Large Scale Fuel Grade Cellulosic Ethanol Production from Mixed Waste Paper

Causes and Origins of COVID-19 Vaccine Hesitancy in the United States

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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

Society is currently searching for cleaner, sustainable alternatives to fossil fuels to meet the world's energy needs. A suitable alternative is needed since fossil fuels are in limited supply and release carbon dioxide to the atmosphere, contributing to adverse climate change. Many environmentalists support the adoption of electric vehicles coupled with making the power grid sourced from renewable energy as the way to reduce use of fossil fuels. However, issues associated with charging electric vehicles and the expense of their batteries are major barriers to widespread adoption. A better solution may be the use of biofuels as a replacement to gasoline in vehicles powered by internal combustion engines. One popular biofuel candidate is ethanol.

Life cycle emissions for ethanol are lower than those of gasoline because the ethanol's carbon source comes from plants that recently obtained their carbon from the atmosphere, whereas the carbon source for gasoline is crude oil made from carbon that has been sequestered for millennia. Since the source material for ethanol-based biofuels is grown within a lifetime, it's considered a sustainable, renewable energy source, unlike fossil fuels.

Currently, corn ethanol is used extensively as a blended add-in for gasoline, allowing for more complete combustion and lower emissions. Corn ethanol is cheap and easily fermented since corn kernels contain simple, fermentable sugars. However, production of corn ethanol competes with food production, effectively raising both the price of food and the price of ethanol production. Another common solution is using inedible, cellulosic sugar sources like corn stover, though corn stover is useful as fertilizer and animal feed. Moreover, the cost of the enzymes needed to break down cellulose and the price of feedstock make cellulosic ethanol more expensive to produce than gasoline. This project is an attempt to lower the cost of ethanol

production by using a cheap and sustainable feedstock in the form of documents destroyed by government entities, businesses, and individuals.

As a general rule of thumb, ethanol fuel is not cost effective to produce if it must be transported more than 50 miles. As such, the location of the ethanol production plant determines what members of society are able to use ethanol fuel. Additionally, the feasibility of ethanol fuel production, at least using current technology, is entirely reliant on government tax credits to compete financially with fossil fuels. The political forces for and against these tax credits have major influence over the adoption of this technology. While these implications are certainly important to consider, the subject of my STS prospectus is unrelated to the technical topic assigned to me by the department of Chemical Engineering.

For my STS thesis, I will be studying the origins and causes of vaccine hesitancy in the United States as it applies to the COVID-19 vaccine. While the advent of any technology begets a wide array of reaction, including skepticism, vaccine efficacy is dependent on complete or nearly complete adoption, motivating research to determine the roots of hesitancy. While research has been conducted on vaccine hesitancy in general, this focuses almost exclusively on parental attitudes towards the vaccination of their children, as this is typically the case. However, with a novel virus such as COVID, individuals will be tasked with making this decision for themselves, and different factors will be at play.

My research will center on the organizations involved in the discovery and communication of novel vaccine technology, including medical researchers, healthcare professionals, governmental bodies, and media organizations, and the degree to which an individual's trust toward and involvement in them influences their attitudes toward vaccine technology.

Technical Topic

The goal of this project will be to design an ethanol production plant that can convert a portion of the documents that the government and businesses pay to shred into ethanol. We estimated our supply on the annual amount of paper disposed of by a single company located in California. That equates to 67 thousand tons of paper feedstock a year (SafeSHRED, 2012). Studies show that 128.3 gallons of ethanol per ton of mixed paper is an achievable yield, so the targeted output of our plant will be approximately 8.6 million gallons per year of fuel-grade ethanol (Shi, 2009). In order to estimate the amount of each material necessary for this process, previous literature was consulted and it was determined that the best glucose yield occurred using 70% weight sulfuric acid for the hydrolysis at a mass ratio of 12:1 acid to dry cellulose using figure 3 in the Appendix (Kong-Win Chang, 2018). Using another previous study, it was found that mixed paper is roughly 75% cellulose (64.1% glucan, 9.9% xylan, 2.9% lignin), giving us roughly 50 thousand tons of cellulose to break down per year (Shi, 2009). At the 12:1 ratio using 70% sulfuric acid, this equates to 603,000 tons of sulfuric acid mixed with 258,430 tons of water per year.

The mixed paper feedstock will first be turned into a slurry, which will be pretreated using sulfuric acid (H2SO4). The pretreatment process will remove impurities, such as ink, from the feed stream. Sulfuric acid is then used to break cellulose into glucose and other sugars through a hydrolysis reaction (Kong-Win Chang, 2018). After hydrolysis, the mixture is neutralized with quicklime to make a calcium sulfate precipitate (CaSO4) that is removed from the solution through use of a rotary vacuum drum filter. Another alternative that is widely used would be enzyme catalyzed hydrolysis using cellulase. Using an enzyme to split the cellulose is significantly faster, allowing a higher rate of production. However, the enzyme must be removed

from the process prior to the fermentation. Because of the ease of removing the byproducts, the acid hydrolysis method is our primary method that we will be attempting. If acid hydrolysis proves to be economically infeasible, then we will pursue an enzyme-based design.

Next, brewer's yeast is added and fermentation begins; the fermentation will take place in a series of four continuous stirred tank reactors (CSTRs) with a cell recycle loop to recoup the yeast cells. A study by Fonseca, Costa, and Cruz using this method found that a continuous fermentation process will have a conversion of nearly 90% at a feed sugar weight concentration of 23% and even greater conversion rates at lower concentrations that are expected in a paper slurry (2017).

The ethanol produced must be purified before it can be used as biofuel. This will be accomplished via distillation. Because an ethanol-water mixture forms an azeotrope, extractive distillation, similar to the design in Separation Processes (n.d.), will be necessary, so toluene will be added as a solvent for ethanol. A two-column distillation system will be used.

The first column isolates the water-ethanol azeotrope: water will come out of the bottom and the azeotrope will come out of the top (Separation Processes, n.d.). The water going out of the bottom of the first column will be removed from the process, removing unfermented sugars and other residues from the process to prevent accumulation and maintain steady state. This waste stream will need to be sent to a wastewater treatment plant at a cost. The azeotrope will then be mixed with toluene, which creates a minimum boiling ternary azeotrope, which when fed to the second distillation column (Separation Processes, n.d.). The new azeotrope is recovered out of the top of the column and can be recycled, and fuel grade ethanol is recovered as the bottoms product (Separation Processes, n.d.).

Based on research of previous processes, the recycled azeotrope must undergo a separate separation process using a decanter, allowing the toluene rich portion to be recycled into the second distillation column, while the water rich portion would be removed as waste or recycled into the feed to the first column (Separation Processes, n.d.).

Corn ethanol is currently about $1.69 per gallon (U.S. Grains Council, 2020). However, in California, Low Carbon Fuel Standards (LCFS) and Renewable Identification Number (RIN) credits drive the price of cellulosic ethanol to $4.98 per gallon. The paper feedstock will have an estimated cost of negative $50 per ton, or negative $0.40 per gallon (SafeSHRED, 2020). The cost of water needed to slurry enough mixed paper to produce a gallon of ethanol product is $0.04 (Milleman, 2020). The cost of yeast nutrient per gallon of ethanol product is estimated to be $0.40 (Calculation 1). The cost of sulfuric acid needed to break down enough cellulose to produce a gallon of ethanol product is $7.16 (Bureau of Labor Statistics, 2020). The cost of quicklime to neutralize the sulfuric acid per gallon of product is $6.58 (Apodaca, 2020). Revenue from selling the CaSO4 precipitate works out to be $0.10 per gallon of ethanol produced. The cost of treating wastewater from the first distillation column amounts to $0.04 per gallon of ethanol product (Beatty and Michell, 2017). Summing all the material costs yields a total net material cost of $13.72 per gallon.

Since these estimates result in a net loss of $8.74 per gallon (even with the tax credit), this process is most likely not economically feasible and as such we recommend that alternatives to using acid for hydrolysis be explored. As previously mentioned, the enzyme cellulase can break down cellulose into glucose, and this method should be explored. The cost of cellulase for enzyme catalyzed hydrolysis is about 10 cents per gallon, making it much cheaper than the cost of the sulfuric acid necessary for acid hydrolysis (Shi, 2009). As a result of our planning, we

conclude that sulfuric acid should not be used to break down cellulose since it is not feasible to turn a profit and compete against corn ethanol. Using cellulase in place of sulfuric acid also eliminates the need for quicklime, further reducing the cost of raw materials.

STS Prospectus

Despite nearly 200,000 total deaths from Covid-19, two-thirds of voters say they will not try to get a Covid vaccine when it first becomes available, and one-fourth of voters don't plan to receive the vaccine at all. While this statistic is troubling, it may not be surprising given the apparent growing sentiments of mistrust toward the scientific community, and those who report on the scientific community, from the American public. This sentiment is not limited to the topic of vaccinations, and it manifests in topics such as climate change denial (More U.S. citizens are skeptics of climate change than in any other western nation) and disbelief in the efficacy of mask use to prevent the spread of disease (30% of Americans "rarely" or "never" wear a mask). While scientific discovery is crucial to determine courses of action that are best in times of crisis, it is equally, and perhaps more, important to relay that information in a way that is most compelling and convincing.

While the disconnect between scientific consensus and public opinion is well documented in many areas, I believe the situation surrounding Covid is uniquely difficult to truly get a handle on. Part of what has turned public opinion against trusting scientific research is the prevalence of biased research, funded by companies with a stake in the outcome. For decades research funded by the tobacco industry claimed cigarettes had no adverse health effects, and likewise oil companies published researching denying climate science for years. For these (and most) issues, there are clear and obvious groups that benefit from misleading research, but it is unclear who would benefit from perpetuating doubt in vaccines. Additionally, aspects of

American culture, including general skepticism and mistrust of 'big government', make communication of scientific information more difficult than in other nations.

In order to identify potential strategies to convince the American public that the Covid vaccine is beneficial, I believe it is important to determine the unique cultural objections to "consensus" science in the United States, the social groups that are most inclined toward these beliefs, and the political forces that are at play, or even the political forces that are *perceived* to be at play. I would study this using a survey administered to members of my home community in Fauquier County, VA, about their attitudes toward groups such as scientific researchers, doctors and other healthcare professionals, government agencies such as the FDA, and media outlets that report relevant information, and their tendency toward vaccine hesitancy. The results from this survey would hopefully give some predictive capability based on trust in these organizations, giving insight into the root causes of vaccine hesitancy.

Literature Review

Vaccine hesitancy is more difficult to define than simply identifying which individuals will not take a vaccine and which individuals will. In fact, while it is generally accepted that levels of vaccine skepticism and hesitancy exist on a spectrum, there is much debate on how to most effectively group individual's attitudes towards vaccines. Keane (2005) identified four groups of attitudes toward vaccination, the "vaccine believers" that are wholly convinced of vaccines, the "cautious parents" that believe vaccine science but don't like to watch their children being vaccination and are uncomfortable with the method, "relaxed parents" that have skepticism of vaccines, and "unconvinced parents" that are entirely skeptical of vaccinations.

This approach was critiqued by Gust (2005) who identified through survey 5 attitudes toward vaccine adoption, labeled as “immunization advocates”, “go along to get alongs”, “health advocates”, “fence-sitters”, and “worrieds”. These categories allow for broader types of reasoning to result in an individual’s placement in each group. Yet another framework devised by Benin (2006) identified a group called “late vaccinators”, or parents that are worried about the pace of vaccinations but believe in overall efficacy.

In an attempt to draw statistical relationships between individual attitudes toward vaccination and likelihood of child vaccination, Opel (2011) designed a survey to determine an individual’s attitudes in four domains linked to vaccine hesitancy: vaccination behavior, beliefs about vaccine safety and efficacy, attitudes about vaccine mandates and exemptions and trust. They used the results from this survey to determine an associative model to predict vaccination status of children. This indicates that there is credibility to the model they devised.

Another challenge to identifying groups of attitudes toward vaccines is the degree to which these groups, and individuals within these groups, shift with the political and social climate. Streefland (1999) points to the existence of “local vaccination cultures” that influence individual’s beliefs differently in different areas of the country and even world. This would indicate a study of vaccine hesitancy could yield different results not just by region, but by community, underscoring the need for random and varied samples for study. Other studies site recent controversies regarding health impacts and vaccines, such as MS and the hepatitis B vaccine (Francois, 2005) and autism and the MMR vaccine (Poland, 2010), despite the evidence for these linkages being missing. It is unclear if fears based on these connections could be assuaged through communication of contradictory data.

A central focus of research in this area is into the major players in the social framework, and their interactions. The first major player is the media, including not only people and media outlets, but technologies for communication. A study from Mason (2000) demonstrated media influence in stoking flames of vaccination hesitancy. This is exacerbated by the opportunities for individuals that are vaccine hesitant to amplify their opinions through internet social media sites (Wolfe, 2002). The shifting of public health policies has also contributed to vaccine hesitancy. Another crucial actor in this system is healthcare providers and professionals. Studies from Connors (1998) and Jellyman (2004) indicate that hesitancy can initiate with an individual's healthcare provider, indicating that nurses and doctors in many western countries show significant degrees of vaccine hesitancy. This hesitancy could prevent these healthcare workers from fully advocating for complete and timely vaccines to patients.

Another interesting factor in vaccine hesitancy is the role of an individual's knowledge level of vaccine science. Studies from Streefland (1999), Bond (1998), and Evans (2001) all indicate that vaccine hesitancy actually increases with increased knowledge of vaccine science, and parents that choose to vaccinate their children have the least knowledge of vaccination. However, a study from Guay (2009) contends this relationship may be causal in the opposite direction, that parents who are already planning to vaccinate their children have no reason to research vaccine science, while parents that are already skeptical of vaccines will be more motivated to seek information to confirm their belief. I am yet to find any studies on the effect of increased levels of knowledge on individuals who are already skeptical of vaccine science, and this appears to be a potential gap in literature.

In general, much of the theory surrounding vaccine adoption is focused on parental attitudes toward vaccination of their children. While this would be a component of COVID

vaccine adoption, there are many groups of non-parental individuals that may choose not to adopt the vaccine for other reasons, which may be a gap in current research as there has not been motivation for this type of research in recent history, as vaccinations typically occur in childhood.

STS Framework and Method

Several STS frameworks were useful in analyzing this research topic. Winner's approach was used to analyze structures of power involved in vaccine development and distribution. Typically, these vaccines are required by government agencies as a prerequisite for public schooling, which does remove the decision making from individuals somewhat, but this could be more acceptable for technologies that affect populations in the way vaccines do. Vaccines are typically deployed through medical professionals like primary care physicians, but in the case of incredibly common vaccines, like the flu shot, they can be obtained from local pharmacies in community hubs like grocery stores. This is helpful as it does not result in too much power of any one agency over the possession of these technologies. There are few barriers to this technology, and often the true cause of non-adoption are political oppositions and skepticism of the industries that produce and advocate for the technology.

Latour's ANT framework was used to analyze the role of all actors, including nonhuman actors, in the system. The development of a vaccine requires many human and non-human actors and actants. The process requires laboratory scientists to design an effective vaccine, manufacturing engineers to produce it in large quantities, medical professionals to administer the vaccine, and, especially in the case of Covid-19, government administrators to promote its use.

Even within these broad categories, additional resources are required for these processes; laboratory and manufacturing work requires extensive infrastructure, making these tasks impossible outside of major city centers with reliable power grids. Many of the raw materials for development must be harvested, either from grown cell cultures or larger organisms. Government agencies, especially in the United States with limited state-sponsored media, rely on independent media outlets to spread the information they provide. Additionally, technologies like the internet and social networking sites influence the way this information is spread, who can make claims regarding these new technologies, and who decides what they or others should interact with.

Currently there is a model for forming an effective actant network, but it does not function to the capacity necessary. Government agencies will fund vaccine development and promote the results, although this financial link can create skepticism from observers. Then officials from these government agencies, or even scientists they have chosen to represent them, utilize media agencies to spread the information they want released. Again, this relationship can draw criticism of bias.

A critical component of this issue is the way in which the technologies of today, namely social media services, can shape the messages that are being delivered regardless of the intent of the individuals involved. I think the structure of sites like Twitter or Facebook result in short form information that lacks the ability to provide relevant context and information, and becomes ripe for individuals to criticize claims as a result. I think this could be an interesting component of the societal network surrounding vaccine development to explore with my research question.

For this research assignment I will chose to gather data via the survey research method, with the potential for additional data gathering using the interview research method. Much of the

broad strokes information to identify whether the individual has skepticism of vaccines currently, and what specific agencies and individuals they find least reliable, can be obtained via survey. Because vaccine hesitancy is likely to be lower amongst college students, I will hope to distribute the survey not just to UVA students, but also in my home community in Fauquier County, Virginia. Since much of the data collection from this survey could likely be automated and I anticipate difficulty in obtaining survey responses, the sample size would hopefully be as high as possible, allowing me to get data in spite of anticipated low rates of survey returns and below 50% rates of vaccine hesitancy. Once this information is collected, individuals of interest (would likely be those who are vaccine hesitant and identify specific and actionable reasons as to why) could be followed up with for a more in-depth interview.

Data from the survey will be qualitative, and can allow me to identify trends between attitudes about vaccine science and levels of trust in and communication with relevant agencies. Data from the potential interview section will be qualitative. The most potential for sources of biases are in my question selection. To mitigate this, questions will be reviewed by a third party to ensure they are not in any way misleading or 'loaded'.

Timeline

The major milestones for this project will be to generate a survey, administer the survey, review the results, and conduct follow-up interviews with candidates of interest if time permits. I plan to have survey questions compiled by the start of the spring semester, with sufficient results by the end of February. At this point, additionally interviews can be conducted throughout the months of March and April, and can be compiled into early May.

Conclusion

Through this STS research project, I hope to determine correlations between an individual's willingness to take a COVID-19 vaccine and their attitudes toward relevant social and political institutions. This would contribute to the current literature by relating ideas currently associated with childhood vaccination to the novel COVID-19 vaccine.

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