirements for ethanol in gasoline, starting with the Renewable Fuel Standards of 2005 (EIA, 2008). Within just a few decades, ethanol usage as a fuel additive drastically increased and remains prevalent in American society. In 2021 alone, over 13.9 billion gallons of ethanol were consumed in biofuel applications (EIA, 2022).

The widespread use of corn derived ethanol in the United States today appears to suggest that this technical concept has been a success. In actuality, there are many pitfalls to this alternative fuel. One prominent downside to ethanol usage is the usage of farmland for fuel rather than food, which has resulted in increased food prices (Tenenbaum, 2008) - a burden that has fallen onto consumers. Additionally, fuel-grade ethanol has been found to reduce fuel mileage of ICEs while having less energy density than standard gasoline (Trindade & Santos, 2017). Moreover, ethanol production as it currently exists could be exacerbating greenhouse gas emissions, potentially even more so than gasoline alone (Douglas, 2022) due to current corn growing practices. Yet despite these pitfalls, there has been a strong resistance to change in the way that ethanol is being produced and used. Other alternative biofuels, such as butanol, have more desirable qualities than ethanol (Trindade & Santos, 2017) and more sustainable feedstocks than corn are available. However, ethanol still remains a primary biofuel and continues to shape many facets of our society, including but not limited to agriculture and government resource allocation. If we do not reassess the role of ethanol in society and how it has gained momentum over time, not only will we not be able to address the current shortcomings, but we also fail to understand how technology evolves from a state of being heavily influenced by society to a position of substantial, often disproportionate, influence over society.

In the STS portion of this project, I argue that there has been an overall shift in the interaction between society and ethanol biofuel from its initial implementation to its current usage today. Prior to its widespread use, ethanol production was heavily influenced by different societal factors and stakeholders; over time this fuel source has become more established, resulting in ethanol production and use having large scale impacts on society, including the current resistance to change over to new, more promising alternatives. As such, I will utilize the STS concept of Technological Momentum (Hughes, 2009) to analyze this shift in influence while thoroughly examining the many factors that have helped influence or have been influenced by ethanol biofuel production and consumption. Technological Momentum, put forth by Thomas Hughes, is an STS framework that seeks to analyze the progression of a technology over time in the context of two-way influence between society and the technology itself. Specifically, he argues that in the beginning a technology is influenced by society, but as technology gains momentum it also gains influence over society (Hughes, 2009). In order to effectively carry out my analysis, I will rely on research into government ethanol policy, stakeholders involved in ethanol production, and contemporary reporting on the issue.

### Conclusion

The deliverable for the technical problem discussed will be a chemical process for converting corn stover waste into fuel-grade biobutanol using chemical engineering modeling

and simulation. The STS research paper will assess how ethanol biofuel evolved from a new fuel additive designed by society to an established technology that now shapes and influences social factors. The STS lens of Technological Momentum (Hughes, 2009) will be applied in this analysis in order to understand the complex nature of ethanol biofuel's social progression over time. In turn, the findings of this research will inform the implementation of the alternative biofuel butanol produced in the technical project proposed. By understanding the complex social factors that have affected and are currently affected by ethanol biofuel, lessons learned can ensure that butanol in this application is successful. Via a thorough understanding of both the technical and STS factors associated with the biofuel production, the challenges faced in how biofuels meet energy needs in the United States can begin to be addressed.

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