An Analysis of United States Ethanol Production & Policy

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Michael Sirot

Spring 2021

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

Advisor

S. Travis Elliot, Department of Engineering and Society

Introduction

The purpose of this paper is to determine why cellulosic ethanol, a highly sustainable source of fuel, is not widely used in the United States over other competing methods and what factors could influence change in its use in the future. Sustainability and renewable energy sources are especially pertinent right now as concerns about carbon emissions and global warming have been increasing with the continuous rise of greenhouse gas emissions. Ethanol production is a major industry in the United States, producing more than 14 billion gallons every year since 2011, and has significant contributions to environmental concerns due to the current methods used to produce it (Renewable Fuels Organization, 2012). The most prevalent method, crop fermentation, has a large impact on the grain supply and requires a large amount of land from agriculture, which raise concerns about its sustainability (Heimlich, Houghton, Dong, Elobeid, Fabiosa, Hayes, & Yu, 2008). However, a new method of ethanol production could alleviate these concerns by using plant-based materials containing cellulose to produce ethanol through sugar fermentation. Despite the promise of the technology, it is not widely used in the ethanol industry currently. To attempt to understand this, I will first explore the economics of cellulosic ethanol as compared to other ethanol production methods, to determine if its use is primarily restricted by investment and operating costs. Then, I would research the current United States policies surrounding ethanol production including regulations and subsidies, particularly those related to emissions and feedstock use. The goal would be to determine what values or policies are currently making corn-based production succeed more than cellulose based production and what policies or values in the USA are inhibiting cellulose-based ethanol production, to allow for future changes to encourage its use in the renewable energy sector.

Background

Ethanol is a substance that is widely used as fuel by blending it with other hydrocarbons and combusted to power engines. There are multiple commonly-used methods for producing ethanol including steam formation from ethene, crop fermentation, and biomass fermentation. Cellulosic Ethanol is produced through the last method, biomass fermentation, where plant cells - specifically, cellulose residing in the rigid cell wall of plant cells - is broken down into sugars and fermented into ethanol using bacteria. This method is the least commonly used for large-scale production despite being the most sustainable method of production. The most significant advantages to using cellulose as a feedstock for ethanol production are reduced carbon emissions compared to steam formation, sustainability when compared to steam formation, ability for feedstock diversity and recycling, as well as reduced land use and feedstock cost when compared to both steam formation and crop fermentation (Hill, Tilman, Polasky, & Hawthorne, 2008). Cellulosic Ethanol is also superior as it reduces the amount of crops that are taken out of the food supply and agriculture industry.

The current ethanol production industry is entirely focused on plants which use either corn or sorghum as the primary feedstock, with monthly averages of 400,000,000 bushels of corn and 10,000,000 bushels used for ethanol production respectively (Renewable Fuels Association, 2021). In comparing this to cellulosic ethanol production, corn-based ethanol accounts to about 10.5 billion gallons, while cellulosic ethanol only represents about 250 million gallons as of 2020 (Osborne, 2007).

STS Framework & Methodology

I will primarily be using the Social Construction of Technology (SCOT) for my analysis. This framework states that the success of a technology is determined by the social contexts and principles that are highly valued in the society implementing it ("Social Construction of Technology", 2020). The key concepts in this ideology are interpretative flexibility and design flexibility, and how the relevant social groups interact with these. Interpretative flexibility entails that a technology can be interpreted in different ways by different stakeholders. The common example given by Bijker and Pinch is that of air tires in bicycles, where some found them advantageous as they allowed for greater speed, but others found them worse due to issues with traction or aesthetics (Bijker, Hughes, Pinch, 1987). From the perspective of this paper, this could be seen through some stakeholders viewing the advent of cellulosic ethanol production as a benefit for its positive effect on greenhouse gas emissions, while others could see it as a detriment for the increased cost for transitioning fuel sources. Design flexibility stems from this as it is the idea that a technology always has multiple ways of being constructed. In the case of ethanol production, there is a lot of design flexibility through the different methods for actually converting the cellulose feed stocks into biofuels, such as the method described in the technical project that incorporates different methods to transform wasted paper into fuel.

For this discussion, the technology would be the specific production method of ethanol where cellulose is used as a feedstock, and the society that is determining its success is the social groups in the United States. The most prominent social groups for this analysis would be the industrial companies that produce ethanol, the U.S. government, and ethanol consumers. Therefore, I plan to analyze the social values and policies in the USA with respect to ethanol production, specifically focusing on beliefs about fuel cost, carbon emissions and global warming, recycling and sustainability, and agriculture to figure out what aspects of current US society lead these social groups to favor corn-based ethanol production over cellulose based methods. The most important aspects will most likely be those that directly impact the financial viability of these methods, such as government subsidies, fuel composition and environmental emissions regulations, and the relative cost & availability of corn when compared to all cellulosic materials. Another important aspect that will be considered is the public opinion of ethanol consumers on how much the method of producing ethanol matters to consumers when compared to an increase in cost.

United States Policy

The best place to begin investigating this technology is the U.S. policies surrounding fuel production. The majority of these policies are regulations for environmental impact, but many are also for industry standards and other values. The Clean Air Act, as of 1992, required that all fuels have added oxygenates to lower tailpipe emissions, which was primarily done using Methyl tertiary-butyl ether (MTBE) (Osborne, 2007). However, as MTBE was banned in many state due to being a contaminate, ethanol began being used widely as an oxygenate, increasing the demand significantly. The 2005 Energy Policy Act (EPACT) has since eliminated the oxygenate requirement for reformulated gasoline, but replaced it with the Renewable Fuels Standard (RFS).

The RFS is a "federal program that requires all transportation fuel sold in the United States to contain a minimum volume of renewable fuels" (Alternative Fuels Data Center). This program started in 2005 and was expanded by the Energy Independence and Security Act of 2007 (EISA). Because of this, the demand for renewable fuels is increasing every year as the RFS regulations are increased yearly up to 36 billion gallons of renewable fuel blending by 2022. In addition, the RFS has specific requirements for the volume of different categories of renewable fuels that are sold, one of which is cellulosic biofuel, with the categorical requirement of a life cycle greenhouse gas (GHG) emissions reduction of at least 60%.

Ethanol-Gasoline blends are also regulated into three categories for sale: E10, E15, and E85, named for the percentage of the blend that is composed of ethanol. E10 makes up the large majority of gasoline sold in the U.S., as all gasoline engines can use E10, but only specialized engines can use E15 or E85, with the largest difference being the energy content of ethanol being lower than gasoline (U.S. Energy Information Administration, 2020). As discussed in the paper by Osborne, ethanol demand depends largely on "whether ethanol is being used as an additive to gasoline or as a replacement for gasoline". Because additive ethanol can only be used widely up to 10%, there is a limit to how much production can be increased before the rest of the ethanol is not used from a lack of demand that is estimated to be around 14 billion gallons. Cellulosic ethanol as a replacement for gasoline in transportation fuels is currently not feasible due to the massive scale; biofuels together currently only account for 7.1% of the total fuel consumption for transportation in the U.S., and increasing this to match the full fuel needs would take further expansion and developments not currently in place (U.S. Department of Agriculture, 2021).

A major development that has happened recently is the Next Generation Fuels Act of 2020. This bill, which has not yet been passed, was intended to "promote low-carbon, high-octane fuels, to protect public health, and to improve vehicle efficiency and performance, and for other purposes." (U.S. Congress, 2020). Key components of this legislation include a new Research Octane Number (RON) which would allow transportation vehicles to be developed for higher emissions standards and fuel efficiencies, supporting higher percentage ethanol blends such as E25 and E30, as well as removing "regulatory barriers preventing mid-level ethanol blends from entering the marketplace" (Minnesota Corn Growers Association, 2020). The Renewable Fuels Association claims that if this bill is passed, it would work to restructure "existing fuel regulations [that] have insulated petroleum fuels from competition and protected the oil industry's market share", as currently, the regulations in place by the RFS are not strict enough to discourage the continued dominant production of oil-based transportation fuels.

As a result of these mandated federal policies, cellulosic ethanol production has increased steadily over time, but has not overgrown any of the other prominent technologies for renewable fuels or transportation fuels as a whole. The general trend of U.S. policies has been to support the development of these renewable energy sources without impacting its competitors drastically through forced transitions, such as oil and gasoline companies. These gradual regulation changes are likely a key contribution to the slow adoption of cellulosic ethanol, as the large companies that would adopt the technology are not greatly pressured to do so as long as they can meet the current regulations without fully swapping over from the existing infrastructure for transportation fuels.

Economics & Technological Limitations

The next important aspect to consider preventing the adoption of cellulosic ethanol is the economical limitations due to the different technology used. Corn and other sugar based production methods extract sugars and starches from the food feedstock and use fermentation to turn that into ethanol. However, in order to do this with cellulose based feedstock, the cellulose must first be broken down into the basic sugars in very costly processes that are not necessary for corn. Currently, cellulosic ethanol costs about $2.65 per gallon to produce, while corn-based ethanol costs between $0.90 to $1.65 per gallon to produce, depending on the price of corn (Osborne, 2007). Fuel ethanol costs about $2.42 per gallon in the U.S., which indicates that it is currently not economically profitable to produce cellulosic ethanol but it is for corn ethanol.

Another large economic factor in the process of producing cellulosic ethanol is the extra investment that must be made for the pretreatment equipment to break down cellulose. According to the study done by Osborne, this could add as much as $106 million dollars to the cost of the ethanol plant, more than tripling the cost for a plant at the scale of 25 million gallons per year. However, these estimates are only for one technology, which uses enzymes to catalyze the reaction to break down cellulose. These values could greatly change in the future as further developments in the technology are made; for example, using the method that replaces enzymes with higher temperature or pressure may reduce overall cost. Osborne listed three possibilities that he saw for reaching a target of $1.07 per gallon to produce cellulosic ethanol, including reducing the cost of enzymes, reducing the cost of cellulosic feedstock, and increasing ethanol yield from cellulosic feedstock. All of these developments are quite feasible in the near future, which give hope for further development in this industry, such as the incorporation of recycled cellulosic feedstock, eliminating the feedstock cost.

Another aspect that has not been considered is the possibility of retrofitting current corn-based production plants with pretreatment equipment to allow for the use of cellulosic feed stocks (ETIP Bioenergy, 2021). This would significantly reduce the investment cost of cellulosic ethanol, as it would allow for the main parts of the process to be recycled from previous plants. However, the downside of this process would be the loss of the corn-based ethanol plant and the additional loss in profits from the downtime associated with retrofitting.

Overall, there is a clear economic pressure driving against the adoption of cellulosic ethanol due to the high price of production with current technology when compared to transportation fuels and corn-based ethanol. While future technological developments have a lot of potential to decrease the economic burden of adopting this technology, the largest aspect that can drive this pressure away from being a deciding factor in the adoption of cellulosic ethanol is government policies, specifically subsidies and tax credits. These policies are the government's attempts to decrease the economic strain of producing these renewable fuels where the government decreases taxes or pays out money to the companies. These make a huge difference in the economic analysis of these fuels, with credits as much as $1.01 per gallon at the federal level, with additional subsidies at around $0.65 per gallon in some states. These bring the cost of cellulosic ethanol per gallon below that of corn-based methods, but does not completely offset the extra cost of investment and pretreatment as previously discussed. Another widely debated issue with these programs is the classification of cellulosic ethanol; some believe that loopholes and poor classification allows these benefits to be used by production plants that use technology that only partially uses cellulosic feed stocks, such as corn kernel ethanol which gets further yield out of standard corn-based ethanol production by turning the cellulose in corn into ethanol in addition. Because of this, it is hard to determine how effective these subsidies actually work at incentivizing cellulosic ethanol production, and without them, it is not feasible for production to increase drastically until technology improves to lower the economic burden.

Public Opinion

The other largest factor affecting the adoption of cellulosic ethanol is the public opinion of the common stakeholders in the U.S.. The most important stakeholders would be the producers and consumers, as well as competitors. Producers in this case would be the large scale ethanol producing companies, while consumers would entail all people in the U.S. who purchase transportation fuel. The most important factor to most consumers in determining what fuel to buy is the price; for most Americans, the implicit factors of sustainability, production method, and more are only an afterthought that comes up in debates (Ansolabehere, Konisky, 2012). In fact, the U.S. is so focused on the price of transportation fuel that the consumer-sentiment index, indicating how satisfied consumers are with the current market has a strong cause-and-effect relationship with the price of gasoline, where “consumer sentiment rose as pump prices fell”

(Desilver, 2014). Competitors with the renewable fuels market includes large oil and gas companies, as well as transportation vehicle companies that make vehicles unequipped to incorporate higher regulation fuels. To these companies, stricter emissions regulations and stronger requirements on ethanol blending would hurt their performance, making them not support the adoption of more cellulosic ethanol production; this is believed to be the cause of many of the strict limitations on renewable fuels in some regulations, as the government appealed to the large domestic oil and gas industry by not rapidly forcing expensive changes to more renewable fuel sources (Renewable Fuels Association, 2020). The producers of the technology logically would want the technology to succeed and be adopted further into society, but these renewable fuel companies are not expanding any faster than they currently are due to the current limitations of the technology; there are only about 30-40 cellulosic ethanol plants in operation or in production, and it is difficult to invest in the technology due to the aforementioned issues with the large economic pitfalls (Gardner, 2009). In fact, one of the largest of the cellulosic ethanol plants in the U.S., operated by Abengoa Bioenergy with a production capacity of 30 million gallons per year, was in operation from 2013 until 2016, when the company went bankrupt and closed the plant as a failure (Fitzgerald, 2016). These issues have led to many major companies that would potentially adopt the technology to wait until further developments are achieved with small scale projects that would lower the economical hurdle.

Conclusion

Combining the perspective of the regulatory landscape in the U.S., the economic and technical limitations of cellulosic ethanol, and the public opinion of the relevant stakeholders, it is clear to see why cellulosic ethanol is unable to be incorporated as a forefront method for fuel production. Using the tenets of SCOT, the technology fails to satisfy the most valued aspects for the stakeholders in the United States, as it fails to be economically profitable for producers and does not lead to lower consumer fuel prices. Government regulations and policies such as the Renewable Fuels Standard have mandated the increase of cellulosic ethanol production, but only accounts for a miniscule amount of the industry while the less effective corn-based ethanol production method is used widely. Ultimately, the technology does not have enough in its favor despite the potential advantages over other ethanol production methods to overcome the hurdles of economic investment, low public interest, and weak government regulations. In the future, these problems could be solved by further technological developments, stricter government regulations mandating the use of second generation biofuels, and a greater public interest in renewable fuel use, in which case the technology could resurface to be widely incorporated for fuel ethanol production.

References

1. Social construction of technology. (2021, March 04). Retrieved March 12, 2021, from https://en.wikipedia.org/wiki/Social_construction_of_technology
2. Renewable Fuels Association (2021, March 10). Feedstock use and co-product output. Retrieved March 12, 2021, from https://ethanolrfa.org/statistics/feedstock-use-co-product-output/
3. Renewable Fuels Association (2021, March 10). Next Generation Fuels Act. Retrieved March 12, 2021, from https://ethanolrfa.org/wp-content/uploads/2020/11/Next-Generation-Fuels-Act.pdf
4. U.S. Department of Agriculture (2021, January 21). U.S. Bioenergy Statistics. Retrieved March 12, 2021, from https://www.ers.usda.gov/data-products/us-bioenergy-statistics/
5. Alternative Fuels Data Center (n.d.). Ethanol production and distribution. Retrieved March 13, 2021, from https://afdc.energy.gov/fuels/ethanol_production.html
6. Alternative Fuels Data Center (n.d.). Ethanol feedstocks. Retrieved March 13, 2021, from https://afdc.energy.gov/fuels/ethanol_feedstocks.html
7. Alternative Fuels Data Center (n.d.). Renewable fuel standard. Retrieved March 13, 2021, from https://afdc.energy.gov/laws/RFS
8. Oseborne, S., Office of Competition and Economic Analysis (2007, November). Energy in 2020: Assessing the Economic Effects of Commercialization of Cellulosic Ethanol. U.S. Department of Commerce. https://www.trade.gov/sites/default/files/2020-12/Energy%20in%202020_Assessing%20the%20Economic%20Effects%20of%20Commercialization%20of%20Cellulosic%20Ethanol.pdf
9. U.S. House, House - Energy and Commerce. (n.d.). Next Generation Fuels Act of 2020 (1248065353 924858200 C. Bustos, Author) [H.R. 8371 from 116th Cong., 2nd sess.].
10. Minnesota Corn Growers Association. (2020, December 01). Next generation fuels Act introduced in U.S. Congress. Retrieved March 13, 2021, from https://www.mncorn.org/2020/12/01/next-generation-fuels-act-introduced-in-u-s-congress/
11. U.S. Energy Information Administration. (2020, September 28). Frequently asked Questions (faqs) - U.S. Energy Information Administration (EIA). Retrieved March 13, 2021, from https://www.eia.gov/tools/faqs/faq.php?id=27&t=10#:~:text=Federal%20law%20requires%20that%20fuel,fuel%20ethanol%20may%20be%20higher.&text=E10%20is%20gasoline%20with%2010,up%20to%2085%25%20fuel%20ethanol
12. GlobalPetrolPrices.com. (2021, March 8). Ethanol prices around the world, 08-mar-2021. Retrieved March 13, 2021, from https://www.globalpetrolprices.com/ethanol_prices/
13. ETIP Bioenergy. (2021). Bioenergy Retrofitting. Retrieved March 13, 2021, from https://www.etipbioenergy.eu/value-chains/conversion-technologies/bioenergy-retrofitting/1st-generation-biofuels
14. Konisky, David and Stephen D. Ansolabehere. 2012. The American public's energy choice. Daedalus 141(2): 61–71.
15. https://www.pewresearch.org/fact-tank/2014/12/16/gas-prices-consumer-sentiment/
16. Gardner, Timothy (February 19, 2009). "TABLE-Open and planned US cellulosic ethanol plants". *Reuters*.
17. Fitzgerald, Patrick (29 March 2016). "Spain's Abengoa Files for Chapter 15 Bankruptcy in U.S." Archived from the original on 4 April 2016 – via www.wsj.com.
18. Renewable Fuels Organization. (2012). 2012 Ethanol Industry Outlook. https://web.archive.org/web/20120514044111/http://ethanolrfa.3cdn.net/d4ad995ffb7ae8fbfe_1vm62ypzd.pdf