# Prospectus

## An Integrated Design to Algal Biofuels
(Technical Topic)

## The City of West Lafayette: Anaerobic Digestion Wastewater Facility
(STS Topic)

By

Amna Tahir

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Technical Project Team Members: David Vann, Jack Pagan,
Michael Schapowal, Schuyler Dineen

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.

Signed: ______________________________________________

Approved: ______________________________________ Date _______________________
Ben Laugelli, Department of Engineering and Society

Approved: ______________________________________ Date _______________________
Eric Anderson, Department of Chemical Engineering

## Sociotechnical Problem

In a world with 7.7 billion people and growing, the energy needs to sustain the world population is increasing. Currently, coal, oil and other fossil fuels, account for over two thirds of the United States' electricity generation. However, fossil fuels are neither environmentally friendly nor sustainable. In 2017 alone, fossil fuels were the source of about 76% of the United States' greenhouse gas emissions (US Energy Administration, 2019). It is becoming increasingly important to minimize the production of greenhouse gases to prevent adverse effects of global warming, such as a rise in sea level, coral bleaching, and loss of biodiversity ("Effects of Climate Change"). Many international and US organizations have come together to put forth plans and goals of cutting back on greenhouse gas emissions, such as developing an alternative source of fuel that Is both renewable and environmentally friendly.

Biofuel, an alternative fuel, can potentially serve as a substitute for fossil fuels. Biodiesel, a kind of biofuel, is renewable and has been shown to produce 74% less carbon dioxide than other fossil fuels used to power cars (U.S. Energy Information Administration, 2019). For our technical portion of this project, we will design an algae plant that converts microalgae biomass into multiple outputs, namely ethanol and biodiesel. Having multiple output products is projected to increase the productivity and economic efficiency of our plant, making this process financially feasible.

In order to create an effective fuel process, it is important to consider not only the technical but also the social aspects of the system and technology. It is important to understand how technologies have to function within larger networks comprised of various kinds of actors, each of which contributes to a project's success. No technology ever exists in a vacuum and it is important to understand how it interacts with pre-existing actors and how it needs to recruit actors in its network to succeed. Without understanding these interactions, it is possible for a design and technology to fail as networks are inherently vulnerable and rogue actors can go against the plan of the actor builder.

I claim that in order to develop a successful biofuel process, both technical and social aspects must be considered. For the technical portion of this project, my capstone group and I will design an algae plant that converts microalgae biomass into multiple outputs, namely ethanol and biodiesel. For the STS portion of this prospectus, I plan to use Actor Network Theory to study the interactions between multiple actors in the biogas production network that was established by the City of West Lafayette in collaboration with Purdue University, EPA, the local food bank, and various other actors. This will give us a better understanding of how this particular example of a biofuel network was successful.

# Technical Problem

In the United States today, bioethanol, primarily from corn, and biodiesel, primarily from soybean and rapeseed oil, are the most common biofuels in use, accounting for 16.1 billion gallons of ethanol and 1.83 billion gallons of biodiesel in 2018 (U.S. Energy Information Administration, 2019). Biofuels produced from algae are a potential significant advancement to commercialized biofuels. Algae grow quickly, can be rich in oil, and is currently the only biofuel source that can meet more than half of U.S. fuel usage, as traditional biofuels require large amounts of land (Chisti, 2007). Further, 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).

Although several approaches have been developed to commercialize algal biodiesel, difficulties in algal cultivation have hindered attempts to commercialize. Open ponds and closed photobioreactors are commonly used to grow algae. Open systems are cheaper, but 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 are expensive and difficult to scale up (Saad et al., 2019). One company, Solazyme, attempted to get around the issue of light penetration by engineering algae to produce oil using a sugar substrate, allowing the algae to grow without sunlight in industrial fermenters (Biello, 2013). However, this approach is highly dependent on the price of sugar, and the use of sugar conflicts with avoiding competition with food and increases the negative environmental impact of the process. For photosynthetic algae, however, the limits of light penetration can cause low cell density in cultivation, leading to lower production yields

(Dassey & Theegala, 2013; Li, Horsman, Wu, Lan, & Dubois-Calero, 2008). 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 algal biofuels, 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 to algal biofuels simply 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, Aden, & Pienkos, 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 fossil 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 to produce coproducts 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 biofuels alone. While it’s 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.

## STS Problem

The City of West Lafayette currently runs a Wastewater Treatment Plant (WWTP) that utilizes anaerobic digestion, through microorganisms such as algae, to convert food waste into biogas, which is a source of renewable energy, and a solid residual that can be used as soil amendment (“Industrial Uses for Wasted Food”, 2015)**.** In 2009, when the city’s wastewater treatment plant’s solid handling process needed upgrades, it decided to take a proactive approach to going green by incorporating a more diverse range of feedstocks and co-generation, which allowed for conversion of the biogas produced into electricity (Henderson, 2015). The feedstocks that the facility uses includes waste fats, oils, and grease (FOG), food waste from Purdue University’s Dining Courts, vegetable waste from Purdue’s agricultural research, and spoiled produce from a local food bank (Henderson, 2015**).** Using food waste as a feed source for biogas not only reduces the natural gas usage but also reduces the amount of food waste that gets sent to landfills and incinerators, which is another problem that the growing population poses.

One factor that has contributed to the success of this facility has been the cogeneration system that has been put in place by the City of West Lafayette. The electricity produced through this co-generation process supplies approximately 20% of the facility’s operational energy costs, has led to a 40% reduction in natural gas usage, and has saved the city over $100,000 in 2011 alone (“Digester Renovation”). Even though the incorporation of this technique has played a key role in the success of this network, there are multiple other actors, both human and non-human, that played a key role in the success of this network. One of these factors include the partnership with Purdue University. The focus and support from Purdue in terms of both the FOG and food waste they provide, and their research focus on renewable energy, play a significant role in the success of West Lafayette’s wastewater facility.

Another factor that that has contributed to the success of this network are the nature of the feedstock (food waste) and the Environmental Protection Agency's (EPA) push towards reducing food waste. In order to tackle the growing food waste problem, the United States Department of Agriculture (USDA) and EPA have announced their goal to reduce food loss and waste by half by the year of 2030. The EPA has recognized West Lafayette's efforts, featuring them and other Water Resource Recovery Facilities (WRRF) in a report describing available infrastructure for energy recovery from co-digestion of food waste and wastewater treatment facilities (Ely & Rock, 2015). Other factors that could have played a key role in the success of this network include the local foodbank, the specific algae strain that is responsible for the anaerobic digestion, and the fertilizer that is created as a by-product of the process.

If we continue to think that only the cogeneration process was responsible for the success of this WRRF, we won't understand the role other actors played alongside cogeneration in the success of this network. Drawing on the Actor Network Theory (ANT), I argue that Purdue University and the EPA played a key role in the success of this network through their continued support, research, funding, and feedstocks. ANT allows for a better understanding of the technology-society relationship by examining power dynamics in a heterogeneous network, which is comprised of both human and non-human actors. ANT relies on a network builder, in this case the City of West Lafayette, to build the network in order to reach a desired goal, in this case to be more environmentally friendly. Some actors have to be recruited into a network by the network builder, such as the algae, and other actors align themselves to become a part of the network such as Purdue University. Stable networks can also act as actors in other larger networks, which is likely the case for West Lafayette's wastewater facility as a part of EPA's network of WRRFs. I plan to use ANT to examine the relationship and power dynamics between the different actors that have led to the success of West Lafayette's wastewater facility's success.

## Conclusion

For our technical project, we will design an algal biofuel refinery that is more economically feasible, environmentally friendly, and does not compete with food for land as other biofuels do. Further, through my STS research, I will study the interaction of different actors that lead to the success of the Wastewater Treatment Facility in West Lafayette that utilizes anaerobic digestion to produce their own renewable fuel, with the Actor Network Theory. This study as a whole will present a more feasible biofuel plant design, through which we can produce renewable energy to replace fossil fuels and the analysis of the already existing and successful biofuel system will shed light on different actors that must come together to create a successful network for a biofuel facility.

Word Count: 1836

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