Prospectus

Producing Biodiesel and Ethanol from Algae
(Technical Topic)

Analysis of the U.S. Federal Government's Role in Corn Ethanol Usage Using Actor Network Theory
(STS Topic)

By

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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

The continued use of fossil fuels is the greatest contributor to greenhouse gases causing climate change, and the use of fossil fuels within the transportation sector is the largest source of carbon dioxide emissions in the United States (U.S. EPA, 2017). Biofuels, currently consisting mostly of corn ethanol and biodiesel from soybean and rapeseed oils, have been proposed as an alternative to fossil fuels due to their compatibility with existing vehicles and transportation infrastructure. There are significant problems with these biofuels, however. Corn ethanol, for example, barely recovers the energy used to create it (Murphy, Hall, & Powers, 2011), and there are questions about the net effects of biofuels on emissions due to land-use changes as well as concerns about their effects on food security (Biello, 2011; DeCicco et al., 2016; Gomiero, 2015). More advanced biofuels from cellulose and algae are in development and seek to solve some of the issues associated with current biofuels, such as competition with food and a patent inability to replace fossil fuels on a large scale (Chisti, 2007). Initial approaches to commercializing algal biofuels have been unsuccessful, largely due to issues with algae cultivation causing an inability to reach the needed price point to compete with fossil fuels (Chisti, 2013; Davis, Aden, & Pienkos, 2011).

Without a large-scale conversion to electric vehicles, there will still exist a need for a suitable fuel to replace fossil fuels in vehicles in order to reduce emissions from transportation. As evidenced, the approach to algal biofuels as merely a technical issue has been inadequate thus far, though technical issues do remain to be solved. Current biofuels did not reach their present prominence through technical superiority to fossil fuels. Rather, their use today reflects a coordinated effort by the U.S. government to increase the use of renewable fuels through the formation of a network incorporating relevant actors (technology, industry, farmers, etc.) using legislation and policymaking. Without a similar effort towards more effective biofuels (such as algal biofuels), there will continue to be a significant struggle to increase their development and adoption.

Failure to reduce emissions, which must involve reducing fossil fuel usage in transportation, is likely to cause warming of up to 2°C by the end of the century (IPCC, 2018), and other estimates have predicted warming greater than 2°C (Raftery, Zimmer, Frierson, Startz, & Liu, 2017). Predicted effects of this are rising sea levels, greater extremes in temperature and weather, higher risk of droughts, loss of biodiversity, and risks to human health, food security, and water supplies, among a host of other negative effects (IPCC, 2018).

Since there remain technical problems to be solved with the development of algal biofuels, and since large-scale adoption of algal biofuels would require significant organizing of relevant actors on the part of the U.S. government, the goal of replacing fossil fuels in transportation with algal biofuels is socio-technical in nature. As such, a solution must address both the technical and social aspects of the problem by designing a refinery capable of delivering lower cost algal biofuels through the simultaneous production of more valuable co-products as well as by reaching a greater understanding of the ways in which biofuel adoption has historically been driven, using the case study of corn ethanol in the United States.

Technical Problem

In the U.S., bioethanol, primarily from corn, and biodiesel, primarily from soybean and rapeseed (canola) oil, are the most common biofuels in use today, with production volumes of 16.1 billion gallons of ethanol (~10% of current motor fuel usage) and 1.83 billion gallons of biodiesel in 2018 (U.S. Energy Information Administration, 2019a). Algal biofuels represent a potentially significant advancement to presently commercialized biofuels. Algae grow quickly, can be rich in oil, and are the only biofuel source technically capable of meeting at least half of U.S. fuel usage due to the immense land requirements of doing so with traditional biofuels (Chisti, 2007). In addition to lower land usage overall, algal biofuels do not compete with food for land – a concern with current biofuels (Ajanovic, 2011) – since they can be grown in a wide variety of conditions and can be easily modified through genetic engineering for different strain characteristics (Gomiero, 2015; Hannon, Gimpel, Tran, Rasala, & Mayfield, 2010).

Several approaches have been developed to commercialize algal biodiesel, but there have been difficulties in algal cultivation that have hindered attempts to do so. In growing algae, open ponds and closed photobioreactors have been used. Open systems are cheaper, but they are difficult to control, vulnerable to contamination, and can have issues with light penetration for photosynthesis (Saad, Dosoky, Zoromba, & Shafik, 2019). Closed systems give higher yields, are controllable, and save water, but they are expensive and difficult to scale up (Saad et al., 2019). The company Solazyme attempted to avoid photosynthetic issues by engineering its algae to produce oil using a sugar substrate, allowing its algae to grow without sunlight in industrial fermenters (Biello, 2013); however, the cost of this approach is dependent on the price of sugar, and the use of sugar conflicts with food production and increases the environmental impact of the process. For photosynthetic algae, limited light penetration can cause low cell density in cultivation, leading to lower production than theoretically possible, though still much higher than from typical agricultural sources (e.g., soybeans) (Dassey & Theegala, 2013; Li, Horsman, Wu, Lan, & Dubois-Calero, 2008). Additionally, low cell densities, combined with the small size of algal cells and the high water content of algal biomass, make harvesting and drying algae costly (Li et al., 2008). While there are other costs associated with the production of biodiesel and other products, these are not unique to algae and are not as great a challenge as scaling up the growth of algae.

Ultimately, the high cost of cultivation and harvesting makes a biodiesel-only approach unfeasible. A recent economic analysis of algal biodiesel production found a selling price of $8.52/gallon was needed for an acceptable rate of return (Davis et al., 2011). Given that the current average petroleum diesel price in the U.S. is $3.05/gallon (U.S. Energy Information Administration, 2019b), algal biodiesel is not economically competitive with fossils fuels on its own. Without a substantial increase in oil prices or a breakthrough in algal cultivation techniques, this will likely continue to be true, despite the necessity of replacing fossil fuels in the face of global climate change and fossil fuel depletion.

The proposed solution to this problem is the design and development of an integrated algal biorefinery which can produce several higher value co-products in addition to biodiesel. In doing so, the aim is to be able to sell algal biofuels at a lower cost than would otherwise be profitable if producing biodiesel alone. While it is possible to produce and sell the higher value products by themselves, combined production with biofuels contributes to the ultimate goal of decreasing fossil fuel consumption.

To accomplish this, the process will be modeled using Aspen Plus and fundamental chemical engineering principles to determine technical feasibility, and economic analyses will be performed on costs and outputs to determine economic feasibility. Data will be found from literature to design most unit operations of the process, including algal growth, algal composition, and kinetics for harvesting, transesterification, and other relevant chemical processes.

STS Problem

The U.S. federal government played and will continue to play a large role in shaping corn ethanol usage in America. In response to concerns about foreign dependence on oil, climate change, and a desire to promote rural communities and economies, the federal government enacted a variety of policies in the early 2000s to promote greater usage of renewable fuels (Schnepf & Yacobucci, 2011). A key legislative measure was the Energy Policy Act of 2005 which established the Renewable Fuel Standard, requiring an initial mandate of 4 billion gallons of renewable fuel in use by 2006, increasing annually, and was expanded through the Energy Independence and Security Act of 2007, which raised the mandate to 36 billion gallons by 2022 (Schnepf & Yacobucci, 2011).

Typically, the rise of corn ethanol is framed as a phenomenon for which the U.S. federal government was largely responsible. While it is certainly true that legislation and policy initiatives provided a significant impetus for the incorporation of ethanol into the fuel supply, this approach fails to consider the other actors involved, such as industry, technology, farmers, and individual policymakers within the U.S. federal government itself as well as within lower levels in state and local governments. If the scope of understanding increases in ethanol usage is limited to the federal government's actions, it will prevent a greater understanding of the ways in which other actors contributed to the success of the government's initiative.

By analyzing the rise to prominence of corn ethanol through the lens of an actor network (Callon, 1987), it will be possible to reach this greater level understanding of the actors (governmental, industrial, technological, etc.) which allowed corn ethanol to succeed. Actor network theory posits that developments of technology rely on collaboration between human and non-human actors in a heterogeneous network formed by a specific network builder, and that all elements within the network have to work towards the goal of the network for it to succeed. I will argue that the U.S. federal government, the network builder, identified a need to replace fossil fuels with renewable alternatives and recruited both human (government, industry, farmers) and non-human (fermentation technology, compatibility with existing gasoline infrastructure, corn) actors into its network. Each actor was assigned a role (industries needed to put ethanol into their fuel products, farmers needed to grow more corn) to perform and the federal government enforced these roles through the use of incentives (e.g., subsidies) and penalties. Actor network theory will additionally allow me to view each actor as a black-box, understanding that each actor individually comprises its own actor network, a phenomenon that may be ignored as long as individual actors within the black-box work in conjunction to comprise a coherent, stable network.

Conclusion

The present study has proposed the design of an integrated algal biorefinery which will avoid the seemingly intractable issue of algae cultivation contributing to the high cost of algal biodiesel by producing higher value co-products which will allow for the sale of algal biofuels at a lower cost than previously possible, allowing better economic competition with fossil fuels. In addition, I will analyze the historical development of corn ethanol in the United States, using Callon’s concept of an actor network, as a network built by the United States government that involves industry, farmers, fermentation technology, and other relevant actors which needed to work in conjunction in order for the renewable fuel initiative to succeed.

By giving a greater understanding of the technical and social factors involved, I hope to provide a clear path forward to large-scale adoption of algal biofuels in service of the goal of replacing the fossil fuels in transportation. Without such an approach, it is doubtful that emissions from transportation will be able to be meaningfully reduced using biofuels, contributing to our current trajectory towards global climate catastrophe.

Word Count: 1843

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