The societal and environmental challenges associated with the production of biofuels

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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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STS Research Paper

If we could travel back in time 20 or 50 or 100 years ago, the problems humanity faced pale in comparison to the problem that we now face that is global climate change. Presently, the world is scrambling to stand by lofty promises of decarbonization and sustainability made years ago that pledged to protect the planet. However, global temperatures are still rising steadily, sea levels are creeping up on land, and many species are becoming increasingly more endangered by the changing environment. Many people think that the task of addressing global warming is not their responsibility and continue to shrug this issue to the side for the next person to deal with. However, unless humanity wishes the 21st century to forever be marked as the beginning of the end of our world, change must be made much faster.

In this paper, I will focus on a small corner of the behemoth that is climate change: integration of biofuels for a more sustainable fuel alternative to fossil fuels. Biofuels offer better sustainability to traditional fossil fuels because the growth of crops or biological material for biofuels offsets some of the carbon that is released into the atmosphere when they are burned. Plants “fix” carbon dioxide from the atmosphere, which means the carbon dioxide they use for photosynthesis is taken from the atmosphere and sequestered in the plant in the form of sugars. This carbon dioxide sequestration is how biofuels offset the emissions created by their burning. Biofuels offer an opportunity to reduce emissions during the energy transition from fossil fuels to cleaner energy sources such as green electricity, solar, and hydrogen.

In the 20th century many countries began subsidizing and requiring the supplementation of ethanol to gasoline. However, this innovation was not originally intended to address climate change and reduce emissions. Ethanol was found to provide an octane boost to gasoline fuel during World War II and it wasn’t until the Energy Policy Act of 1978 when the ethanol subsidy was officially created (Johnson et al., 2021). Despite further legislation being passed into the start of the 21st century, causing the biofuel industry to grow dramatically, global emissions in 2030 are projected to have risen by 9% since 2010 levels (UNEP, 2023). Evidently, efforts to transition off of fossil fuels have not been as successful and widespread as was pledged in the Paris Climate Agreement. This brings us to the role of biofuels in the energy transition and how their implementation into society has fallen short. The challenges that biofuels have faced in the recent decades began after the oil crisis of the 1970s when oil prices dropped and all incentive to continue investigating biofuels as an alternative energy source vanished. As a result, technological innovation stagnated and cost-effectiveness did not improve. In more recent years, the biofuel boom of the early 21st century brought with it challenges of integrating biofuel production and farming of biomass feedstock with local, and often underdeveloped, communities and ensuring environmental sustainability. Despite the expansion of the industry, biofuels are far from phasing out fossil fuels, and alternative energy sources, especially electric vehicles, are gaining significant momentum in the transportation sector.

However, alternative energy sources for transportation don't share as much infrastructure with current fossil fuel machines, so a complete transition would not be possible very quickly. Since biofuels were designed to supplement fossil fuels initially, it is much more likely that slight modifications to current fossil fuel machinery can be made to achieve this transition in a more timely manner. If any lasting change to our energy problem is to be made, we must make sustainable progress towards fazing the whole world out of oil, natural gas, and coal. To aid this, current infrastructure may be adapted to withstand a higher biofuel fraction or biofuels can further be innovated to be integrated into current combustion engines. For this to happen however, society must embrace the change so that biofuels can overcome the challenges that have recently slowed their progress.

Background and Significance

To understand the challenges that biofuels currently face in the global energy transition, we must first understand their history and the different types of biofuels. Modern biofuels produced on a large scale date back to the late 19th century when ethanol was first used as a fuel. Ethanol's popularity grew with the advent of the automobile, especially when Henry Ford designed the Model T to run on ethanol or gasoline (Gustafson, n.d.). Ethanol is what is known as a first generation biofuel because it is produced from edible energy crops such as sugar-based crops (sugarcane, sugar beet, and sorghum), starch-based crops (corn, wheat, and barley), or oil-based crops (rapeseed, sunflower, and canola) (Moodley, 2021). Specifically, ethanol has typically been produced in the United States by fermenting sugars from corn due to the popularity of the crop for animal feed and the subsequent high supply of the crop. However, since first generation biofuels are derived from edible fuel sources, there is a conflict between whether the food crops should be used for food or fuel (Cavelius et al., 2023). There is also large land and fresh water usage to grow food crops, making the food vs. fuel conflict have even deeper implications. With an ever-growing global population, the demand for efficient food production is growing in parallel, so sacrificing valuable resources to produce biofuel raises concerns with many people. For this reason, other sources of biofuels began to come to light.

Second generation biofuels are derived from lignocellulosic biomass (organic material not intended for consumption) and other waste streams such as organic and industrial wastes (Cavelius et al., 2023). This includes food crop waste such as the husks of corn, soybean plant stems and leaves, etc. One of the ways second generation biofuels are made is through the fermentation of sugars derived from the cellulose and hemicellulose in crop waste to form ethanol. This process is very similar to first generation biofuels but the appeal behind second generation biofuels derives from the valorization of waste. By using inedible biomass and waste streams, the production of ethanol is attractive for municipal governments. The human desire to be as efficient as possible and optimize everything serves as the foundation for this source of energy, and these second generation biofuels bypass the food vs. fuel conflict that 1st generation biofuels are plagued with. Unfortunately, this type of biofuel is not as ideal as it may seem. Firstly, there is a limited amount of biomass and the energy density of the waste streams is much lower than first generation biofuels since they have been processed prior to arrival to the fuel creation process. In addition, there is more extensive pretreatment necessary for these waste streams than edible food sources since the waste is more complicated and diverse (Cavelius et al., 2023). This increases the cost of production of this type of biofuel, and as a result the concept of third generation biofuels broke new ground as to what biofuels could be derived from.

Third generation biofuels are derived from microalgae and cyanobacteria. Algae cells have high oil contents which can be synthesized to produce all types of biofuels such as biodiesel, gasoline, butanol, propanol, and ethanol with high yield (approximately ten times higher than second generation biofuels). Algae is an attractive source to produce biofuels because it completely decouples biofuel production from the need for arable land and fresh water since algae can be grown in waste or brackish water (Cavelius et al., 2023). Algae and cyanobacteria also offer diverse opportunities to make alternate products such as proteins and other high value compounds in addition to biofuel (Khandelwal et al., 2023). In addition, some strains of algae can grow from diverse energy sources such as light (autotrophic), nutrients (heterotrophic), or a mix of both (mixotrophic). Thus, they offer a wide range of possibilities towards the production mechanism of biofuels. Despite algae having great potential to be the source of biofuel, there are still significant challenges with regards to scale-up of algae cultivation and the downstream processing energy requirements to grow substantial amounts of algae in an economically viable manner (Cavelius et al., 2023).

Finally, the newest form of biofuels are fourth generation biofuels created from genetically engineered feedstock with genomically synthesized microorganisms such as microalgae or cyanobacteria. This can include genetically modified algae as a source of the lipids required to make biofuels. The main advantage of fourth generation biofuels over third generation biofuels is that the yields are increased due to genetic engineering (Cavelius et al., 2023). However, the threat of the genetically modified organisms entering the ecosystem is a large disadvantage in addition to the remaining high downstream processing costs.

The status of biofuels since the onset of the 21st century has ebbed and flowed, based on the economic prosperity of the nation and the world, the progress of other alternative fuel sources and the public's opinion regarding the feasibility and appeal of biofuels. Understanding the challenges associated with the production of biofuels as well as the legislative and public opinion blocks that stand in their way will aid in the growth of biofuels as a viable energy source to help the world transition from fossil fuels to completely sustainable energy sources that help reduce emissions.

Methodology

The objective of this undergraduate thesis is to investigate the challenges associated with the integration of biofuels as an energy source to aid the global energy transition off of fossil fuels. The technological momentum theory is the approach used to investigate these challenges. The technological momentum theory assumes that for society to accept a technological system, it must first align with social context and goals (Hughes, 1983). The typical stages of development of a technology include the invention and local application, transfer to other places, development of supportive infrastructure, and finally becoming the standard accepted system that has momentum and is difficult to replace (Hughes, 1983). Currently, the fossil fuel industry consisting of the import of oil and national production of gasoline among other things is the standard accepted system that is difficult to replace. However, the social context and goals have never been aligned better for the transition of fossil fuels to other sustainable energy sources, so understanding and addressing the challenges associated with biofuel can help it gain technological momentum.

In this case, biofuels have had ups and downs over the last half-century starting with their initial proliferation after the oil crisis of the 1970s, followed by stagnation until the early 21st century when their production boomed. This method of analyzing the technological momentum in the last 50 years will offer an insightful perspective as to why the progress resulting from the craze for biofuels after the oil crisis of the 1970s stagnated and what challenges arose after the boom in the early 2000s. In addition, the technological momentum perspective will aid in understanding why other technologies such as electric vehicles have gained traction in recent years as a result of some of the new challenges associated with biofuel production.

This research will primarily consist of literature reviews to glean information from secondary sources related to the topic of biofuels in the academic world. This includes research into biofuels, analyses of processing technologies, and comparisons with other sustainable energy sources. Research will be analyzed primarily through case studies, from which social implications will be gleaned. In addition, policy analysis with regards to laws and regulations will provide political context of various countries with regards to biofuels to aid in the technological momentum theory approach.

Discussion of literature and policy

In this section I will investigate how biofuels have faced increasing challenges since their proliferation in the 1970s during the oil crisis. When oil prices peaked in 1979, two countries led the world in terms of searching for viable fuel alternatives: Brazil launched a national ethanol program while the United States launched a smaller corn-based ethanol program (Timilsina and Shrestha, 2010). However, with the subsequent drop in oil prices in 1986, there was no incentive to continue expanding biofuel production in most countries with Brazil as the one exception (Timilsina and Shrestha, 2010). This is the first major challenge the biofuel industry faced: lack of incentive to continue expansion when fossil fuel prices are cheaper than biofuel. Despite a return to lower fossil fuel prices, Brazil outperformed the rest of the world by providing incentive to continue the expansion of biofuels through high ethanol blending mandates (Timilsina and Shrestha, 2010). As of 2008, the Brazilian government mandated 20-25% ethanol blends in all gasoline sales. This was only feasible because ethanol production was supported during the industry's development through price guarantees, subsidies, public loans, and state-guaranteed private bank loans (Timilsina and Shrestha, 2010). The United States experienced a similar explosion in the biofuel sector some time after Brazil paved the way in the industry.

In the early 2000s, the growth of ethanol production in the United States was primarily driven by fiscal incentives, like taxes and subsidies, and regulatory instruments such as biofuel blending mandates (Timilsina and Dulal, 2008). In addition, other legislative acts were passed such as The Energy Policy Act of 2005 created a Renewable Fuel Standard (RFS) program to increase the biofuel mandate to 36 billion gallons by 2022 from 9 billion gallons in 2008 (EIA, 2009). As a result of this wave of legislation and fiscal incentives, the American biofuel industry grew to be a world-leading industry. However, the production of biofuels is more nuanced and faces more challenges than simply legislative incentives and policies to promote expansion. The following two case studies of jatropha cultivation in Sucopo, Mexico and the expansion of the palm oil sector in Brazil illustrate some of the social and environmental challenges and consequences that can result from poor oversight on biofuel projects.

Global Clean Energy Energy in Sucopo, Mexico

The first failed biofuel project investigated in this paper belonged to Global Clean Energy Holdings Inc. (GCE) in Sucopo, Mexico. This project began in 2008, two years after the United States surpassed Brazil as the number one producer of ethanol in the world and one year after the US surpassed France as the second largest producer of biodiesel in the world (Timilsina and Shrestha, 2010). GCE, headquartered in California, sought to sustainably produce biodiesel from a plant called jatropha (*Jatropha curcas*) which was proposed by several international publications as a suitable biomass source for second generation biofuel production in agriculturally marginal areas (Barta 2007; Raswant et al. 2008, Robinson and Beckerlegge 2008). GCE settled on the community of Sucopo, Mexico in the northeast of the state of Yucatan for their project due to federal and state subsidies for companies that decided to invest in jatropha. With promises of employment for the local community for 15-30 years with high wages and social programs to improve living conditions, GCE was welcomed by the local community.

However, after merely five years, GCE underwent restructuring and laid off most of its employees, leaving the community of Sucopo disillusioned from the promises of stable income for decades. The abandonment of this project in the midst of company restructuring was likely due to the fact that after only a few years, it was clear that yields were significantly lower than had been expected and suggested by previous publications (Jongschaap et al. 2007).

In addition to the disillusionment of the local community, there were larger lasting effects on the region with regards to community health, financial security, and environmental destruction. GCE employees enjoyed medical services as well as mortgage and pension programs during their employment while also enjoying a steady job near home without having to work in a sector where conditions were far less favorable (Selfa et al. 2015). The worst effects on the local community however were caused by the cutting and burning of 3000 ha of *Monte Alto* (tall forest) for GCEs jatropha plantation. As a result, wild animals no longer had extensive areas for foraging, leading them to attack the traditional agriculture plots, known as milpa, growing maize, beans, and squash (Selfa et al. 2015). This substantially diminished the sustainability of the traditional agriculture cycle in Sucopo and also adversely affected the sale of honey due to a loss of wild flowers from deforestation (Selfa et al. 2015), which is an important income generating activity in the region.

In addition to the previous fervor and advocation for the expansion of the biofuel industry globally in this paper, it is clear from the proceedings of GCE in Sucopo that there are more nuanced implications involved with the production of biofuels. Yes, legislation is needed to expand the industry; however, companies should have non partisan oversight to ensure that the local community is not adversely affected. Alarmingly, GCE did have external oversight to ensure they were complying with Global Sustainability Standards by SCS Global Services, who reported that “GCE’s agricultural activities added no extra risk to soil, water, air, human, and land rights” (Selfa et al. 2015). Evidently, the perspectives of investors motivated to fulfill globally defined sustainability standards and the local interpretations of sustainability did not overlap and not enough care was taken to integrate sustainable biofuel production with the local community. In the future, external organizations upholding sustainability standards need to consult local experts to ensure that adverse consequences don’t negatively impact the community and local environment. In this case, Mexico had little existing legislation and policy, so GCE was able to operate as they pleased and leave a tarnished imprint on the local community. Similarly, Brazil, with over a century of biofuel policy, struggled in the early 2000s with social inclusion and the growth of the palm oil sector for biodiesel production.

The palm oil sector for biodiesel production in Brazil

Another case of biofuel production having adverse and unforeseen effects on the local community and ecosystem is exemplified by the expansion of the palm oil sector into the northern region of Brazil in the state of Pará. Palm production in the region started in the 1980s and Agropalma is one of the companies that has been in the region the longest. In 2004, the Brazilian government launched the National Program of Biodiesel Use and Production (PNPB) and a progressive blending program for biodiesel and in 2010, they launched the National Program of Sustainable Palm Oil Production (PSOP) in an effort to expand palm oil plantations for biodiesel (Selfa et al. 2015). What made this case different to that of GCE in Mexico is that from the start the Brazilian government focused on social inclusion and rural development in ecologically degraded and economically depressed regions (Selfa et al. 2015). This was incentivized through tax and trade benefits to companies who partnered with small farmers for production of biomass for biodiesel. However, by 2013, biomass produced on large mechanized farms still accounted for 77% of the feedstock used for biodiesel production (Selfa et al. 2015). This is where the side effects of this massive industry begin to be seen.

The massive land requirements for growing palm oil vastly contribute to reducing the region's already extremely threatened rainforest. According to Conservation International (2009), the region outlined for palm plantation expansion includes one of the most threatened regions of the Amazon with about 70% of its area affected. Although there is some evidence that planting palm on existing degraded lands can help restore the biological balance of the rainforest (Selfa et al. 2015), this should not justify the continued deforestation of the world's largest and most biodiverse rainforest.

In addition to the ecological concerns that biomass feedstock agriculture brings, the local communities are adversely affected despite the government's intention to bring social inclusion and rural development to the area. The societal impact lies in the land grabbing that began to occur when large-scale agribusiness firms were incentivized to expand palm plantations. Small farmers were pushed to either partner with these companies and adopt palm oil monocultures, or sell their land for palm production. In either case, the land that was previously farm land used to produce food crops was converted to a palm oil monoculture. This severely impacted the food security in the region and also disrupted traditional communities such as the quilombolos (Selfa et al. 2015). Oftentimes, the farmers who sold their land also ended up working on palm plantations and were subjected to quite poor working conditions since the region is so remote and external oversight from sustainability standard organizations such as the Roundtable on Sustainable Palm Oil (RSPO) was poor. Evidently, the goal of social inclusion and rural development, although well intentioned, was not attained and the expansion of the palm oil sector in economically depressed regions resulted in decreased food security, loss of natural rainforest land, and disruption of traditional livelihoods.

Regardless of the situation, these two case studies indicate that there are significant social and environmental challenges due to the necessity of a workforce and ample land to cultivate biomass to produce biofuel. It is also important to note that the social and environmental consequences were paralleled in both cases and yet in Mexico there was virtually no legislation surrounding biofuels while Brazil has the longest history of biofuel legislation in the world. This just goes to show that even though legislation may be needed to aid the transition from fossil fuels to biofuels, they cannot fully be entrusted with integrating biofuel projects into

Conclusion

In summary, despite the significant progress in biofuel legislation and production that occurred in the early 2000s, challenges regarding how biofuel projects negatively affected the local lives and ecosystem also became evident. The two case studies discussed in this report highlight how regardless of how involved the government is, biofuel projects can still have unintended effects. As a result, when incentivizing biofuel projects, governments need to also integrate representatives from the local communities for said projects to help oversee and integrate biofuel projects in the region. Currently, organizations that seek to uphold global sustainability standards are not sufficient arbiters for biofuel projects located in rural regions, especially rural regions of developing countries. Therefore, once technological limitations are overcome and the science behind biofuel production is optimized, a new system of integrating this new industry into society will need to be implemented. One in which the social and environmental impacts of biomass cultivation are considered and adequately addressed.

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