ETHANOL BIOFUEL IN THE CONTEXT OF TECHNOLOGICAL MOMENTUM

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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

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). 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 other alcohols 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). There are also indications that other forms of energy production are far superior, including photovoltaics (Gutierrez).

There are many societal factors involved in the production and implementation of biofuels. 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. Technological momentum is an STS framework that is used to analyze the interplay between society and technology while factoring in how that relationship changes over time (Hughes). 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, to fully address the shortcomings of current alcohol-based biofuels, social factors must be accounted for. 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 regulation, 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 presence of alternative energy forms. 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.

This analysis will be done using primary sources related to ethanol production in the United States. Specifically, I will use sources such as the Renewable Fuel Standards, Department of Energy ethanol production data, and contemporary ethanol lobbying material to show the progression of ethanol technology over time.

Literature Review

Research currently exists that examines ethanol usage in biofuels. Particular attention has been paid to the government incentives and policies that have allowed ethanol to rise in prevalence in gasoline production. There is also a plethora of research demonstrating the failures of ethanol as it currently exists as a biofuel for internal combustion engines. The published works on these topics do not provide an analysis of why more technically superior biofuels are less commercially available, nor do they provide an in-depth analysis of how ethanol's rise to societal prominence has resulted in its biofuel market dominance despite the availability of better-performing alternatives.

In the paper *Ethanol production in the United States: The roles of policy, price, and demand* (Newes et al.) the authors took into account market dynamics, government incentives, and additional factors that led to the substantial growth in the production of ethanol as a biofuel. The paper concluded that economic conditions at the time provided competitive pricing, which was one of the largest factors contributing to growth, while government standards and subsidies provided additional substantial incentives for the growth of ethanol production in the United States during the 2000s. This study notably acknowledged that earlier years of ethanol production in the 2000s were heavily influenced by the availability of infrastructure to support production. This analysis did not factor into account how this rapid growth of ethanol as a gasoline additive is now preventing better gasoline alternatives from being adopted by the petrochemical industry.

In the journal article *Review on the characteristics of butanol, its production, and use as fuel in internal combustion engines* (da Silva & dos Santos), the authors researched the performance of ethanol and butanol in internal combustion engines, providing a comparison of the two as gasoline additives. They determined that butanol performed better than ethanol, yielding results more similar to gasoline in energy output while having potentially lower production of greenhouse gasses (da Silva & dos Santos). The research team determined that butanol is a promising alternative to ethanol. They also acknowledged the barriers to butanol production currently in place, such as the lack of economic feasibility based on current fuel additive conditions (da Silva & dos Santos). This paper focused more heavily on the technical failings of ethanol and the benefits of butanol, while a more thorough analysis of social factors as play was lacking.

Both pieces of literature examined here provided unique views on some of the technical and social aspects of the production of gasoline fuel additives, both were missing analysis of how the rapid and substantial growth of ethanol production has resulted in its influence on society. The goal of this paper is to analyze the rise of ethanol from a technology influenced by society to a position where its current usage is influencing society and preventing the adoption of better alternatives, such as butanol or photovoltaics. By doing this, I will be building upon the currently existing scholarship to provide a better understanding of the broad social implications attached to gasoline additives as they exist in society today.

Conceptual Framework

The sociotechnical framework of Technological Momentum was proposed by Thomas Hughes in response to the previously proposed ideas of Technological Determinism and Social Constructionism. Technological determinists believe that technology, in essence, determines the developmental direction that both future technology and society as a whole will take (Hughes). Social constructionism argues that technology does not develop in a vacuum and instead social and cultural elements decide technological change (Hughes). These frameworks fail to take into account how technological influence might change over time. Technological momentum, proposed by Thomas Hughes, combines elements of both of these frameworks and argues that at a technology's inception, society holds a position of heavy influence over said technology, but as a technology gains momentum it begins to influence social practices and power dynamics. Technological Momentum takes into account the evolving relationship between a technology and society over time.

Technological Momentum defines momentum as the increase in social integration and complexity of a technology (Hughes). As a technical innovation gains momentum it will be gaining scale and infrastructure, while people become more invested and reliant on the technology (Hughes). Hughes identifies gaining momentum as when a system develops some or all of the following: scale and complexity, acquired skill and knowledge, special-purpose machines and processes, enormous physical structures, and organizational bureaucracy (Hughes). When significant momentum is built, the system will have significant stability and influence, which comes with a strong resistance to change (Hughes). As such, it is much easier for the designers of technical systems to shape technology in its early stages before significant momentum has been gained (Hughes). This framework is particularly relevant to ethanol as a biofuel, which at its inception was deeply affected by large-scale societal values and decisions, but has now grown to become a macroscale industry that currently affects the biofuel field as a whole, the automotive industry, and many other areas of modern society.

In this paper, ethanol as a biofuel will be the innovation whose significant increase in momentum will be examined. I argue that ethanol biofuel has grown in momentum and is now in a position of considerable influence while being resistant to change despite shortcomings. The following section of this paper analyzes this rise in prominence and influence of ethanol biofuel using Technological Momentum in three distinct sections: (1) ethanol biofuel in its infancy when societal values and beliefs held weight in its application (2) how ethanol biofuel built momentum, and (3) ethanol's current influence over American society and resistance to change.

Analysis

Ethanol in its infancy

In its infancy, ethanol biofuel was used in response to the needs and demands of society. Although designed to be run with gasoline, the Model T could be fueled with ethanol if it was available. When gasoline engines needed an octane booster in the 1920s, ethanol was blended with gasoline (Gustafson). As such, it can be seen in these applications that during the early years of ethanol biofuel, it was applied as the creators of these technologies saw fit. Ethanol was chosen because it was readily available and corn as a feedstock was abundant in the United States (Gustafson). The conditions in society at the time determined how and why ethanol was called up to fill a role in the energy field. The builders of a society, in this case the engineers, thus had considerable influence over the technology. This influence that society had on ethanol in its first gasoline applications is in line with the social influence expected for an early stage technology under the framework of Technological Momentum (Hughes).

Ethanol's role in more modern biofuel applications began in the 1970s when leaded gasoline was phased out of use and foreign oil embargoes were put in place, thus petroleum prices rose significantly (Gustafson) with shortages occurring regularly. This energy crisis affected everyday consumers given that gas stations were frequently closed, as evidenced by Figure 1, and people were left wondering how they would fuel their cars (Thebalt).

Figure 1. Gas station closure during the 1973 energy crisis (Thebalt)

These impacts felt by everyday consumers spurred those in charge to act (Thebalt). An alternative fuel was needed, and much like in the early years previously discussed, ethanol was called up by engineers, policymakers, and the petrochemical industry to fill this role (Gustfson). This reintroduction of ethanol into automotive fuel was directed by these key social players who determined its role and how it would fit into the lives of American consumers. It can thus be seen that in these early stages it was very much that society had much more influence over ethanol than ethanol had over it, just as Hughes theorizes (Hughes). It was from this original intended purpose that the technology began to be ingrained in society and build momentum.

<u>Building Momentum</u>

After its reintroduction into gasoline, ethanol as a technology gained momentum in the 1970s. There are three key signs of momentum building put forth by Hughes that are particularly relevant for this technology: (1) organizational bureaucracy, (2) special-purpose processes and machines, and (3) enormous physical structures.

To mitigate national energy concerns as well as environmental concerns related to greenhouse gas emissions, the United States government had a vested interest in encouraging the use of ethanol as a gasoline additive (Gustafson). As such, state and federal programs incentivized its use. One of the most noteworthy of these programs was the Renewable Fuels Standard Program, first established in 2005, and the subsequent program iterations (Gustafson). This standard is in essence a federal requirement that transportation fuel in the United States contain a certain percentage of renewable (U.S. Department of Energy, 2024), predominantly ethanol, biofuel. The fuel percentage goals for this biofuel standard can be seen in Figure 1 (EPA).

Year	Cellulosic biofuel standard (%)	Biomass-based diesel standard (%)	Advanced biofuel standard (%)	Renewable fuel standard (%)	Supplemental total renewable fuel standard (%)
2010	0.004	1.10	0.61	8.25	n/a
2011	n/a	0.69	0.78	8.01	n/a
2012	n/a	0.91	1.21	9.23	n/a
2013	0.0005	1.13	1.62	9.74	n/a
2014	0.019	1.41	1.51	9.19	n/a
2015	0.069	1.49	1.62	9.52	n/a
2016	0.128	1.59	2.01	10.10	n/a
2017	0.173	1.67	2.38	10.70	n/a
2018	0.159	1.74	2.37	10.67	n/a
2019	0.230	1.73	2.71	10.97	n/a
2020	0.32	2.30	2.93	10.82	n/a
2021	0.33	2.16	3.00	11.19	n/a
2022	0.35	2.33	3.16	11.59	0.14
2023	0.48	2.58	3.39	11.96	0.14

Figure 1. Biofuel standards put forth by the Renewable Fuel Standard (EPA)

The gradual increase in required biofuel percentage in Figure 1 (EPA) indicates that the government standards actively ramped up production and incentivized the production of biofuel for transportation (EPA). This national push for increases in biofuel composition in gasoline meant the government was now standardizing biofuels, making rules and regulations for production and use on a national scale. The Renewable Fuel Standards thus ensured that ethanol biofuel was legally ingrained in the production and consumption of gasoline (EPA). This added layer of bureaucratic complexity of ethanol biofuel helped bring ethanol out of its initial technical application as an alternative to fossil fuels into a new phase where its influence on society was building. This increase in organizational bureaucracy and complexity is in line with Hughes' notion of what a technology gaining momentum would look like.

In addition to the increase in organizational bureaucracy, ethanol biofuel has also gained momentum through the design and implementation of special-purpose processes and machines. Ethanol produced as a gasoline additive is derived from a fermentation process that requires a sugar-rich feedstock (EIA). Given the abundance of corn in the United States, it was naturally selected as the primary feedstock (EIA). To meet the growing demand for ethanol, instead of a portion of existing corn production being redirected to this application, the scale of ethanol usage grew to a point where corn was grown specifically for this purpose. Farmers began to structure their harvests and financial bottom line around corn for the ethanol industry resulting in a specific economic process called the "Minnesota Model" (Bevill). The development of this special technique specific to ethanol biofuel production shows that ethanol was building technological momentum by Hughes' standards. Farmers were now becoming dependent on ethanol (Bevill), making it integral to American agriculture and increasing its permanence and stability in society. Another example is the design of cars capable of using high concentrations of ethanol, so-called “E85” vehicles (U.S Department of Energy). The incorporation of ethanol into a special-purpose machine application is once again a sign that ethanol is gaining momentum in society. Without ethanol biofuel, E85 vehicles become obsolete.

Technological momentum has also been built through the development of enormous physical structures. To meet the rising demand for ethanol biofuel brought on by environmental factors, the petrochemical industry began to construct large scale, fermentation based ethanol production facilities. The number of ethanol production facilities in the United States rose significantly over the years, especially after the implementation of the 2005 Renewable Fuel Standard (U.S. Department of Energy, 2022). In fact, between 2005 and 2021, the number of American ethanol plants more than doubled (U.S. Department of Energy, 2022). This rapid increase over time can be seen in Figure 2. Blue bars represent the number of ethanol plants in the United States each year. The red line tracks the combined capacity of these plants while the green line shows the combined production, both in billions of gallons per year.

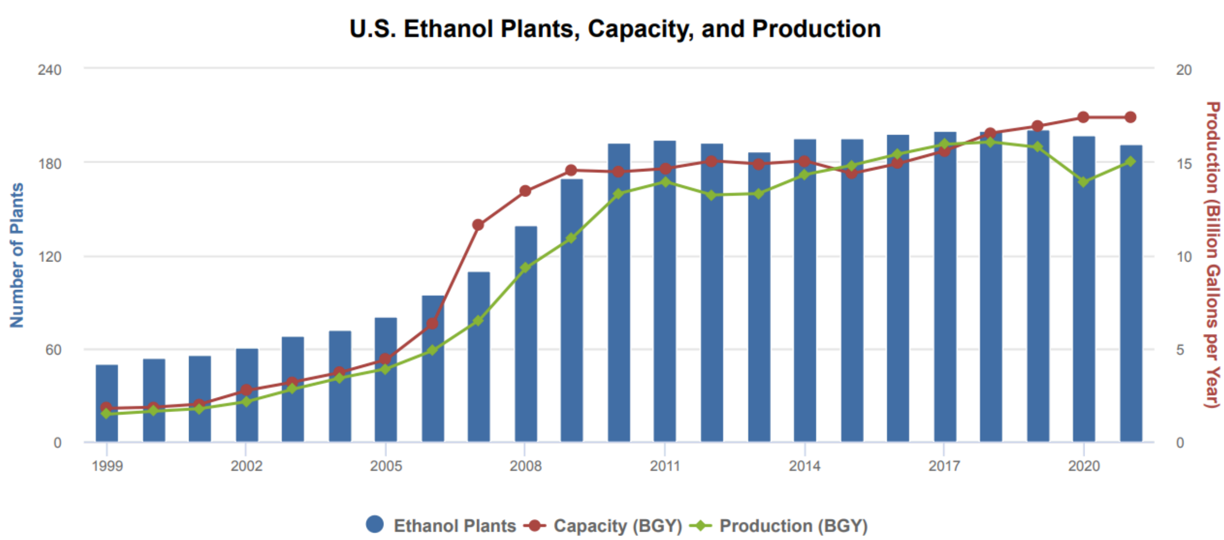

Figure 2. Ethanol plants, capacity, and production from 1999 to 2022

(U.S. Department of Energy, 2022)

This rapid increase in infrastructure is in line with Hughes' concept of building technological momentum via physical structures. These plants, which in combination have a total capacity of 17.38 billion gallons of ethanol per year (U.S. Department of Energy, 2022), represent enormous physical structures that did not exist on such a large scale at the inception of ethanol as a fuel additive. Ethanol grew in prominence such that these plants now have significant output while representing viable economic endeavors that affect stakeholders from the companies that own them all the way to employees in plant communities. These enormous physical structures show the growth in permanence of the production of ethanol biofuel in society, and, as will be discussed in the next section, the increase in societal influence that ethanol has over the biofuel landscape.

Ethanol as it Exists Today: Influence and Resistance to Change

Ethanol biofuel has become ingrained in federal and state law, helps determine corn production and vehicle design in the United States, and has led to the construction of facilities on an enormous scale. As things currently stand, over 98% of all fuel in the United States contains ethanol (U.S. Department of Energy, 2024), meaning that ethanol biofuel touches the life of practically every American. After building considerable momentum through the previously described methods, ethanol has reached a point of significant social influence, just as the framework of Technological Momentum has described. The social impact that ethanol has is evident in the resistance to change despite its applied and technical inadequacies.

The incorporation of ethanol into federal law through the Renewable Fuel Standards cemented ethanol biofuel into federal law, but According to David DeGennaro at the National Wildlife Federation, “while originally well-intentioned, the Renewable Fuel Standard… has failed to live up to its promise of greenhouse gas emissions reductions while destroying important wildlife habitat in the process" (Gutierrez). When a technology is failing to meet its intended purpose while actively causing harm, it is only logical that immediate change should be made. In fact, however, there is active resistance to changing these laws to allow for newer forms of energy, such as photovoltaics, to be supported by federal programs instead of ethanol (Gutierrez). Just as Hughes predicted, this technology, after having gone through a process of building momentum, is now strongly resistant to change and has reached stability in society.

The corn growth in the United States that is dedicated to the production of ethanol is another example of just how much influence ethanol has on American society. The special process, the "Minnesota Model," has given farmers incentives to remain invested in the production of ethanol biofuel. Having benefited economically from this industry, farmers are hesitant to give up their economic interests in ethanol, especially given that the ethanol industry represents the second largest corn customer in the United States (NCGA). Figure 3, a screenshot from the National Corn Growers Association website, shows how much pressure there is to maintain the current corn production for ethanol (NCGA). The headline and text urges average Americans to support ethanol and push for its use by reaching out to Congress and other policymakers.

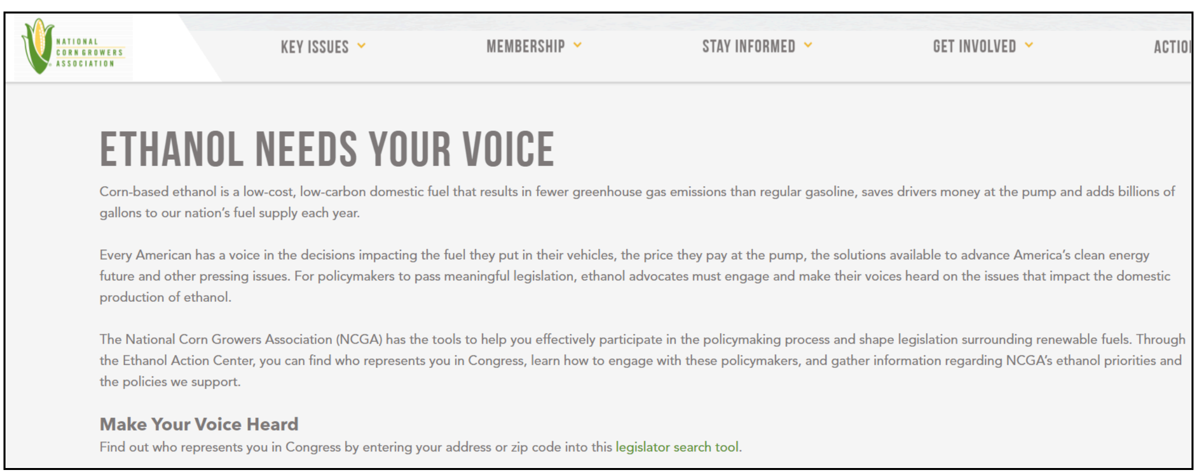

Figure 3. National Corn Growers Association Website Screenshot (NCGA)

Despite the known issues with ethanol as a biofuel, the National Corn Growers Association is still pushing for the use of ethanol (NCGA) while also urging Americans to do the same. This speaks to the idea that any change in the ethanol industry would significantly affect key players in American agriculture, thus it is imperative for American corn growers that the status quo biofuel, ethanol, remain as it is. Ethanol has thus built enough momentum and become so ingrained in society that it is exerting substantial influence over the decisions being made around biofuels and society as a whole. Ethanol has thus reached a position of stability and influence over society, just as Hughes predicts for a mature technology. The same goes for the automotive industry. The incorporation of ethanol into the designs of their vehicles means that changes in ethanol usage affect car designs and in turn all of the stakeholders involved there.

These two examples show that in building momentum, ethanol became intertwined with the agriculture and automotive industries; ethanol now has the power to shape and change large sectors of American society. The far reaching effects of ethanol show the substantial influence that this technology has acquired, which is again in line with Hughes understanding of how a technology has considerable influence after reaching stability through momentum. The resistance to change that comes with this influence is felt in both of these industries.

The enormous physical structures constructed, i.e. the numerous ethanol production facilities, are now presenting strong resistance to change. Butanol, as previously mentioned, is a higher performing alternative to ethanol that some see as a potential replacement to ethanol (Fountain). Despite this superiority, the widespread adoption of butanol is being prevented by the difficulty associated with converting ethanol production facilities into butanol facilities. These conversions are expensive and the butanol yield is lower than that of ethanol (Fountain) making it difficult to readily change to butanol. These physical and financial limitations on the production of a better alternative are due to the momentum that ethanol built. Here, ethanol is once again proven to have reached a state of social influence and stability while being highly resistant to what some might argue is a necessary changeover to better alternative transportation energy sources.

With that being said, it is important to recognize that there might be other factors besides ethanol affecting the transition to greener forms of energy. Like ethanol at its inception, electric vehicles are currently one potential solution to greenhouse gas emissions, but they have failed to catch on at a large scale like ethanol did. This, according to Iowa State, could be due to the lack of infrastructure for electric vehicles in the United States (Crespi et al.). I argue here that had ethanol not already been such a socially integrated and prevalent form of transportation fuel, electric vehicles would not be facing as much resistance in their rise to widespread adoption. Ethanol being the dominant “green” fuel source at present has resulted in electric vehicles receiving fewer government subsidies and more competition for legislative support (The Editorial Board). Thus once again it can be seen that ethanol’s influence in society after building momentum is preventing necessary change to alternative forms of transportation energy.

Conclusion

Ethanol was initially applied as a gasoline additive to address issues related to fuel, but over time ethanol grew in prevalence to a billion dollar industry (USDA, 2023). This rise of ethanol biofuel can be viewed through the lens of Technological Momentum. Ethanol was initially heavily influenced by key social players: engineers and government officials chose ethanol based on its ability to fill a role. Over time ethanol began to build Hughe’s concept of “momentum” through the creation of (1) organizational bureaucracy, (2) special-purpose processes and machines, and (3) enormous physical structures. After this rise in momentum, ethanol is today situated in a position of vast social influence and is currency preventing the transition away from ethanol to better alternative forms of transportation energy.

The application of Technological Momentum to this specific case is particularly important given that it provides a new, previously unexplored perspective on the challenges that may be faced by alternative energies, such as butanol biofuel, given the influence of the ethanol industry. The analysis here can inform the designers of alternative energy while providing a better understanding of the factors influenced by ethanol, especially if ethanol is to one day be replaced.

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