THE ENVIRONMENTAL AND SOCIO-ECONOMIC CONSEQUENCES OF BIOETHANOL SCALE-UP

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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

Climate change is encroaching upon a threshold from which it may not be able to recover, and it is swiftly moving to the forefront of pressing global challenges. The dependence of society on fossil-fuel based technologies has led to the rapid depletion of the ozone layer and caused massive climate ramifications on a global scale. Reallocation of resources into the development of alternative fuel sources is urgent to mitigate the planet's worsening environmental conditions.

Bioethanol is a promising alternative to conventional fossil-fuel usage due to the lower environmental strain associated with its production and consumption. Under current conditions, bioethanol is not an economically feasible substitute for conventional fossil-fuels; designing economically viable plant schematics is critical to addressing the global climate change crisis. The technical portion of this capstone project aims to examine the process and design of an optimized production facility that converts corn into fuel-grade ethanol in a profitable manner.

The aim of the plant is to transition a raw corn starting material into two primary products: fuel grade anhydrous ethanol and Distillers Dried Grains and Solubles (DDGS). Plant design is centered around a goal of producing 150 million gallons of ethanol annually, with DDGS being sold as a coproduct to minimize waste and help recuperate costs.

The technical report includes in-depth analysis of the functionality and design of all equipment necessary to reach the plant's production goals. The design of every piece of equipment is first discussed and outlined before the final design considerations are established. The final design proposal clearly delineates the movement of the material streams throughout the process and the operating conditions of all equipment.

To analyze the corn in its journey from stalk to barrel, the economics and energy requirements of the plant serve as key indicators of efficiency. Additional factors, including the importance of worker health and safety, local and global environmental considerations, and overall social impact influenced the decision on the viability of the plant design.

Based on the findings of the technical report, it has been recommended that the current plant design not be implemented. Although the process outlined allows for the plant to function and turn an economic profit, it operates at an energy deficit. Considering one of the primary purposes of the plant is to provide net "green" energy to the world, using such massive quantities of non-renewable energy to create the ethanol defeats the purpose. Though the original design aim was to generate profit, the environmental implications complicate the decision-making process. The report establishes that there is validity in converting the stored energy in corn for use in the transportation industry, but a "No-Go" decision has still ultimately been reached. Further design work should be conducted to investigate the potential for lower gravity corn fermentation to minimize external energy input.

This STS discussion will examine the ethical and environmental consequences of the expansion of the bioethanol market. To operate in a feasible capacity, there are important tradeoffs that need to be considered in process design. To produce what can be considered "green" energy, most plants fall into the realm of economic shortcoming. When this is deemed acceptable by the general public and government, the operation can be continued with the help of subsidies and tax relief. In plants where economic success is the motivating factor, energy usage during the production process is significantly raised. The energy requirements of profitable bioethanol production are appreciable, and they detract from the notion that final product can be considered "green" or "clean" energy. Examining the ramifications of these tradeoffs is critical in assessing the viability of the current bioethanol market. By restructuring the way people consider the economic and environmental characteristics of “green” energy, it can be more effectively integrated into society.

Literature Review

It is worth considering the validity of transitioning energy into a usable form. Creating a viable energy source from a renewable and abundant material like corn can help to decrease dependence on the oil and gas markets. The energy that is stored in corn is unlocked through the bioethanol production process and put towards an industry that can significantly benefit from it. The transportation sector accounts for thirty-five% of U.S. energy consumption totaling roughly 24.3 quadrillion Btu in the year 2020 (U.S. Energy Information Association, 2021). It has been stated that bioethanol serves as “the cleanest and most affordable source of octane on the global market today” (Renewable Fuels Association, 2017). This is due to the fact that bioethanol blended gasoline emits 19-48% less greenhouse gas than unblended gasoline (Kumar and Singh, 2019). This cleanliness suggests that ethanol as an additive to the global fuel supply can have massive environmental ramifications on the battle against climate change.

To begin analyzing the environmental toll of bioethanol production, the first consideration comes from the growth of the corn feedstock. Corn growth in the United States is predicated around the implementation of inorganic nitrogen fertilizers, chemical pesticides, and agricultural mechanization alongside complementing technologies (Nielsen, 2012). By centering production around these tenets, overall corn yields have improved significantly over time, but at the expense of environmental safety.

The land that the corn is grown on is the first to suffer from the implementation of advanced corn growing methods. To produce corn on the scale necessary for feasible operation, natural conditions in the plant's location are altered severely. Corn requires a large amount of nitrogen to grow, which is often provided through potentially harmful ammonium nitrate-based fertilizers. There have been documented health consequences for both human and animal populations due to increasing nitrate content in water sources (Hecnar, 1995). Chemical pesticides have been estimated to be reach their targeted organisms with only approximately 0.1% effectiveness (Carriger et al., 2006). This leaves the vast majority of the applied pesticide chemicals to harmfully leach into the surrounding soil, water, or remain on the crop. Committing substantial amounts of land to corn that is grown using these chemicals has the potential to be devastating on local animal populations due to the scale of growth demanded. Furthermore, it potentially endangers the surrounding communities if the chemical impact is not mitigated through proper waste treatment.

Aside from disruptive chemicals being added to the environment to aid in corn production, it is worth considering how the crop itself impacts the land it occupies. It has been shown that groundwater usage and soil erosion occur at significantly higher rates, and overall biodiversity is disrupted due to the reallocation of naturally occurring nutrients (De Oliveira, 2005). The gradual degradation of the land used for such intense corn production is a concern for both the ethanol manufacturer and the farmer alike. Abusing the soil ensures that either costly reparations need to be made to revitalize the growing conditions or lose out on periods of production.

One of the other primary concerns associated with corn growth revolves around crop harvesting. The mechanization of farming via the employment of a vast fleet of tractors and other large-scale equipment has been crucial in the development of the United States agriculture industry. Many of these machines operate primarily through the burning of diesel, which has an elevated level of environmental strain associated with its usage due to high greenhouse gas rates. The agriculture industry is responsible for approximately 1.9% of United States energy usage, totaling around 1.872 trillion Btu in 2016 (United States Department of Agriculture, 2018). The growth of the bioethanol industry will further the energy demand of this sector and lead to increased diesel usage.

For further development of the bioethanol industry, an increasing amount of land will be required to contribute to the domestic and global fuel market. To meet the needs of the entire fleet of U.S. automobiles, it is estimated that all the currently available cropland will be allocated towards corn growth (De Oliveira, 2005). The need for such immense amounts of land and corn spell disaster on existing supply chains. In fact, corn-based bioethanol production already impacts the corn supply chain and leads to higher prices for consumers (Gardebroek, 2013). The creation of an additional American bioethanol plant will further increase the scarcity of corn, and result in even higher prices for domestic consumers.

Creating disruptions in the corn supply chain and raising prices will have a significant impact on the food security of families across the United States. Issues with food security will have a disproportionately more pronounced impact in lower income and ethnic minority communities (Coleman-Jensen, 2014). This is clearly an unintended consequence of bioethanol production that needs to be addressed.

The economics of energy indicate that bioethanol in the United States needs to be subsidized to run a profitable operation. This is a result of several factors including the existing infrastructure and systems that are tailored to fossil-fuel technologies and the soaring prices associated with the bioethanol production. When considering the feasibility of expanding bioethanol subsidies, there needs to be consideration of the volatility of energy markets. It is shown that the implementation of policy, alongside other geo-political factors have a prevalent impact in the volatility of energy prices (Karali and Ramirez, 2014). Furthermore, the volatility of the corn, crude-oil, and plastics markets have direct relations to each other, and policy encouraging corn-based energy can be observed impacting prices in those industries (Jiang, 2015). Stakeholders must be mindful of the impact of policy and regulation on the food, fuel, and adjacent markets to avoid major disruptions both industrially and for domestic consumers.

The shift of subsidization in the existing energy market can help increase the feasibility of renewable energies and bioethanol-based fuels. The restructuring of the energy market can lead to a comprehensive shift away from conventional fossil fuels by the year 2050. It is estimated that total energy subsidies may be capable of decreasing from 0.8% of the United States' GDP in 2017 down to 0.2% in 2050 (Taylor, 2020). Despite the positive impact this may yield in overall infrastructure, it is not without its personal consequences. To promote the usage of ethanol-based fuels, the need for increased taxes on regular gasoline may make it more expensive for the average person to drive their car day-to-day (Vedenov, 2008). As this transition in subsidization occurs, the ever-turbulent nature of the market and its associated externalities will cause trouble for the average person along the way.

Methodology

The design and implementation of the theoretical bioethanol plant was supported by publicly available research dedicated to the global and domestic bioethanol industry. Specific calculations were done using a combination of equations tailored to specific equipment and the manipulation of ASPEN simulating software. Socio-technical analysis was performed through extensive research into the environmental and economic consequences of the bioethanol industry.

Environmental and Social Impact

The global reliance on fossil fuels has been a longstanding issue and requires significant research and development to create cleaner alternatives. Ethanol is the primary biofuel integrated within the United States' energy supply. Given the narrow margin for profitability and energy return on investment, ethanol production facilities must operate under a highly efficient manner to produce a viable biofuel. As the net energy consumption continues to increase, ethanol consumption will mirror the trend. Developing large scale bioethanol facilities will be essential to continue to meet the demand of energy consumption. This can be achieved by integrating economic considerations within process research and development. Developing a process focused on plant economics and energy return on investment will ensure that the plant can operate efficiently while remaining competitive within the market.

In its current state, the design for this particular ethanol production facility is off target in meeting this energy goal. By producing 150,000,000 gallons of ethanol per year, the equivalent energy output of the fuel corresponds to approximately 11,207,000,000 MJ per year. To operate the facility at this manufacturing capacity, calculations for utilities indicate that 21,721,000,000 MJ per year of energy will be required. Attempting to operate the facility at such a significant energy deficit appears to defeat the point of creating "green" energy.

Additional consideration needs to be put towards the energy that is required to harvest and grow the corn, which is not considered within the scope of this project but is part of the focus of the STS discussion. Even without the additional energy requirements from corn growth, the plant does not appear to be viable from the standpoint of an energy balance.

These findings strongly influenced the notion that society needs to restructure its perception of “green” energy. The shift to focus on the economic profitability of the plant, with the goal of benefitting industry and consumer alike, results in the usage of more energy than the process is worth. Allowing the plant to operate at a more energy efficient capacity results in a loss of profitability and requires the addition of subsidization. Enacting policy and pumping government money into this process can have the unintended impact of disrupting adjacent markets and harming consumers.

Optimizing the design of the plant to maximize positive externalities and minimize harmful disruptions then lies in the development of renewable energies. The United States produces about 11.6% of its energy from renewable sources (U.S. Energy Information Association, 2021). This means that most of the utility energy being used by the plant is being sourced from non-renewable sources. Some of the natural gas heating requirements are inevitable and necessitate the usage of non-renewables, but there is still large-scale room for improvement. By bolstering existing infrastructure to incorporate more renewable sources, then the production of bioethanol could be considered ethically “green.”

Conclusion

The burgeoning bioethanol industry in the United States has the potential to have significant environmental benefits associated with its expansion. Since it is a cleaner burning alternative than conventional gasoline, there is a promising outlook to its incorporation into existing infrastructure. The development of a successful bioethanol plant is fickle and contingent upon the economic and energy related support that it has access to. Existing plants do not have the capability of maximizing profits while simultaneously producing a net “green” form of energy. Analyzing the tradeoffs between environmental consciousness and financial success is critical into implementing the most ethical plant possible. Keeping in mind the well-being of the global environment and the domestic consumer alike, the implementation of a successful plant requires a delicate balance and compromise between all stakeholders involved. Through the furthering of the renewable energy market, there is a strong pathway forward into creating ideal bioethanol plants in the future.

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