Biofuel Adoption: A Case Study in Understanding Emerging Technology

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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

Biofuels are arguably one of the most defining inventions of our species. They allow for early homo-sapiens for the first time to create warmth, cook food, and see at night. So why is an invention that has been iterated and employed for so long still a point of contention in today's society? Biofuel's now have an even more enticing value proposition: they can act as a carbon-neutral source of energy to power a world who is failing to understand the scale and importance of environmental responsibility. There is no longer any debate that we can power all of the activities of the world with fossil fuel energy sources. In contrast, this world also cannot simply run-on renewable energy; there must be a diverse energy infrastructure that balances our emission of carbon-dioxide with energy demands.

Biofuels, a potential part of this new era of energy, have struggled to be adopted as a scaled energy source and provide a relatively miniscule amount of energy in comparison to the dominant fossil-fuel industry. This solution cannot be solved by itself, it will take key players to promote the adoption and prove the feasibility of the industry. This thesis will work to understand the major and minor actors, how they have or have not influenced adoption, and their potential for improvement. It is clear that biofuels cannot stop climate change or the eventual shortage of fossil fuels without the tandem use of renewable and fossil energy, but also understanding who is most responsible could shed light on its long-term adoption and practicality.

Context

Climate change has been on the rise since the first industrial revolution as a result of burning carbon-based fuels and releasing greenhouse gasses into the atmosphere. The trapping of heat within our atmosphere has resulted in a temperature increase with implications for major catastrophic events taking place. As a result, bio-based fuels have emerged as a carbon-neutral solution for energy and heat production.

The first generation of biofuel technology that has emerged is that of ethanol and biodiesel. Their ability to act as liquid fuel for transportation and storage, unlike other renewable resources, is valuable in replacing traditional fossil fuels. Both ethanol and biodiesel are sourced from biomass and can use commonly found feedstocks in agriculture. Ethanol is commonly made from the fermentation of plant starches and sugars which naturally yield ethanol under the right conditions. Biodiesel can be sourced from most forms of fat and oil typically through exposure from alcohol.

Biofuels are emerging in increasing quantities particularly as agents within fuel blends. Roughly 97% of all gasoline in the USA contains trace amounts of ethanol. More concentrated blends are beginning to emerge for modern fuel-flexible vehicles where blends from 50-85% of Ethanol are used for transportation. Large blends of ethanol however are not as common, and where they can be found blends of up to 10% ethanol are actually approved for traditional gas-powered vehicles. Biodiesel tells a similar story with common blends up to 20% in composition. Biodiesel, however, has a different use case for vehicles with diesel engines that are typically concentrated in the long-haul transportation industry and the blends can be sourced up to 100% from biomass.

Together the growing use of biofuels, ethanol and biodiesel, have demonstrated fundamental value for the transportation industry and the verticals of liquid fuel but many other factors influence adoption. The role of biofuels has implications among the economics, politics, and technologies in the energy industry, these factors will be put into more context throughout this paper.

Framework

The framework behind this paper is analyzing the adoption of biofuels through the lens of the socio-technical triangle or STS triangle. This perspective is relevant because of how technology, society and organizations are always interconnected when trying to understand a full picture. In respect to the biofuels, and its immense scope, the STS triangle can begin to understand the role and connection of many factors at play. By working to understand biofuel adoption through the STS Triangle, I hope to get a better understanding of where the industry is moving and why.

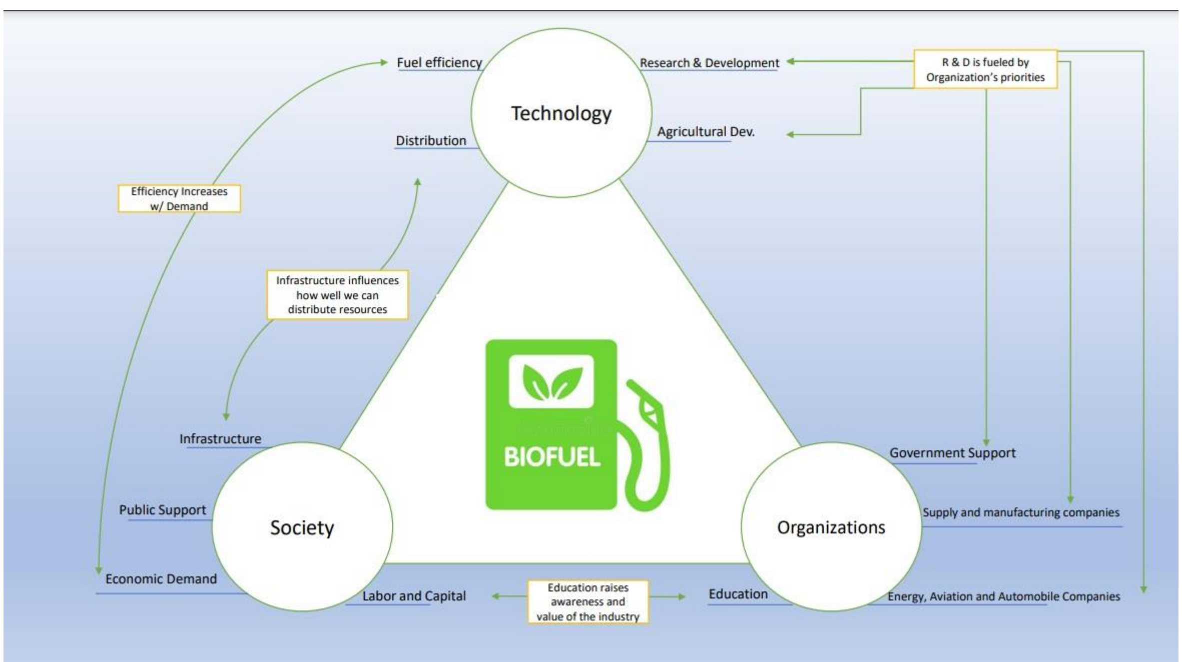

Figure 1

The theory behind studying the STS triangle is for its ability to demonstrate the interconnectedness of technology, society, and organizations. Using Figure 1 as a visual representation of the framework, the three sides of the triangle portray relationships between 2 of the 3 points. The evidence gathered for this paper will shed light on how each side of the triangle influences biofuel adoption. The benefit of understanding adoption through the three relevant socio technical relationships, isolates the most important factors supporting adoption. Together these factors paint a complete picture of how biofuels advance as an industry. Organizations work to prioritize human and technological capital based on their political and infrastructural power. Similarly, the economics of small and large consumers shift the supply and demand of new and old technologies. As a consequence, looking at all the actors together can make a convoluted picture of the sociotechnical nuances so this paper will work to highlight the most influential relationships for the biofuel industry. This framework will incorporate political beliefs, emerging companies, conservation, infrastructure, government incentives, and overall economics. Breaking down the key components of biofuel adoption will in return help synthesize an overarching understanding of the industry's status.

Methods

To establish a ground for analysis of the adoption of biofuels, this paper will share evidence gathered from relevant online sources and published research. To encompass the three-sides of the STS triangle the paper will outline the industry through recent government publications, 1st and 3rd party press releases on business activities, and scientific research papers. These three source categories will outline the current climate of organizations, society and technology involved in biofuels. The framework used to understand the adoption of biofuels will be supplemented by this evidence and further analysis of each relationship.

Evidence

Society and Technology

Political Beliefs

In 2014, a study was conducted to understand the interplay between party identification and risk/benefit perception on public opinion about biofuels. This study concluded that party identification wasn't the sole determination in how the public feels towards renewable energy technology. Americans are framed by their political identification but they also are able to form outside thoughts determined by their consideration of who is benefited and harmed. For example, Democrats are more likely to support the use of renewable energy including biofuels when they are framed as a positive social decision through a media presence but are not as keen to biofuel adoption when political implications reduce the resources of other renewables. These findings are the tip of the iceberg in portraying the power influential people and media have on biofuel and renewable adoption. It's now proven to be possible that groups can be united or divided in their feelings on biofuels based on the exposure they have to certain issues in the industry. The power of bi-partisanship in America could bring people together to support further developments and research towards biofuels. However, in contrast, fair competition in the energy industry, a major a bi-partisan ideal, is extremely important and a major factor in holding back the adoption of biofuels (Fung, 2014).

Policy-makers have likely realized this bi-partisan trend in the energy sector. Taking away capital resources from fossil fuels to support biofuel infrastructure is an impactful way to increase biofuel use but would strongly hurt polling numbers. This is likely why infrastructural bills, such as the trillion-dollar bill signed this year, lack any strong funding for biofuel infrastructure(whitehouse.gov). This political action is juxtaposed by the clear support of biofuels in the media with a lack of policy to back it up. People in general support a laissez-faire market but also support a campaign for renewable energy. This goes to show that there is an ideological gap in how emerging markets become mainstream in a highly standardized market. Both policy makers and society are stuck in a stale-mate, as Fung says, to determine whether the risks and benefits are worth the development of biofuels.

Emerging Technology

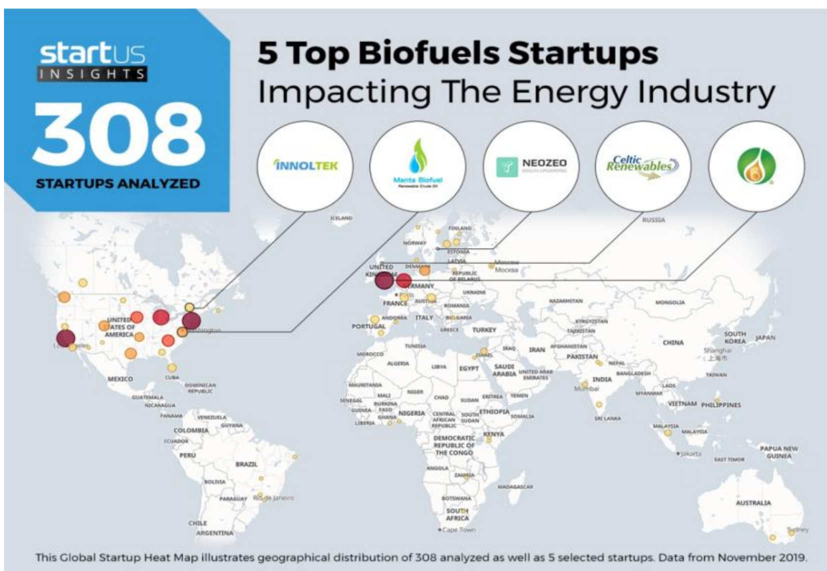

Figure 2: Geographical Map of Major Biofuel Start-ups

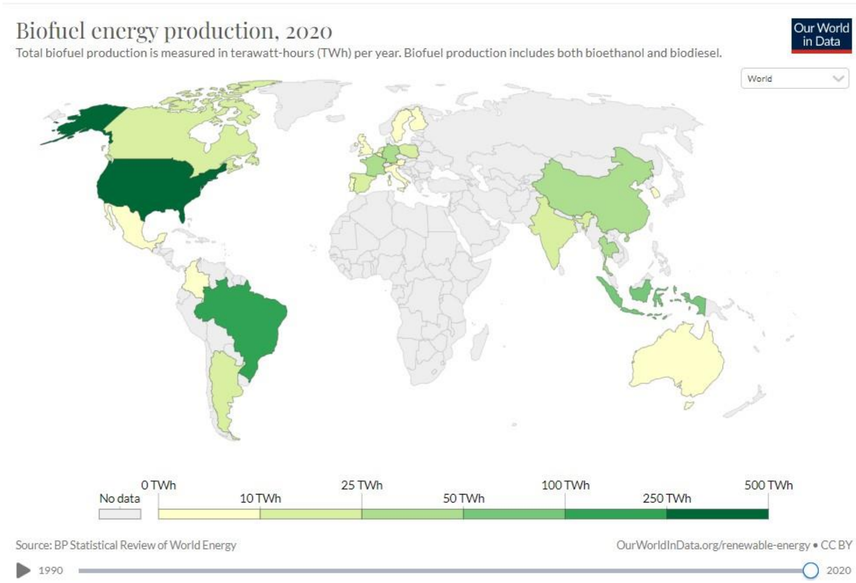

Figure 3: Geographical Map of Biofuel Energy Production

Society's influence on the economic viability of biofuels is not limited to politics, but also the development of biofuel technology. There is a disparity between the countries who are producing biofuel feedstock and those who are developing the technology to support it. Asian and South American communities that are among the top regions of biofuel production potential, are geographically distant from its economically scalable potential. Start-ups are a good measure of capitalizing on a market opportunity, but this trend seems to only be occurring in the United States. The regions that have a large potential to capitalize on the growing industry are outsourcing their supply to other regions; economically, this slows down the supply chain and hurts the economic viability of the industry.

One case study, Manta Biofuel, shows the separation from value-creating opportunities to the supply of resources. To be specific, Manta Biofuel hopes to reduce the land needed to produce biomass by using more efficient carbon-producing feedstock, algae. Algae’s biological advantage to convert sunlight into more oils compared to other crops has a very strong value proposition for emerging markets. To grow biomass requires inputs of nutrients, sunlight, water, etc. so the ability to produce more biomass with less input resources is a vital value-add for commodities such as energy. Places like South America and Southeast Asia, who have rapidly growing energy demands and population, could find a lot of value domestically sourcing their production of fuel and food. These two resources are competing with one another when it comes to biofuels and creates conflict for biofuel adoption.

However, the top start-ups like Manta are based in places like America, whose proprietary information to increase biofuel production efficiency, is isolated from many geographical sources (Start-us). In the emergence of biofuel technology, societal awareness of the new market potential could improve the geographical landscape of the industry and help it scale in more optimal conditions.

Organizations and Society

Conservation

The development of biofuels has positive benefits for carbon emissions and diversifying the world’s energy portfolio, but many times it is overlooked the impact of macro crop production. To produce large scale energy from biomass puts a large burden on the land it's grown upon. The overuse of agricultural land by some plants can deplete the nitrogen and stability of certain ecosystems. Monoculture and poor fertilization techniques can add to this by making the land and irrigation increasingly harmful to the wildlife and plant life surrounding the farmland as well. Because of this, the Conservation Reserve Program (CRP) has actively protected and set aside about 35 million acres of sensitive and highly erodible lands which invokes a cost of about $1.8 B a year. However, long term farmers could be assured of the market and resources to overcome these issues (NCRS). The assurance of land for biomass farming while simultaneously harming the agricultural ecosystem, creates a push and pull effect for biofuel production. This unsolved conflict can limit the land available for agriculture; however recent developments in biomass production have mitigated the risks of land availability.

Perennial and aquatic biomass crops are becoming increasingly beneficial to sustainably producing biomass for energy. Under the support and understanding of the CRP, farmers could potentially begin improving the conservation needs and wildlife habitats. If the CRP and farmers could work together it would be mutually beneficial to preserve or at least upkeep the lands under conservation plans. This is because the perennial and aquatic crops have certain traits that improve the ecosystem. Firstly, perennial and aquatic crops often don't need annual tillage that destroys acres of land during harvest. Secondly, many of these biomass crops have deep and strong root systems, such as switchgrass, that hold soil and reduce erosion. A well-known part of biomass crops value proposition as well is their ability to sequester carbon and supply it to the ecosystem.

The impact of conservation determines how farmers must operate under the emergence of Biofuels. The agricultural consequences caused by monoculture and large crop cultivation influence what and where farmers should grow. The growth and strength of conservation efforts give way to aquatic and carbon-rich feedstocks. Yielding biomass as a result of aquatic plant growth such as algae limits the eco-systemic effects of land-based agriculture such as erosion and loss of biodiversity. Being intentional about using carbon-rich feedstocks such as sugar cane, can maximize biomass yield per acre, because these plants are more efficient in storing carbon than others. Collectively, conservation reserves relationships with the agriculture industry impact where and what biomass is being sourced.

Economics

Supply is a very important issue for biofuels and more specifically, its strong influence on demand. This is a common issue with any developing or emerging market, especially in energy. The utilities and end-users of biofuels don’t want to rely on a technology that will not have a consistent supply or else they have made a poor investment. But similarly, farmers and distributors don’t want to continue producing and transporting a product that doesn't have a consistent and reliable market to serve. Commercial viability is a major issue for biofuels because the large sales-cycle of energy products is not compatible with the historically lower prices of biofuels’ competition. This is shown in how it takes almost 7-10 years to create a reliable supply stream from scratch for biofuels (NCRS). Organizations and society determine the feasibility of biofuels and in return have a large economic impact on the scalability of producing, processing and consuming the energy as a resource.

Supply is just as important as distribution when emerging markets can’t guarantee access for end-use consumers and if anyone could ensure biofuel availability for the world, it would be oil companies. Large fossil-fuel companies are seeing an inflection point in the energy market and whether they are pivoting or showing face for public relations, they have demonstrated interest in biofuels, especially Exxon. As of 2022, Exxon Mobil reports partnerships with universities, government agencies and relevant companies to advance biofuel delivery and benefits. Part of their thesis in this environment is their claim to 50% less greenhouse gas emissions from algal biofuels vs. petroleum and the increase in energy demand incorporating global responsibility. They claim to have invested over $250 M in biofuels research but for the average American consumer this funding isn’t seen by the public eye. Exxon does not currently have algal biofuels in its infrastructure but targets 1,500 gallons of fuel per acre per year and produces 10,000 barrels per day by 2025(Exxon, 2022). For reference ExxonMobil produces about 4 million barrels of a natural gas equivalent per day (Exxon, 2021).

While they are producing 0 barrels per day of algal biofuels now, they hope to scale this by partnering with Clariant, a cellulosic biofuel research group. They evaluate the potential use of cellulosic sugars from sources such as agricultural waste and residues to produce biofuel, which could reduce the feedstock amount to produce fuel even further (Exxon,2022). So, Exxon’s portfolio is putting money where its mouth is in R&D and acquisitions; however, their slow rate of development is not indicative to the end-use consumer of adequate momentum towards their pledge to greater environmental responsibility. While Exxon is a case study and not the sole actor in this network, they are indicative of the trend of big oil that is hedging their bets on biofuels and renewables.

Fossil fuels acknowledgement of biofuels is important because of their unique position to scale the industry; however their approach does not seem fullhearted. Exxon pledging only 10,000 barrels of algal biofuels in respect to their 4 million barrels of natural gas is a 400:1 ratio - and that is only by 2025. Their press releases on the subject and various partnerships will certainly impact the awareness of the industry, but the adoption of biofuels will be measured by its increasing incorporation into our infrastructure. It's hard to justify that Exxon and other oil incumbents are “all-in” on alternative carbon energy without major implementation in their own supply chain.

Incentives

Biofuels are highly incentivized by the government to increase its adoption. One of the major concerns for biofuels lies in its inefficient feedstock production. This stems from its overwhelming use of land, water, and opportunity cost for farmers and landowners. The Department of Energy, well-versed in these critiques, has made large efforts in prioritizing feedstock infrastructure above all other steps in the supply chain. Under the assistance of the Biomass Crop Assistance Program, Qualified farmers can receive reimbursement for 50% of the cost to establish biofuel crops on their land and a $1 for $1 stipend for up to 20 dry tons of feedstock sold to biofuel producers (DOE). Many farmers, who are already producing these cash-crops, can be successful if they can simply find a sufficient demand for their pre-existing harvest. While incentives may change, it is hard to justify a lack government support for biomass feedstock in America is to blame for a slow adoption of biofuels.

End-consumers, like fuel providers and wholesalers, are similarly dependent on demand- not incentives- for success. Fuel providers last year who purchased fueling equipment for fuel blends, containing at a minimum 20% biodiesel, could receive a tax credit worth 30% of the total cost up to $30,000 but that initiative ended in December, 2021. In actuality, the only practical benefits for wholesalers is possible grant money for purchasing, installing, and retro-fitting fueling stations for end-users (DOE). These wholesalers in the process will likely be providing less petroleum fuel as a consequence of supplying biofuel. Right now, biofuels are still more expensive than gasoline, so wholesalers will experience economic pressure to stay in business as they decrease their margins in hopes of selling biofuel.

There seems to be a weakness for end-consumers to purchase and sell biodiesel to distribute biodiesel through the DOE, creating a bottleneck within the supply chain. More specifically, the only incentive provided by the DOE for end-consumers is public projects involving low or zero emission transportation vehicles. This rarely includes biofuel because of the wide adoption of EV's creating a lack of demand regardless of infrastructure. This bottleneck will continue to occur because refineries don't want to absorb the risk for a product that isn't distributed wholesale, and farmers can't sell to refineries for incentives without their demand.

Organizations and Technology

Infrastructure Integration

Biofuels are far from being absent in our current infrastructure, but their main consumers are unaware of their presence unlike other energy generators such as wind, solar, and oil. It's reported by the NCRS that 55 to 60 percent of power used by the pulp and paper industry is self-generated, an industry that is the fourth largest consumer of electricity nationwide. The symbiotic relationship between fuel and pulp & paper is resourceful and promotes the use of exhaustive manufacturing and recycling of byproducts. The industry is chemically-poised to produce the same biomass that powers the creation of its central films and fibers for consumption (Le, 2014). While this may not be the case for non-biomass producers, it shows the integrative potential of biofuels across the global energy infrastructure.

As of now around 150 electric power plants fuel themselves exclusively from biofuel energy and another 365 use a combination of biomass and fossil fuels (NCRS). Notably, 6 major electric utility companies and independent power producers are using biofuels, while others experiment with crop types, fuel mixes, and combustion technologies for their viable use(NCRS). The continual development of large power producers to not only adopt the technology but identify integration potential will lead to more symbiosis between energy and end-use on the scale of the pulp and paper industry.

Incentives

Further down the supply chain, the incentives are a bit less inclusive and appealing but if successful, there is potential for large benefits. The biorefinery assistance program(BAP) provides funding in the form of loans and grants for the development and construction of commercial-scale biorefineries. Under these terms companies can receive loans for up to 80% of project costs up to 250 million. The issue with these terms is that while their upstart cost is low, paying back government loans without strong market adoption means these projects take on a lot of risk. In addition, BAP provides grants that will give a maximum of 50% of project upstart costs, however these grants are exclusive and require heavy preliminary investment that is usually only practical for scaled energy providers with diversified profit streams and solidified proof of concept(DOE). Once the refineries are able to absorb the upstart costs, they can receive tax credits for developing the biofuel infrastructure. This encompasses tax credits on transporting B100 biodiesel fuel, blending with petroleum diesel, and in-house research and development. All of these market opportunities are essential to biofuels, but their success is much more reliant on feedstock supply and end-use demand; it’s hard to justify that large up-start loans and tax credits for large capital investments will be a major factor in biofuel adoption.

Analysis

Evaluating the adoption of biofuel technology within the scope of the sts triangle demonstrates how the impact of the relationships between organizations, society, and technology can influence the successful integration or feasibility of biofuels. The impact of these relationships is not exclusive of one another but they are helpful to note when grasping the trends of the industry. For example, an organization's impact on society has different consequences than their impact on technology, like how an energy company’s efforts to support biofuel technology can be powerful to support the feasibility of the technology but it's their implementation of biofuels into society that integrates biofuel in our energy infrastructure. This analysis will highlight the key factors in implementation and feasibility that impact biofuel adoption.

Implementation

The socio-technical triangle portrays implementation of biofuels with a few major themes: the free market, economic incentives, and social awareness. Collectively, economic and political incentives work together to establish the industry artificially. This artificial boost by organized entities, usually the Department of Energy, is controversial because it is a bi-partisan ideal to protect the capitalist energy market. However, it’s apparent by those same entities that the strength of traditional fossil-fuel incumbents will be tough to beat free of intervention. Those major companies such as Exxon, are slow to implement their biofuel product and only do so at a miniscule amount. Similarly, some of the regions best positioned to produce biomass as a feedstock are slow to implement the energy because of a lack of progressive energy development. As a result, awareness of these trends by society could possibly motivate more approval of biofuel incentives and policy. Implementation of biofuels can be strongly influenced by societal pressure to support the new energy resource through government intervention on the free energy market.

Feasibility

The implementation of biofuels is integral to adoption but the implicit value of energy is its viability in our infrastructure. The implementation of biofuels is mostly dependent on its economic compatibility and convenience. Conservation and environmental responsibility were reiterated many times throughout the evidence found on biofuel adoption because a major conflict within biofuel viability is the excessive use of land. This conflict is a major motivating factor in improving manufacturing technology like MantaBiofuel or feedstock cultivation like algal biodiesel. Seemingly the root of the issue is trying to optimize the benefits of biofuel technology while minimizing the risks of land-use and opportunity cost. Overcoming this risk/benefit tug of war is most successful by incorporating biofuels into compatible industries such as the pulp and paper industry. In conclusion, the feasibility of biofuels economically seems to correspond to uses where it is used exhaustively and created efficiently.

Conclusion

The sociotechnical triangle framework identified the adoption of biofuels as the result of implementation and feasibility. Collectively, organizations, technology, and society work together to determine if the benefits of the industry can outweigh the consequences of its risks. Certain trends in biofuels' economic implications, incentivization, as well as social and environmental responsibility are imperative to understanding the rate of adoption. In synthesis, the relationships and themes laid out in the sociotechnical triangle are enlightening to major decision makers and industry leaders to make an informed impact on biofuel adoption. Moving forward the incorporation of biofuel as an energy source will be a consequence of intentional action within the major themes prevalent in our infrastructure surrounding feasibility and implementation.

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