# Algae Cultivation for Biofuel:

# Prospects and Challenges

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# Abstract

In today’s world energy has become an important issue, not only for economically advanced countries, but for those developing as well. The increase in energy prices and fossil fuel shortages has led many to seek a new solution towards this energy crisis. Alternative energy is the key answer to this problem, but what kind of alternative energy is most beneficial remains an unknown. There are many forms of alternatives energy from those renewable energy such as wind and solar to energy which are created through the harvest and processing of natural raw materials. Algae are one of those ingredients that are now being looked upon as a possible answer to the creation of biofuels. This research report will analyze the different types of algae based biofuels as well as examine the many methods that turns algae to biofuel through findings based upon economical viability. Although algae are a great source of biofuel, where its use allow for food crop nurture grounds to be free for use, the technology itself still remains expensive, however reliable. For full benefits of algae based biofuel more research must be exerted and different methods should be used based upon the type of algae and the geographical location of the biofuel plants.

# Introduction

Algae is comparable to that of a sleeping giant, virtually unlimited potential when it comes to energy, but all of its potential has not yet been brought out and fully utilized. In today's modern world, algae is cultivated and used mostly to produce and create human nutritional products, only a small amount is placed into the biofuel industry. Research regarding algae and biofuel is still an ongoing business that has yet to be resolved. Many question arises when it comes to algae's potential as a feedstock for biofuel; Is it worth while cultivating? High yields or low yields? Is it economical and sustainable?

Today there are many ways to farm and many ways to harvest crops, with new and more sophisticated technologies being created virtually everyday. However most of the crops grown are still the ones that have been grown for centuries, and thus the benefits are relatively unchanged, although the amount of crops to be produce might have increased with the improved level of technology. Algae could be considered a new type of crop, with multiple new benefits as well as advantages in its cultivation process. Therefore it serves not only as a new energy alternative, but also a reliable economical crop for the agriculture sector as well.

Although more and more technology has been developed to support algae cultivation, to say that algae can be easily cultivated for biofuel synthesis purposes is still not yet a reality. There are some difficulties in the sustaining an abundance amount of algae culture through simpler and less technology oriented methods, such as the open pond method. Mass cultivation of algae on the other hand is prospering and giving extremely positive results. Despite some issues regarding production algae is nonetheless a very viable source of energy with various economical and environmental benefits. When it comes to algae anyone can cultivate them, but not everyone will be successful. However those that are, algae is without a doubt one of the best, and most sustainable, feedstock for biofuel that is available, with high value energy conversion and with waste water treatment benefits.

## Background

Energy consumption has steadily increased since the 1970's. It is reported that global energy use, has risen approximately 70% since the 1970's and will continue to rise dramatically in the future, due to increased economic development throughout the world (International Energy Agency). Energy demand is projected to continue rising at a rate of over 2 percent each year, according to the International Energy Agency or IEA. Enerdata Publications also stated that there was over a 5% increase of world energy use in 2010.

Renewable resources serve as an alternative to potentially more dangerous energy, such as nuclear power plants. Renewable Energy Policy Network for the 21st Century, REN 21, states that renewable energy is energy that comes from nature. Therefore extracting energy from algae and using that energy in the form of biofuel, is a potential renewable energy source that could prove to be beneficial not only to the economy, but the environment as well.

Stefani Newman, a writer for Discovery, elaborates that President Jimmy Carter first mentioned the topic of algae as a potential source for energy in 1978. The topic was brought up due to a dire issue related to oil or gas prices which were continuously increasing, and the government was trying to look for potential methods to alleviate the situation. After extensive testing it is found that high-yielding plants, algae included, could become a viable alternative. “After testing more than 3,000 types of algae, the program concluded that the high-yielding plant, if produced in large enough amounts, could replace fossil fuels for home heating and transportation purposes.” (Newman, S.)

## Research Objective

There are a number of crops that are used in the production of biofuel, namely corn and switchgrass. Algae has some unique qualities that other biofuels are significantly lacking. Algae does not use precious farmland, which is much needed for consumable crops. It also does not need harmful commercial fertilizers in order to sustain an adequate production.

According to the United Nations World Food Program (WFP), as the price of food increases, it becomes more and more difficult to provide food for the poor and malnourished. If algae were to be used as a source for biofuel instead of other biofuel crops, like corn and switchgrass, there would be more farmland available to grow the agricultural crops, so needed throughout the world. This increased production of consumable agricultural crops, could possibly make great strides in alleviating world hunger.

This research will help explain how algae cultivation could be both economical and environmental, and that it is a viable new agricultural crop not only for developed countries, but developing countries alike. If it can be shown, that algae is a prominent and sustainable product for biofuel synthesis, then this research could help promote awareness in this field and further develop the biofuel industry. Furthermore this research is to explain on the possible benefits of converting conventional farming to algae farming.

## Hypothesis and further discussion

As algae and many land crops share common components, such as the structure, which is composed cellulose, its use as a source of biodiesel would most likely be possible. Algae does not take up as much land as other plants, could be cultivated in arid land, and so maybe a more economically stable crop or potential source for biodiesel.

## Expected Outcomes and Landscape

If the outcome of this research would match that of the expected result and hypothesis, formerly mentioned in corresponding sections, then algae would be a viable candidate for biodiesel; with proper usage and implementation of the technology it could be use to add to the declining fossil fuel reserve we currently have and somewhat alleviate problem that relates to fuel shortages and rising gas prices.

## 2.1 Introduction to Biofuel

Conventional fuels that are the products of nature; including gas and petroleum, which are the products of hydrocarbon, are the being used rapidly today. Naturally these conventional fuels do replenish themselves but very slowly, much slower than the rate at which they are being used now.

Biofuels are nonconventional fuels, also referred to as alternative fuels. Biofuels are usually manmade products, which is synthesized and used as a replacement or addition to conventional fuel. Speight (2011) explains, “nonconventional fuels (alternative fuels) are any materials or substances that can be used as fuels, other than conventional fuels” (p. 3). The name biofuel refers to a platitude of different alternative fuels, including biodiesel, biomass, and bioalcohol, which include methanol, ethanol, and ethanol. Biofuel is derived from virtually any organic substance or any kind of biomass. “A biofuel is any fuel that is derived from biomass, i.e. recently living organisms or their metabolic byproducts. Biofuel has also been defined as any fuel with an 80% minimum content (% v/v) of materials derived from living organisms harvested within the ten years preceding its manufacture” (Speight, J.G. 2011, p.169). The ideal source would be one that can be replenished at a fast pace. Plants are the top candidates as they are a good source of carbon, and their growth can be easily maintained and influenced with modern day technology.

Although there are different forms in which biofuels come, the most widely used one would be liquid. Ethanol-derived fuels are among the most used commercial liquid biofuel. According to Hansen, Kyritsis, and Lee (2010) most ethanol are produced from “grain, sugarcane, or sugar beet, and biodiesel produced from a variety of vegetable oils and animal fats” (p. 3).

Although there are many different feedstock for biofuel, this report will focus on algae, and its different forms, as a feedstock alternative for biofuel. As algae is a crop that might hold significant benefits with advantages over conventional land crops. Algae are not grown on land and thus might be an answer for countries where arable land is scarce or for those that have food shortages and need all the available arable land to plant food crops. Algae can also be cultivated quickly some species can grow at a very rapid rate. With today's ever advancing technology algae is becoming a more viable source for the synthesis of biofuel. Further elaboration on algae's competitive edge will be referred to in chapter 2.9. This chapter will continue to explain and explore in detail the types of biofuels that are available today.

### 2.1.1 Biodiesel

Biodiesel is a product usually made of vegetable oil or animal fat. Combining the biomass, in this case the oil, with a base, which is sodium hydroxide, and methanol, produces Biodiesel (Figure 2.1). Biodiesel's structure is very similar to that of conventional diesel, with many shared traits and properties it can be easily mixed with diesel and used, thus allowing a reduction in price, since biodiesel processing is generally cheaper than that of diesel.

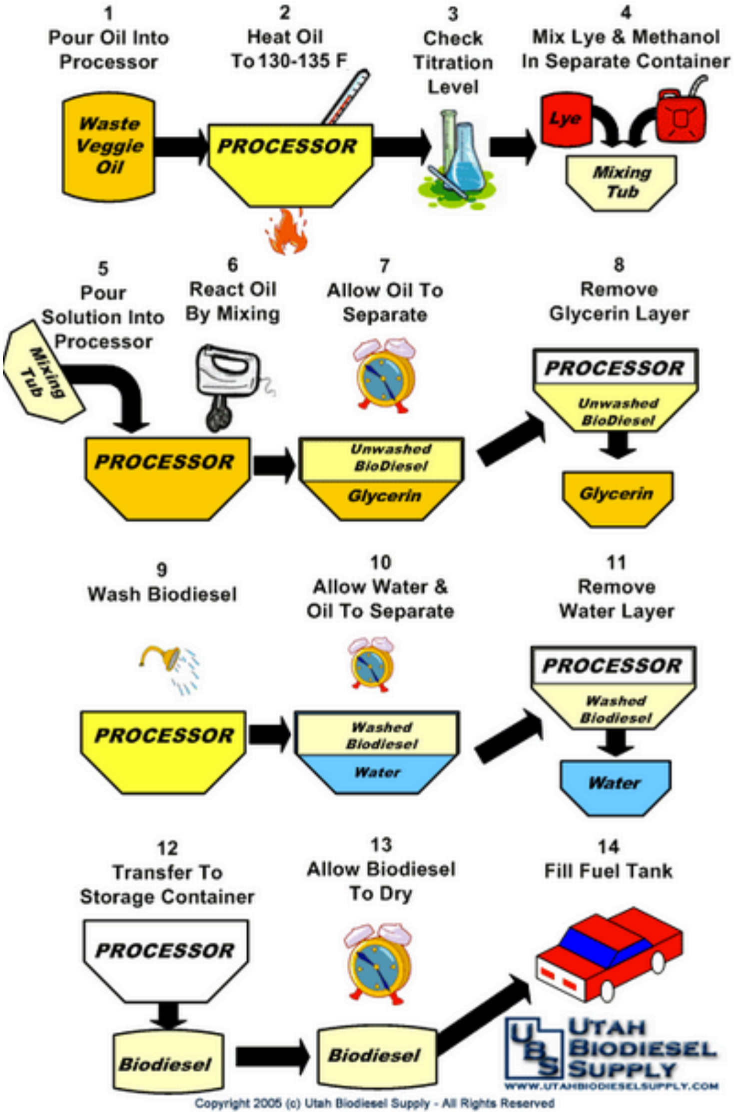


Figure 2.1 Biodiesel Production Process

(Utah Biodiesel Supply, 2005)

### 2.1.2 Bioalcohols

Bioalcohols are the result of a fermentation process. Speight (2011) explains that bioalcohols are “produced from the fermentation of sugars by various enzymes and micro-organisms” (p. 173). Conventional feedstock for bioalcohols are sugar cane, wheat, corn, or any saccharide source that alcohol could be obtained from, this also include some form of algae such as kelp. The bioalcohols that this report will focus on are the two more well known bioalcohols; biobutanol (Figure 2.1) and bioethanols. Ethanol is the most popular among bioalcohol due to some of its distinctive qualities. “Ethanol is the most widely produced, since it is biodegradable and reduces harmful noxious emissions” (Speight, J.G. 2011, p. 173). Ethanol also burns with a high-octane value, and can be synthesized from highly renewable source, i.e. microalgae, making it a cheap alternative compared to petrol. Biobutanol that is the result form the fermentation of acetone has been claimed to be a candidate for the replacement of conventional gasoline. Speight (2011) mentions that biobutanol can help improve vehicle fuel efficiency as well as offer better fuel economy.

### 2.1.3 Bioethers

Bioethers are made from bioalcohols and was first introduced in the 1970’s as an alternative to lead, which is usually a component in conventional fuel. It is claimed tha bioethers or fuel ethers can helpl enhance engine performance as well as reduce the toxic exhaust emissions. According to EFOA (European Fuel Oxygenates Association) the best route for biofuels is bioether as bioether helps improve air quality, reduce carbon dioxide emission, and overall contribute to a better environment. Bioethers characteristics are overall similar to that of the previously mentioned bioalcohols.

### 2.1.4 Biogas

Biogas, as the name implies is gas made from the fermentation of organic matter through anaerobic digestion. Biogas also have different names depending on where it is produced, it maybe known as swamp gas, marsh gas, landfill gas, and digester gas. Algae can also be used to create biogas, referred to as algal biomass, where algae are fermented so that anaerobic reaction occurs and biogas is produced.

Biogas is similar to natural gas, and thus can be used in the same manner granted that the quality of the biogas is high, as most biogas must be cleaned thoroughly before use.

### 2.1.5 Biooil

Biooil is somewhat equivalent to crude oil and is also called biocrude. Biooil is the product of biomass that has undergone pyrolysis and thermochemical conversion. Pyrolysis refers to the process in which an organic material is exposed to extremely elevated temperatures so that change in chemical composition occurs. Biomass is that is general used for the synthesis of biooil include crop residues, waste paper, and other organic wastes. Although algae can be used for the production of biooil there are other materials that may prove to be cheaper and are less time consuming to gain access to. Therefore algae for biooil are not a suitable derivation and should be exempted. Biooil can be processed and converted into fuel, such as biodiesel.

### 2.1.6 Synthesis Gas

Sythesis Gas or syngas (Syngas Biofuels Energy, Inc., 2009) is the result from a process known as gasification. The materials used are organic matters, usually wood, organic waste, biomass, and even fossil fuels such as petroleum can be used. Gasification is the conversion of the aforementioned materials into carbon monoxide, hydrogen, and carbon dioxide by reacting the materials at an elevated temperature (>700 degrees celcius) without combustion.

Syngas is used to produce hydrocarbons or methanol. Furthermore syngas can be used directly in engines instead of fossil fuels.

## 2.2 Biofuel Classification

Biofuel is usually classified according to its method of preparation, which is related to the material composition of the biofuel. Furthermore the classification is distinguished by the starting material in the composition structure of the biofuel, in general there are two classification; first generation and second generation.

### 2.2.1 First Generation

The first generation of biofuel refers to those that are synthesized or created directly from biomass. This can be explained further that the biomass used is usually directly a part of a food chain, for example first generation biofuels can be made from different types of starch and sugars. First generation biofuels after purification and cleaning can be used for various equipment as well as vehicles.

### 2.2.2 Second Generation

Contrary to first generation biofuel, second generation biofuels are usually created from materials, or rather biomass, that is not ordinarily part of the food chain. Therefore examples materials that go into the production of second generation biofuel would include urban wastes, and waste from agriculture, or lists of biomass from the landfills. The benefits from second generation biofuel is that, it does not threaten food supplies, as well as biodiversity of the community in which it is being produced. The main material component in second generation biofuel is cellulose and thus they are also known as cellulosic fuel. Cellulose for the second generation could come in abundance from residual forest biomass.

Studies in second generation biofuel is increasing as when compared to first generation biofuel it is considered to be more environmentally friendly as well as being more sustainable. First generation biofuel can sometimes produce a large amount of carbon dioxide and thus does not contribute to a state of better environmental protection compared to that of the second generation.

## 2.3 Biofuel Production

There are multitudes of different unique method one can use for the synthesis of biofuel. From simple biofuel creation by mixing lipids and alcohol to the more sophisticated production using biorefinieries. As this report will deal with the importance of algae in the fields of biofuel; this report will only cover methods that are applicable to microalgae, which comes to a total of five different possible methods – further elaborated in chapter 2.6.

### 2.3.1 Biomass Feedstock

Apart from the different types of algae that is available as feedstock for the synthesis of biofuel there are many other options that are available for biomass as well. Biomass energy sources are wood and wood wastes, municipal solid waste, agricultural waste, food waste, animal waste, and aquatics plants and algae.

When it comes to feedstock for biofuel, its sufficiency as biomass energy depends on various sectors. Speight lists different issues: chemical composition o the biomass, cultivation practices, availability of land and land-use practices, use of resources, energy balance, emission of greenhouse gases, acidifying gases and ozone depletion gases, absorption of minerals to water and soil, injection of pesticides, soil erosion, contribution to biodiversity and landscape value losses, farm-gate price of the biomass, logistics cost (transportation and storage of the biomass), direct economic value of the feedstock taking into account the coproducts, creation or maintenance of employment, and water requirements and water availability.

## 2.4 Role and Benefits of Algae in Biofuel Production

Seaweeds and microalgae are important not only in the biofuel industry and its history extends long into the history of cultivation. They are a commercial product and thus are subject of interest to many different group of individuals, whether scientist or merchants. The topic of algae as a source of energy came into views in the 1970s. As the price of energy rises, alternative fuels become more and more important, and even within those list of possible materials, there are those that are more sustainable, some that are economically beneficially, but perhaps algae holds the answer to both side of the spectrum as it can be both extremely economical and at the same time sustainable.

Algae have many benefits over other land-based fuel crops, or feedstock also referred to as high plants, when it comes to biofuel production. The first and foremost is their ability to grow in water; this allows the avoidance of water related problems and nutrients limitation. Another most coveted advantage is that algae can be cultivated at a rate that is considered close to maximal productivity. Algae does not have unproductive parts, whether it be roots or stems, thus allowing for more growth in limited space, as well as maximum conversion rate from their raw form to energy.

The second and one of the biggest advantages of algae is that, they can be grown virtually anywhere. Algae do not require arable land and can be grown horizontally in ponds with virtually any kind of water; brackish water, saltwater, or freshwater. Algae can also be grown vertically, as recently companies develop what is called a bioreactor system (Figure 2.2), and algae are suspended in a clear container and exposed to sunlight on both sides, while water and carbon dioxide is pumped through the system. This ease in cultivation would allow for algae to be grown in countries or areas with limited arable land as well as for those with problems regarding food shortages. As algae require less space, the arable land that is available could then be used for food crop cultivation.

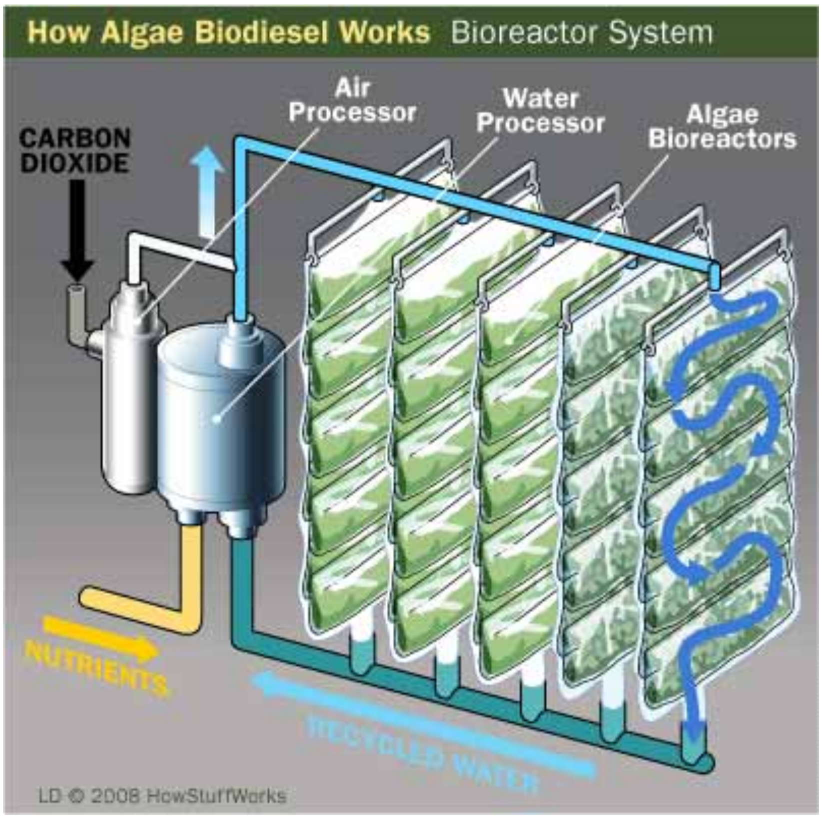


Figure 2.2 Bioreactor System

(howstuffworks.com, 2008)

### 2.4.1 Usage of biodiesel

Biodiesel use is increasing gradually every year, with Europe and the Americas being pioneers in this field. Indifferent from the conventional diesel fuel, biodiesel can be used in virtually all standard diesel engines, for vehicles and machines. Although biodiesel can be used independently on its own in the aforementioned biodiesel engines, it is usually blended before use. Blended biodiesel refers to the process in which biodiesel and regular, conventional, diesel is blended together to create a new blend of fuel.

Biodiesel blends have different names depending on the percentage of biodiesel that is in the formula. Different blends are distinguished by name with emphasis on the B factor. For example a blend with 20 percent biodiesel would have a B factor of 20 and thus would be referred to as B20, and one with five percent biodiesel would then be called B5. A pure biodiesel formula would then be referred to as B100. Although biodiesel can be used independently there are possible side effects that one need to put into consideration. A diesel engine could encounter problems with clogs and such with biodiesel that contain impurities, therefore a good way to avoid possible problem would be to use biodiesel blends. The most common biodiesel blend used is B20 as this is the highest blend that a standard diesel engine could use without any side effects.

### 2.4.2 B100

As formerly mentioned pure biodiesel or B100 can be used on its own in its pure form it is usually blended. There are mainly five ways in which one goes about creating blends from B100.

Mixing in the fuel tank at the manufacturing point is a straight forward way, but not overly popular due to the fact that different customers have different B factor preferences and that might not the most beneficially way to go about business if all the biodiesel is mixed with only one constant B factor.

Splash-mixing in tanker truck and in-line mixing are similar techniques used by all sides of the parties. Some manufacturers mix biodiesel with conventional diesel in tanker trucks upon request or send both ingredients to the tanker truck at the same time to mix the two diesels to create a new blend, which is called in-line mixing.

The last and arguably most popular way to go about creating a biodiesel blend is metered pump mixing. This process happens when biodiesel and diesel are kept separately but can be mixed at will by the purchasing customer. Gasoline stations also utilize this technique where a customer would choose the X value or B factor for the blend, upon the input variables the two fuels would be mixed in a holding tank of sorts before being pumped into the customer's vehicle.

## 2.5 Types of Algae

There are two types of algae microalgae and macroalgae. Macroalgae, as the name suggest are the larger of the two types and would include species of seaweeds and aquatic plants. Microalgae, also known as microphyte, refer to algae that are the unicellular species. Microalgae size can range from a few micrometers to a few hundred micrometers. Microalgae do not have roots or stems and can be found in almost any type of water body. There is a wide range of algae species, approximated at 200,000 to 800,000 species, but only about 50,000 are explored and explained. Algae is a growing commodity, and its research and development would only continue to grow as more and more benefits from algae cultivation is revealed.

## 2.6 Microalgae Derived Biofuel

Microalgae can be considered as a type of biomass, and thus could be used to synthesize different types of biofuel. Although not suitable for every type of biofuel production, they are nonetheless extremely versatile and could be used for variety of purposes.

### 2.6.1 Microalgae Combustion

Firstly, combustion and thermochemical conversions, a versatile method, which could be used to create multiple different types of biofuel, but is not a popular method due to its high costs. Vertès, Qureshi, Blaschek, and Yukawa (2012, p.167) explains, "most simply, harvested algal biomass (typically 80-95% moisture content) could be dried and combusted to generate electricity (Matsumoto et al., 1995; Kadam, 2002). However, this approach is the least attraction option, sine drying is expensive. Even solar drying is not without cost, while combustion, like other high-temperature thermal processes, destroys the nitrogen fertilizer content of the biomass and generates elevated emissions of NO." This particular method coverts algae to biofuel through gasification or pyrolysis.

### 2.6.2 Methane Production

Methane production by anaerobic digestion is the second method. This second method refers to the process of anaerobic digestion, which could be explained as the microbial conversion of organic matter to biogas. This is not a particularly effective method and generally results in low yields. “ This low yield is due to several factors, including the recalcitrance of some algal species to biodegradation, and the inhibition of the microbiological conversion process by ammonia released from the biomass. (Vertès, Qureshi, Blaschek, and Yukawa 2012, p.168)”

### 2.6.3 Ethanol Production

Third, ethanol and other solvent fermentation, generally consist of two different ways in which ethanol can be created. Microalgae can be converted into ethanol through yeast fermentation. Yeast fermentation is possible due to carbohydrate in the product or feedstock that is being used, examples include starch in green algae, and glycogen in cyanobacteria. Currently there is development in the fields of yeast fermentation, but it still remains somewhat unattractive due to the fact that there is a low yield rate.

### 2.6.4 Hydrogen Production

The fourth method is biofuel from microalgae through hydrogen production, which could be divided into three different principles; dark fermentation, light-driven fermentation, and biophotolysis.

### 2.6.5 Oil Production

Biofuel through oil production is the fifth method. This is one of the most effective methods and one that is particularly useful when it comes to algae and biodiesel. Many different species of microalgae can accumulate large amounts of lipids, especially that of tricylglycerols, a main ingredient for the production of vegetable oil. The oil extracted through different various method, oil press being a more common method (Figure 2.3). The oil produced can then be used to create fuel, which is generally used in the transport sector, usually as a fuel supplement or replacement for vehicles used in transportation.

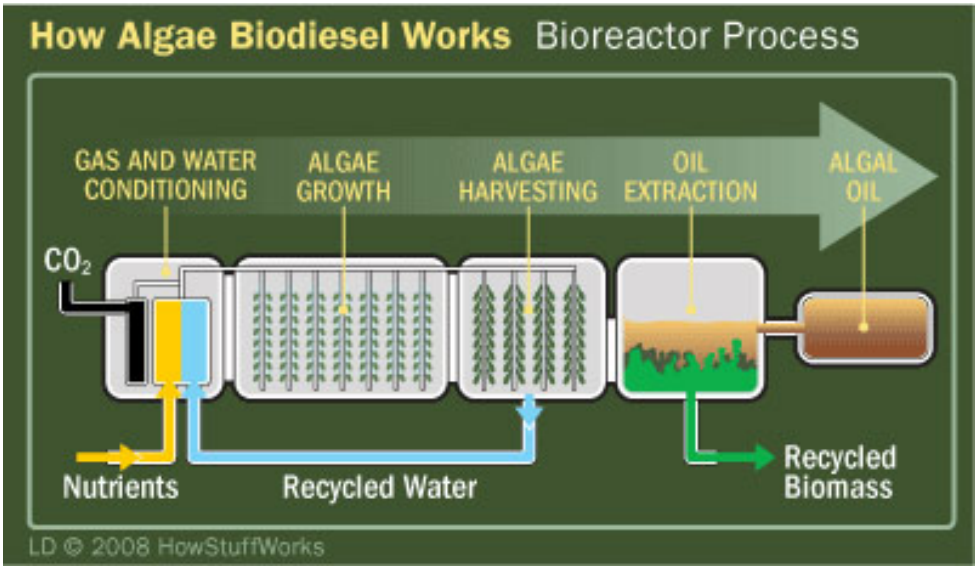


Figure 2.3 Algae Oil

(howstuffworks.com, 2008)

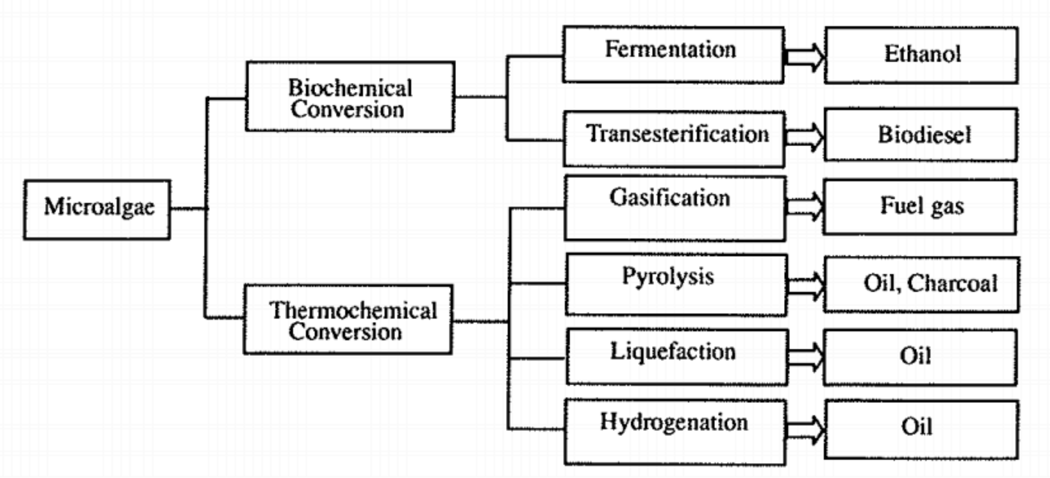


Figure 2.4 Microalgae conversion and products

(EMCC, 2013)

## 2.8 Microalgae Culture and Limitation

Not until recently that, algae cultivation became a viable option. Fifteen years ago algae cultivation and production was possible, but not at all profitable. “At that time, it was already evident that the original concept viewing microalgae as a future agricultural commodity for solving world nutrition needs has no basis in reality. Photosynthetic efficiency in string sunlight falls short of the theoretical potential resulting in low yields which are the major culprits for the forbiddingly high production cost of algal cell mass. Economically, therefore, outdoor cultivation of photoautotrophic cell mass is inferior to conventional production of commodities such as grains or soy beans. At this stage of our experience with mass production of photoautotroph microalgae, it is indeed evident that certain very ambitious roles that have been suggested for large-scale microalgae culture – e.g. reduction of global carbon dioxide using large areas of unlined, minimally mixed open raceways – are unrealistic, being based on unfounded assumption concerning, in particular, maintenance costs and the expected long-term productivity. (Richmond, A. 2004, p.xiii)”

## 2.9 Algae cultivation and Integration in modern farming

There are many new and emerging industries in today’s fast paced developing world. There are many new goods being produced and manufactured, and many new ways to produce and manufacture both the old and the new. Algae is not a newly discovered plant, but it is a possible new business crop. There are many possible ways in which one could explore cultivation of algae. One of the most important and influential advantages of algae is that is could be vitally integrated into any type of existing industries or farm and could allow the producer to gain economical benefits from it.

Apart from algae in the transportation sector and biofuel sector, algae can be seen in the many biorefineries rich sectors as well. Algae could be used to produce several alternative products due to its unique composition and changes in chemical structure dependent on the way it is raised. Algae could be used to create antiviral and antibody production in the medical sector, glycerin for the chemical sector, and multiple benefits for its integration into the food and agriculture sector (Figure 2.5).

Algae could also be integrated into conventional feedstock as it requires virtually the same conversion process. It can be grown separately but could be processed together with conventional feedstock making it a viable alternative or as an experimenter crop for farmers looking for alternatives to their current crops, but are unsure of change (Figure 2.6).

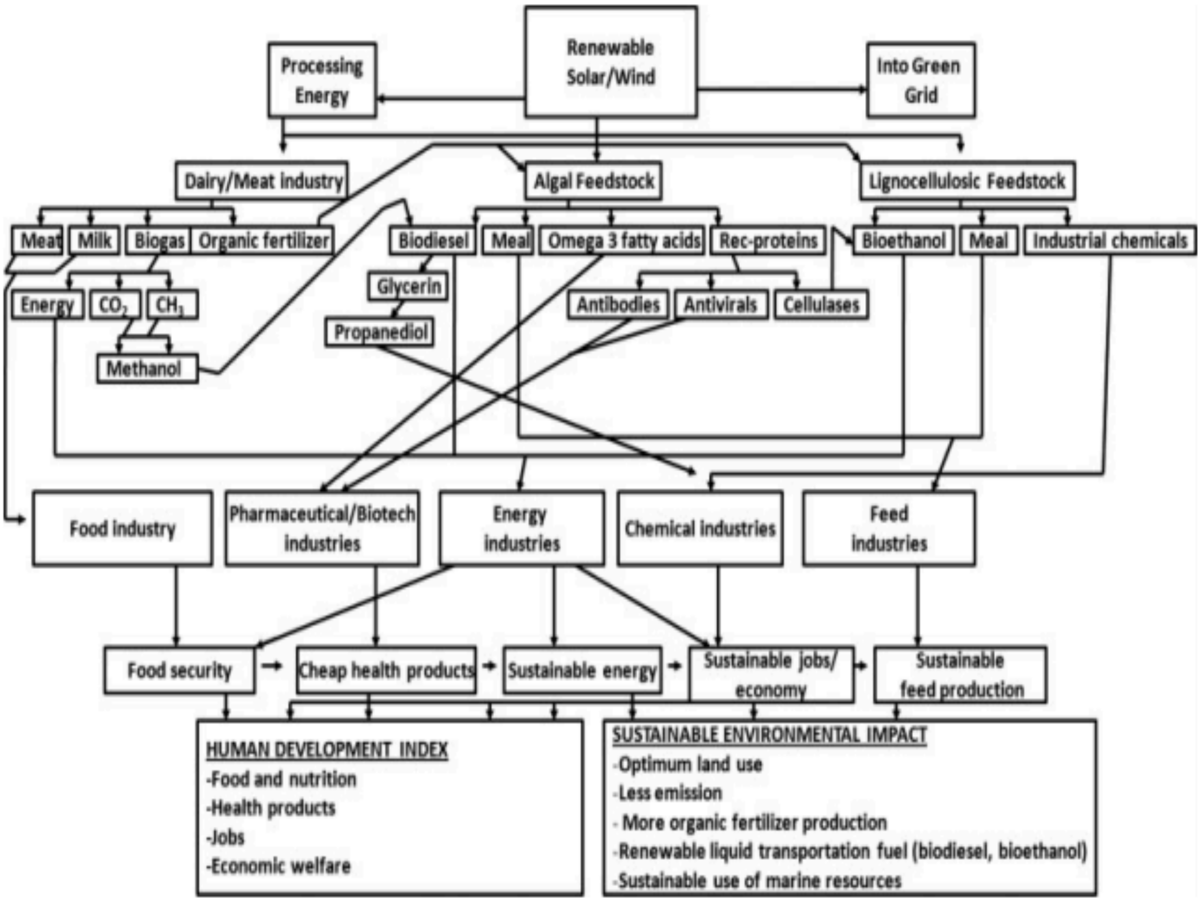


Figure 2.5 Converting and integrating alternative energy into algae production and energy conversion

(EMCC, 2013)

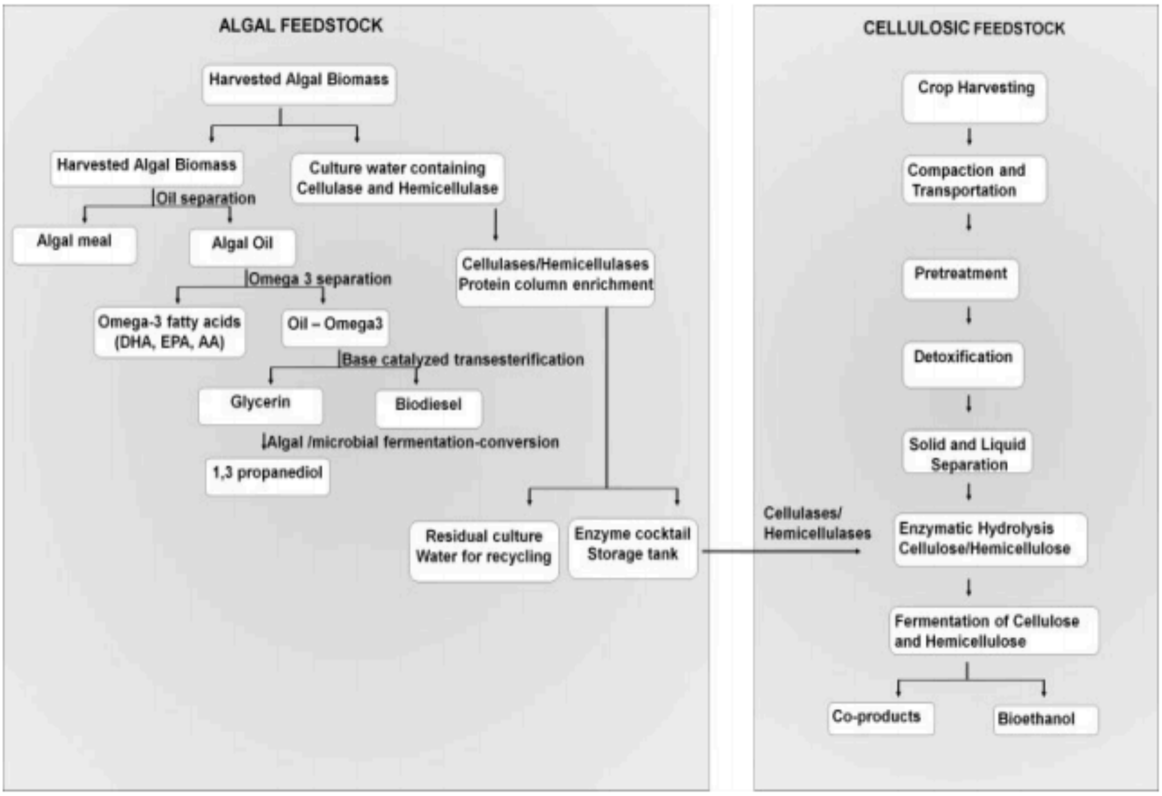


Figure 2.6 Algal Feedstock and Cellulosic Feedstock

(EMCC, 2013)

### 2.9.1 Algal biofuel and Aqua Culture

Algae is grown in body of water, and thus goes hand in hand with the concept of aquaculture. It could be integrated into Shrimp farms to provide multiple possible benefits.

Renewable energies from the solar and wind could provide energy processing power in the cultivation and production of algal feedstock, as well as production and processing energy. The algal feedstock or the algae itself could be used for several different industries or for use in different business. First the possible products of algal feedstock is omega 3 fatty acids, meal, rec-protein, and biodiesel. The algal meal and omega 3 fatty acids could be used as shrimp feed for aqua culture sector. With the shrimp feed provided by algae production, shrimp farming is enabled which would create another chain of product. The rec-proteins from algae would then be used to create antibodies or antiviral for the pharmaceutical companies, but it also could be used as antivirals for shrimp farms as well. Lastly the biodiesel could be used for the production of glycerin for the chemical industry or used as a fuel for the energy industry.

Further benefit of this is, beneficial wastewater management. There would be waste and wastewater from shrimp production, including shell waste, and the most problematic organic rich effluent water. The water from shrimp ponds are usually very rich in nutrient, and thus all the nutrients could not be absorbed or processed in time resulting in contaminated or polluted water. But this could be treated with algae, since algae could be grown in virtually any water condition it is to an extent possible to use wastewater from shrimp farms.

Possible integration is to set up a rotating farming style. After shrimp production is complete, wastewater in the shrimp ponds should be lightly treated, using aeration processes or simple filtration systems. Then algae could be cultivated in those pool of water with no need of fertilizers, the algae would then consume most of the excess nutrients allowing for the water to then be later reused for further shrimp farming.

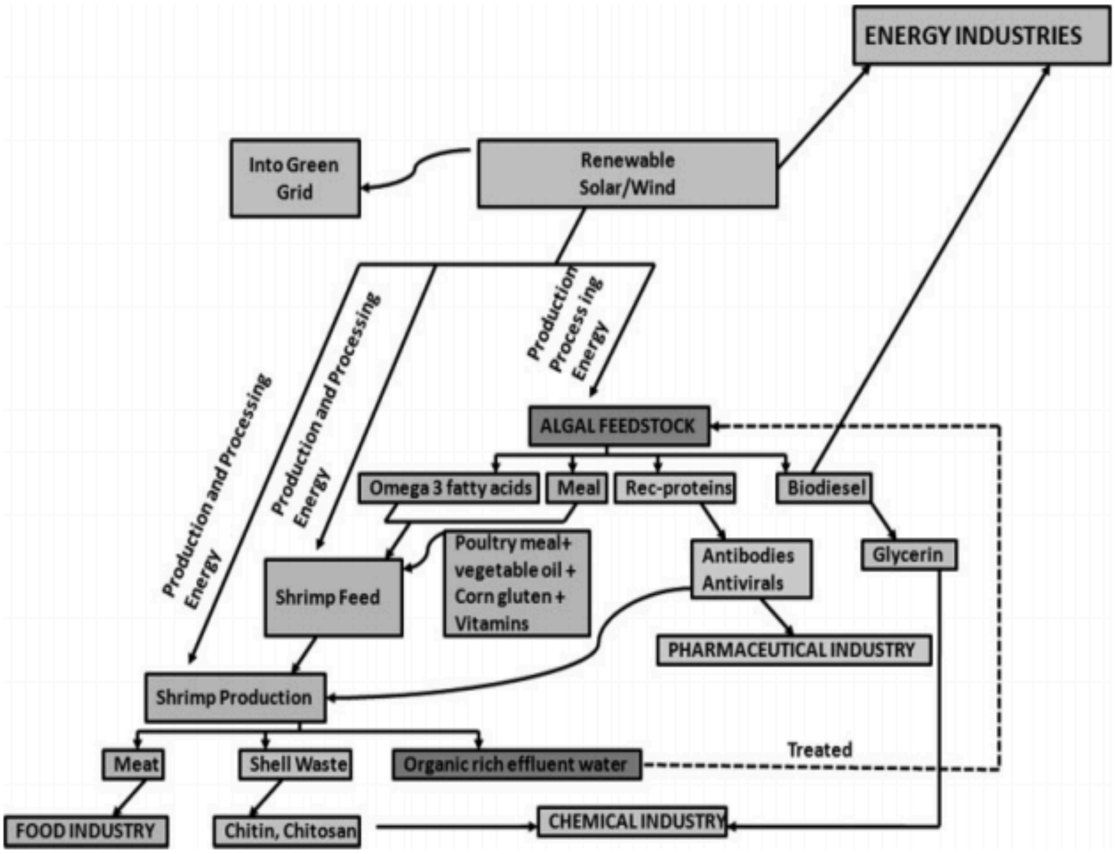


Figure 2.7 Aqua Culture and Algae Cultivation Intergration

(EMCC, 2013)

## Cost Analysis

The National Alliance for Advanced Biofuels and Bioproducts or NAABB is one of the world leaders in alternative energy production, specializing in biofuels, with many technologies for the production of algae biomass. NAABB uses the Monte Carlo simulation model for aid in the financial and feasibility analysis in terms of how economical the production of algae biofuel is. NAABB developed a model, which is referred to as FARM, or the Farm-level Algae Risk Model. FARM is specifically used in projects for the sole purpose of economic viability analysis.

### 3.1.1 FARM Model

The FARM model is used in a way in which it creates a model of an algae energy business, which is recursive over a period of 10 years. The FARM model is used to analyze a single project well over 500 times, each time implementing different sets of data value; such as inflation rate, and production value.

This specific model can be used when all data from certain algae projects are placed into an input worksheet, while the calculations would then appear in a model worksheet. “FARM requires that all input for an algae farm be entered in the INPUT worksheet and most all calculations are in the MODEL worksheet. The model is simulated by drawing annual stochastic prices, production, and costs randomly from known probability distributions. The parameters for the distributions are provided as input by the researcher. Analysts must enter all of the data to describe the scenario to simulate for a farm. This includes data for the type of cultivation, harvesting, extraction, and use of co-products.” (NAABB, 2013)

The FARM model also requires input in regards to the harvesting and extracting systems that is in a project. Furthermore the model also allows for the placement of financial statuses, such as interest, dividends, and debt.

Through the information provided the model would then analyze the annual production of the methane extract, and lipid extract, as well as possible byproducts. These figures would then be applied onto the income statement. After the income statement the model is then used to calculate all costs, which would be based upon information that was formerly placed in the INPUT section, some of the costs would include; water loss, evaporation, recycled water, etc. As for operating costs, could be analyzed through two main methods; “The analyst can provide operating costs in two ways: an annual sum for the operating cost category or by providing ratios of consumption or use per short ton of algae produced or processed. If an annual value is entered for an operating cost category it is inflated over the farm's 10 year span and then summarized in the Expenses section of the Income Statement. If a ratio is instead entered the cost is calculated in the model as well. For example, if one pound of CO2 is required for each pound of biomass produced then the total pounds of CO2 required for the farm will be calculated based on that year's stochastic biomass production. Once the total amount of material is calculated it is multiplied by that year's inflated price for the input to determine the annual expense to the farm for the operating cost category. The operating cost categories include, but are not limited to, CO2, media, water, harvesting and extraction chemicals and catalysts, and natural gas. The costs from each of the operating expense categories also flow to the Income Statement and are used to calculate the operating loan interest costs as well as the annual net cash income." (NAABB, 2013)

### 3.1.2 Scenarios

There will be four scenarios that is selected from NAABB to highlight and explain how research results for financial purposes could be achieved and what kind of outcomes are possible. Different scenarios represent different combination of technology as well as different techniques in cultivation and harvesting. Table 3.1 represents the different possible accumulation of unique input factors including but not limited to, harvesting, extraction, and cultivation. Scenario 1 will be based upon the early stages of NAABB, with influences from reduced algae production rates as well as the usage of conventional cultivation methods. Scenario 2 will cover aspects involving electrocoagulation or EC, instead of centrifuges. Comparison of Scenario 1 and 3 is to determine the possibility of economical gains of HTL-CHG. Scenario 4 will then allow for the investigation of economic contributions from ARID cultivation system.

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Products | Algae Crude Oil & LEA | Algae Crude Oil & LEA | Algae Crude Oil & Methane | Algae Crude Oil & Methane |
| Cultivation | Open Pond | Open Pond | Open Pond | ARID |
| Biology | Generic | Generic | Generic | Generic |
| Harvesting | Centrifuge | EC | Centrifuge | EC |
| Extraction | Wet Solvent Extraction | Wet Solvent Extraction | HTL-CHG | HTL-CHG |
| Nutrient Recycling | No | No | Yes | Yes |
| Biomass Production (tons/a) | 119,883 | 119,883 | 119,883 | 152,215 |
| Crude Oil Production (Gallons/a) | 4,679,762 | 5,095,741 | 13,505,602 | 20,332,113 |
| Location | Pecos, TX | Pecos, TX | Pecos, TX | Tucson, AZ |

Table 3.1 Summary of the Technologies Analyzed for the Alternative Scenarios (NAABB, 2013)

Each Scenario in Table 1 is based upon figures from NAABB and was programmed with FARM model. Information with regards to algae farms are extracted from CAPEX and OPEX cost information, which was provided by Davis, et al. (2012) DOE harmonization report, which is the standard for comparison. As for Scenario 4, the ARID system, which is different from open ponds in other scenarios, the information is provided by the University of Arizona.

### 3.1.3 Electrocoagulation

According to NAABB, electrocoagulation is a harvesting process, dependent on metal ions. "Electrocoagulation harvesting utilizes metal ions, which are released during electrolysis between two metal plates submerged in the media. A number of metals can be used including aluminum and stainless steel. Aluminum plates release aluminum ions with a +3 charge, while stainless steel electrodes release iron ions with a +2 charge. The positively charged metal ions attract the negatively charged algae and create a floc. The floc then settles to the bottom of the media and is separated by decanting the clear media from the top, which can be recycled to the cultivation process. The algae are concentrated from approximately 1 g/L in cultivation to around 8% solids (80 g/L) in the sediment." (NAABB, 2013) Furthermore it is elaborated by NAABB that the capacity of the electrocoagulation unit is dependent upon the material used to create the electrodes, the size of the reactor chamber, as well as the size of the plates. In the scenarios, steel electrodes were used as an evaluation.

### 3.1.4 HTL-CHG

HTL-CHG is a process, when a biomass, from algae, is changed into oil and methane or electricity. According to NAABB the output streams for this particular process would include phosphate, carbon dioxide, water, and nutrients that is recycled back to algae ponds. Harvested algae are placed into a pond and made into slurry, which would then be heated and pressurized. The products from such a process would include oil, effluent water and solid phosphate. The phosphate can recycled and is usually reused in the ponds for further algae production. Once water and oil are separated. Effluent water is sent for further processing, through CHG, once heated and precipitated the product which is left is phosphorus. NAABB further elaborates that; "Once the effluent water reaches the CHG process it is again made into a slurry that is heated and pressurized to produce a liquid and precipitate, phosphorus, that can be processed and recycled. The liquid is then combined with a catalyst in the gasifier to produce CH4 and CO2. This CH4 can be sold or turned into electricity, heat or CNG. The CO2 can be recycled to the ponds and the remaining gas/water mixture can be further separated to obtain the CO2 from the water and nutrients mixture, all of which can then be recycled to the ponds. (NAABB, 2013)"

### 3.1.5 ARID

As explained by NAABB, the ARID system is a cultivation system designed for advance temperature control, in order to fully optimize algae production rate. This particular system is to be used in conjunction with a deep canal like structure, which then would flow through shallow channels. The temperature can be controlled and changed through water surface manipulation. For example water is removed from certain areas in the day to avoid the water surface from heating. The ARID system help reduce energy consumption through water control, only moving water when needed, such as during management and harvesting. NAABB explains that; "a significant advantage to ARID is its reduced CAPEX relative to conventional open ponds" (NAABB, 2013).

### 3.1.6 Scenario 1

This scenario utilized the open pond cultivation system, which produces crude algal oil and LEA. In this particular project, there is a requirement of 2,231 centrifuges that is designed and placed for harvesting along with one wet solvent extraction system. According to NAABB; "The centrifuges have a throughput capacity of 113,560 liters/hour and produce an output that is 10% solids. There is no chemical cost associated with the centrifuge harvesting process. The centrifuges only require electricity. Each centrifuge costs $275,000, resulting in a total CAPEX of $613,525,000 for harvesting equipment. The extraction system can process 394,314 liters of 10% algae solution per hour. Only one extraction system is needed with a total extraction CAPEX of $23,566,667. Makeup solvent is required after each harvest, resulting in an annual cost for extraction chemicals. In the fifth year of operation the extraction chemical cost is $14,091,358" (NAABB, 2013).

### 3.1.7 Scenario 2

In this scenario, the open pond system is in place which produces both the algal and LEA, similar to scenario 1. However electrocoagulation is used for harvesting, with a wet solvent system for extraction. "The EC units have a throughput capacity of 408,780 liters per hour so 620 EC units are required for harvesting. The capital cost for the EC units is $1,000,000 for the first unit and $650,000 for each additional unit. This results in a total CAPEX of $403,350,000 for the EC units. The output of the EC is 8% solids. The EC units require stainless steel plates which degrade over time and must be replaced, resulting in an annual replacement cost. In year five of operation the plate replacement cost is $19,517,998. Similar to the first scenario, only one wet solvent extraction system with a throughput capacity of

394,314 liters per hour is required at a cost of $23,566,667. The makeup solvent cost in year five for this farm is $14,091,358” (NAABB, 2013).

### 3.1.8 Scenario 3

For scenario 3, the products, including crude algal oil and methane, are produced through a ‘lined open pond cultivating system’, according to NAABB. With a throughput capacity of 113,560 liters per hour, 2,231 centrifuge units are used for harvesting. The capital cost per centrifuge is $275,000, resulting in a total CAPEX for harvesting of $613,525,000. Algal oil is obtained from extraction when HTL-CHG is used. However, no LEA is produced as the co-product is methane. The HTL-CHG units have a throughput capacity of 39,583 liters per hour so more units are required as compared to the wet solvent extraction system. The capital cost of each unit is $10,203,472. Since the output from the centrifuge is 10% solids only 7 HTL-CHG units are required, resulting in a total CAPEX of $71,424,304. There is a one-time startup cost for catalyst associated with the HTL-CHG units. The total extraction catalyst startup cost is $34,775,342” (NAABB, 2013)

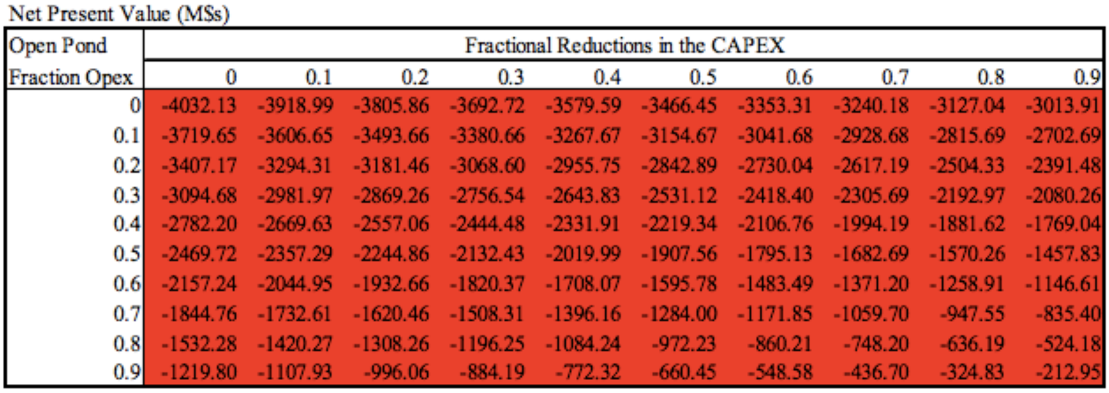
### 3.1.9 Scenario 4

For the last scenario the project is located in Tucson, AZ, and uses the ARID cultivation system. NAABB explains that BAT generated probability distributions of biomass production in Tucson, Arizona were adapted to

actual biomass production records for ARID. At any point during the year when BAT open pond production is greater than ARID, the farm is operated as an open pond facility. The Scenario 5 farm produces crude algal oil and methane and uses EC for harvesting and HTL-CHG for extraction. Due to the reduced water use in the ARID system, less fluid has to be processed by the harvesting and extraction units. Thus, only 185 EC units with a throughput capacity of 408,780 liters per hour are required as opposed to the other scenarios which needed 620. Total CAPEX cost for harvesting is reduced to $120,600,000, which is significantly lower compared to all other scenarios. The stainless steel plate replacement cost for EC is reduced to $5,827,468. Additionally, only three HTL-CHG units are required for extraction resulting in a total CAPEX of $30,610,416. The startup catalyst cost is also reduced to $14,903,718 since only three units are required" (NAABB, 2013).

### 3.2.0 Scenario 1 Results

For Scenario 1, in order to gain a positive value, both CAPEX and OPEX must be reduced by 90% or more, if otherwise the result will be loss of initial investment within the period of 10 years.

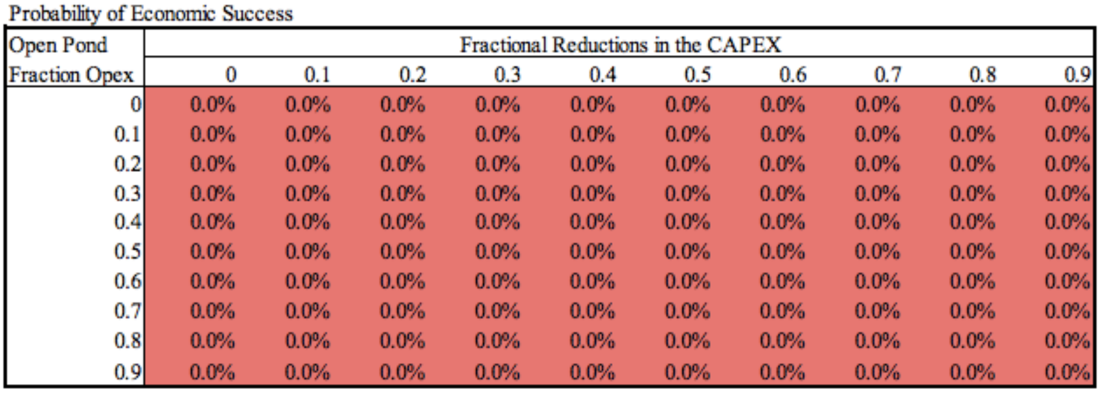


Net Present Value (MSs)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -4032.13 | -3918.99 | -3805.86 | -3692.72 | -3579.59 | -3466.45 | -3353.31 | -3240.18 | -3127.04 | -3013.91 |
| 0.1 | -3719.65 | -3606.65 | -3493.66 | -3380.66 | -3267.67 | -3154.67 | -3041.68 | -2928.68 | -2815.69 | -2702.69 |
| 0.2 | -3407.17 | -3294.31 | -3181.46 | -3068.60 | -2955.75 | -2842.89 | -2730.04 | -2617.19 | -2504.33 | -2391.48 |
| 0.3 | -3094.68 | -2981.97 | -2869.26 | -2756.54 | -2643.83 | -2531.12 | -2418.40 | -2305.69 | -2192.97 | -2080.26 |
| 0.4 | -2782.20 | -2669.63 | -2557.06 | -2444.48 | -2331.91 | -2219.34 | -2106.76 | -1994.19 | -1881.62 | -1769.04 |
| 0.5 | -2469.72 | -2357.29 | -2244.86 | -2132.43 | -2019.99 | -1907.56 | -1795.13 | -1682.69 | -1570.26 | -1457.83 |
| 0.6 | -2157.24 | -2044.95 | -1932.66 | -1820.37 | -1708.07 | -1595.78 | -1483.49 | -1371.20 | -1258.91 | -1146.61 |
| 0.7 | -1844.76 | -1732.61 | -1620.46 | -1508.31 | -1396.16 | -1284.00 | -1171.85 | -1059.70 | -947.55 | -835.40 |
| 0.8 | -1532.28 | -1420.27 | -1308.26 | -1196.25 | -1084.24 | -972.23 | -860.21 | -748.20 | -636.19 | -524.18 |
| 0.9 | -1219.80 | -1107.93 | -996.06 | -884.19 | -772.32 | -660.45 | -548.58 | -436.70 | -324.83 | -212.95 |

Table 3.3 Average Net Present Value for Scenario 1 Assuming Alternative Fractional Reduction in CAPEX and OPEX (M$s).

(NAABB, 2013)



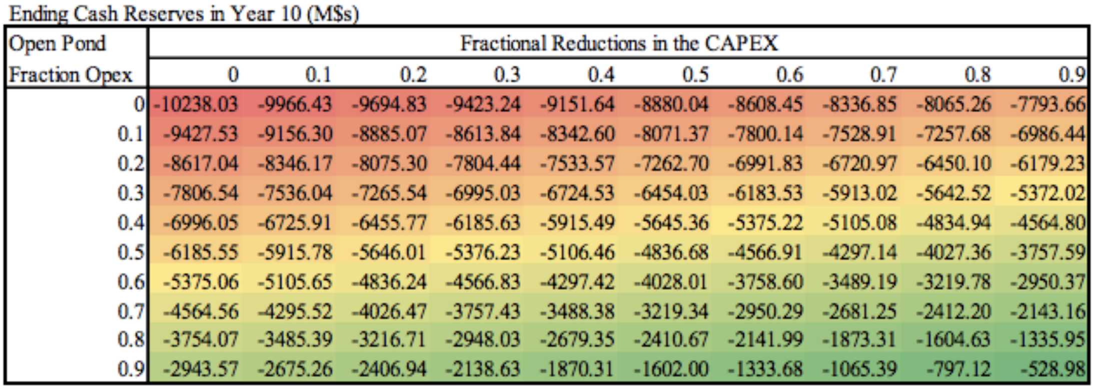
Probability of Economic Success

| Open Pond Fraction Opex | Fractional Reductions in the CAPEX 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.1 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.2 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.3 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.5 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.7 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.8 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

Table 3.4 Probabiliy of Economic Success for Scenario 1 Assuming Alternative Fractional Reduction in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.4 explains the amount of ending capital in fraction in the CAPEX and OPEX, which is based from the algae information in scenario 1. From the table it is clear that all the fraction OPEX and CAPEX do not result in a positive cash flow.

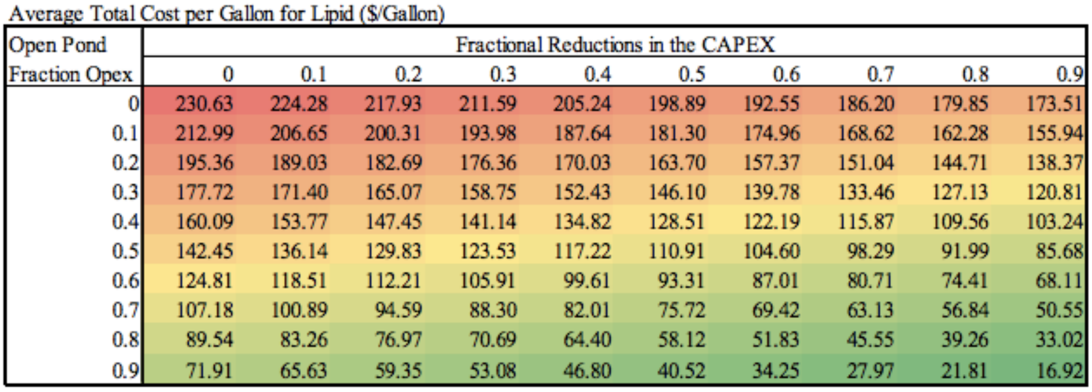


Ending Cash Reserves in Year 10 (M$s)

| Open Pond Fraction Opex | Fractional Reductions in the CAPEX 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -10238.03 | -9966.43 | -9694.83 | -9423.24 | -9151.64 | -8880.04 | -8608.45 | -8336.85 | -8065.26 | -7793.66 |
| 0.1 | -9427.53 | -9156.30 | -8885.07 | -8613.84 | -8342.60 | -8071.37 | -7800.14 | -7528.91 | -7257.68 | -6986.44 |
| 0.2 | -8617.04 | -8346.17 | -8075.30 | -7804.44 | -7533.57 | -7262.70 | -6991.83 | -6720.97 | -6450.10 | -6179.23 |
| 0.3 | -7806.54 | -7536.04 | -7265.54 | -6995.03 | -6724.53 | -6454.03 | -6183.53 | -5913.02 | -5642.52 | -5372.02 |
| 0.4 | -6996.05 | -6725.91 | -6455.77 | -6185.63 | -5915.49 | -5645.36 | -5375.22 | -5105.08 | -4834.94 | -4564.80 |
| 0.5 | -6185.55 | -5915.78 | -5646.01 | -5376.23 | -5106.46 | -4836.68 | -4566.91 | -4297.14 | -4027.36 | -3757.59 |
| 0.6 | -5375.06 | -5105.65 | -4836.24 | -4566.83 | -4297.42 | -4028.01 | -3758.60 | -3489.19 | -3219.78 | -2950.37 |
| 0.7 | -4564.56 | -4295.52 | -4026.47 | -3757.43 | -3488.38 | -3219.34 | -2950.29 | -2681.25 | -2412.20 | -2143.16 |
| 0.8 | -3754.07 | -3485.39 | -3216.71 | -2948.03 | -2679.35 | -2410.67 | -2141.99 | -1873.31 | -1604.63 | -1335.95 |
| 0.9 | -2943.57 | -2675.26 | -2406.94 | -2138.63 | -1870.31 | -1602.00 | -1333.68 | -1065.39 | -797.12 | -528.98 |

Table 3.5 Average Ending Cash Reserves in Year 10 for Scenario 1 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)



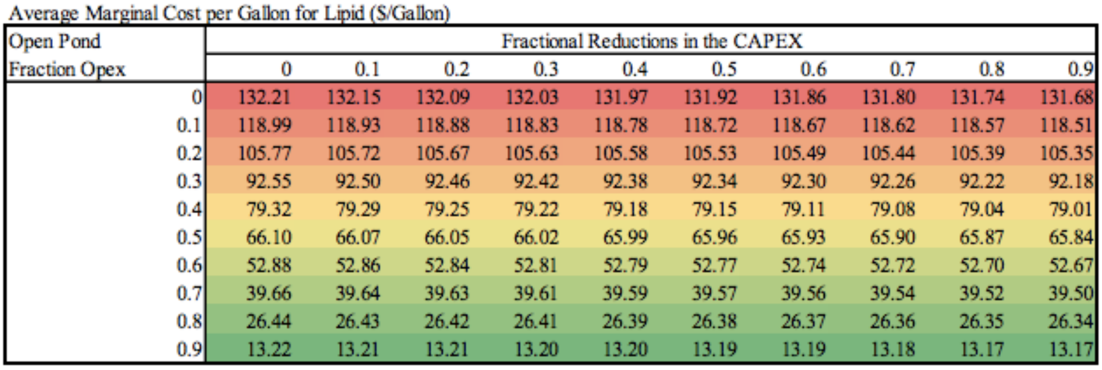
Average Total Cost per Gallon for Lipid ($/Gallon)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 230.63 | 224.28 | 217.93 | 211.59 | 205.24 | 198.89 | 192.55 | 186.20 | 179.85 | 173.51 |
| 0.1 | 212.99 | 206.65 | 200.31 | 193.98 | 187.64 | 181.30 | 174.96 | 168.62 | 162.28 | 155.94 |
| 0.2 | 195.36 | 189.03 | 182.69 | 176.36 | 170.03 | 163.70 | 157.37 | 151.04 | 144.71 | 138.37 |
| 0.3 | 177.72 | 171.40 | 165.07 | 158.75 | 152.43 | 146.10 | 139.78 | 133.46 | 127.13 | 120.81 |
| 0.4 | 160.09 | 153.77 | 147.45 | 141.14 | 134.82 | 128.51 | 122.19 | 115.87 | 109.56 | 103.24 |
| 0.5 | 142.45 | 136.14 | 129.83 | 123.53 | 117.22 | 110.91 | 104.60 | 98.29 | 91.99 | 85.68 |
| 0.6 | 124.81 | 118.51 | 112.21 | 105.91 | 99.61 | 93.31 | 87.01 | 80.71 | 74.41 | 68.11 |
| 0.7 | 107.18 | 100.89 | 94.59 | 88.30 | 82.01 | 75.72 | 69.42 | 63.13 | 56.84 | 50.55 |
| 0.8 | 89.54 | 83.26 | 76.97 | 70.69 | 64.40 | 58.12 | 51.83 | 45.55 | 39.26 | 33.02 |
| 0.9 | 71.91 | 65.63 | 59.35 | 53.08 | 46.80 | 40.52 | 34.25 | 27.97 | 21.81 | 16.92 |

Table 3.6 Average Total Cost of Algae Lipid for Scenario 1 Assuming Alternative Fraction Reduction in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)

Table 3.5 is used to explain the total cost in dollars per gallon of lipid, while Table 3.6 is to explain the marginal cost of the lipid in dollars per gallon for each of the fractional reduction in CAPEX and OPEX based upon scenario 1. The marginal cost for such calculation is based on operation costs per gallon of algae lipid. If there is no reduction in CAPEX and OPEX then the cost for each gallon of lipid remains relatively high. However, even with a 90 percent reduction in OPEX, the farm would still not be feasible in terms of returns.



Average Marginal Cost per Gallon for Lipid ($/Gallon)

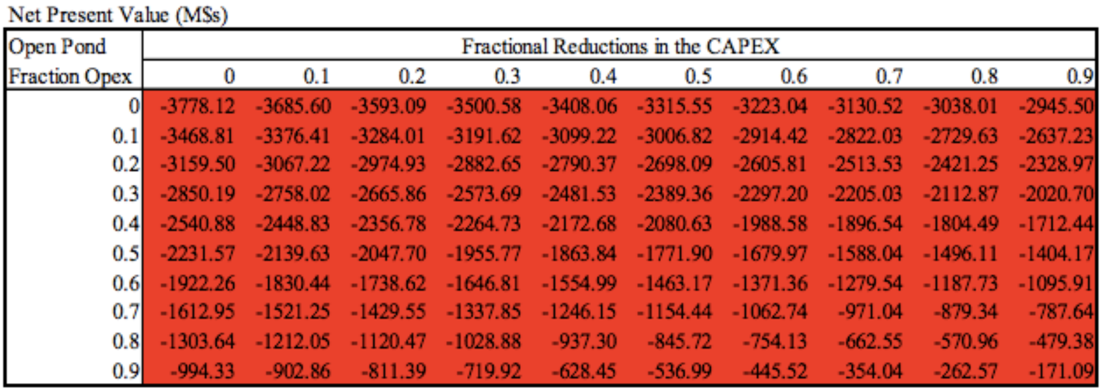
| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 132.21 | 132.15 | 132.09 | 132.03 | 131.97 | 131.92 | 131.86 | 131.80 | 131.74 | 131.68 |
| 0.1 | 118.99 | 118.93 | 118.88 | 118.83 | 118.78 | 118.72 | 118.67 | 118.62 | 118.57 | 118.51 |
| 0.2 | 105.77 | 105.72 | 105.67 | 105.63 | 105.58 | 105.53 | 105.49 | 105.44 | 105.39 | 105.35 |
| 0.3 | 92.55 | 92.50 | 92.46 | 92.42 | 92.38 | 92.34 | 92.30 | 92.26 | 92.22 | 92.18 |
| 0.4 | 79.32 | 79.29 | 79.25 | 79.22 | 79.18 | 79.15 | 79.11 | 79.08 | 79.04 | 79.01 |
| 0.5 | 66.10 | 66.07 | 66.05 | 66.02 | 65.99 | 65.96 | 65.93 | 65.90 | 65.87 | 65.84 |
| 0.6 | 52.88 | 52.86 | 52.84 | 52.81 | 52.79 | 52.77 | 52.74 | 52.72 | 52.70 | 52.67 |
| 0.7 | 39.66 | 39.64 | 39.63 | 39.61 | 39.59 | 39.57 | 39.56 | 39.54 | 39.52 | 39.50 |
| 0.8 | 26.44 | 26.43 | 26.42 | 26.41 | 26.39 | 26.38 | 26.37 | 26.36 | 26.35 | 26.34 |
| 0.9 | 13.22 | 13.21 | 13.21 | 13.20 | 13.20 | 13.19 | 13.19 | 13.18 | 13.17 | 13.17 |

Table 3.7 Average Marginal Cost of Algae Lipid for Scenario 1 Assuming Alternative Fractional Reductions in OPEX and CAPEX ($/Gallon).

(NAABB, 2013)

### 3.2.1 Scenario 2 Results

Scenario 2 is a comparison of the EC harvesting system, and its financial analysis. The difference between scenario 2 and scenario 1 is that there is a difference in the harvesting systems, the rest are identical. The CAPEX and OPEX for scenario 2 is shown in Table 3.8 In this scenario for the project to be feasible the CAPEX and OPEX must be reduced by 90 percent. Scenario 2 is therefore understandably better than scenario 1 in terms of financial feasibility.



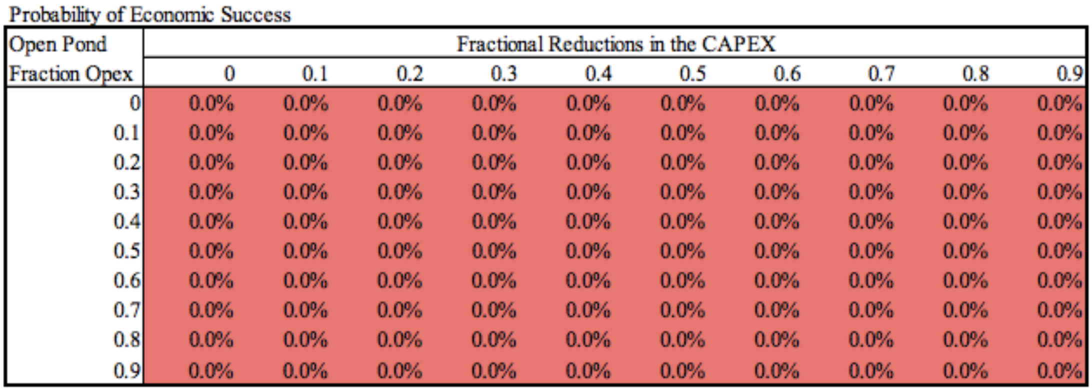
Net Present Value (M$s)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -3778.12 | -3685.60 | -3593.09 | -3500.58 | -3408.06 | -3315.55 | -3223.04 | -3130.52 | -3038.01 | -2945.50 |
| 0.1 | -3468.81 | -3376.41 | -3284.01 | -3191.62 | -3099.22 | -3006.82 | -2914.42 | -2822.03 | -2729.63 | -2637.23 |
| 0.2 | -3159.50 | -3067.22 | -2974.93 | -2882.65 | -2790.37 | -2698.09 | -2605.81 | -2513.53 | -2421.25 | -2328.97 |
| 0.3 | -2850.19 | -2758.02 | -2665.86 | -2573.69 | -2481.53 | -2389.36 | -2297.20 | -2205.03 | -2112.87 | -2020.70 |
| 0.4 | -2540.88 | -2448.83 | -2356.78 | -2264.73 | -2172.68 | -2080.63 | -1988.58 | -1896.54 | -1804.49 | -1712.44 |
| 0.5 | -2231.57 | -2139.63 | -2047.70 | -1955.77 | -1863.84 | -1771.90 | -1679.97 | -1588.04 | -1496.11 | -1404.17 |
| 0.6 | -1922.26 | -1830.44 | -1738.62 | -1646.81 | -1554.99 | -1463.17 | -1371.36 | -1279.54 | -1187.73 | -1095.91 |
| 0.7 | -1612.95 | -1521.25 | -1429.55 | -1337.85 | -1246.15 | -1154.44 | -1062.74 | -971.04 | -879.34 | -787.64 |
| 0.8 | -1303.64 | -1212.05 | -1120.47 | -1028.88 | -937.30 | -845.72 | -754.13 | -662.55 | -570.96 | -479.38 |
| 0.9 | -994.33 | -902.86 | -811.39 | -719.92 | -628.45 | -536.99 | -445.52 | -354.04 | -262.57 | -171.09 |

Table 3.8 Average Net Present Value for Scenario 2 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.9 is used to explain the probability of financial success for the different combinations of fractional reductions in CAPEX and OPEX values for scenario 2. As denoted in Table 3.9, there combinations of reduced CAPEX and OPEX that would allow for a high economical success.



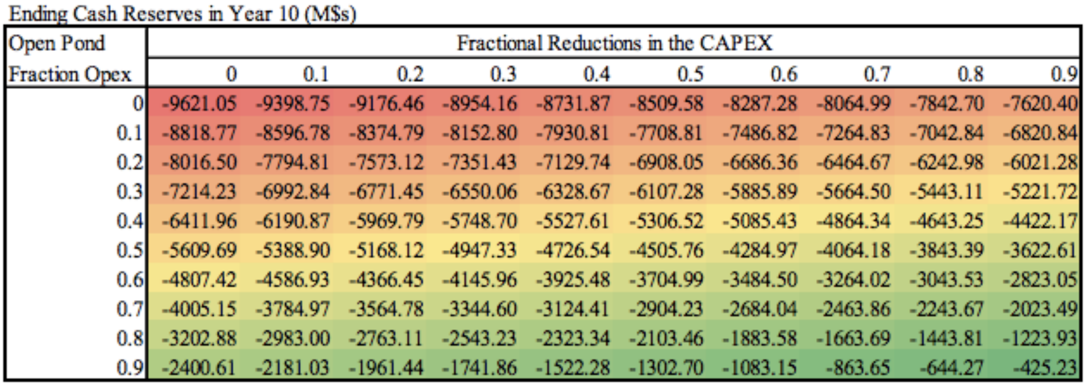
Probability of Economic Success

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.1 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.2 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.3 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.5 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.7 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.8 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

Table 3.9 Probability of Economical Success for Scenario 2 Assuming Alternative Fractional Reduction in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.10 is used to explain the average ending cash reserves for each fractional reduction in CAPEX and OPEX values from scenario 2. For a positive cash flow to appear, more than 90 percent of reduction in CAPEX and OPEX must be reached.



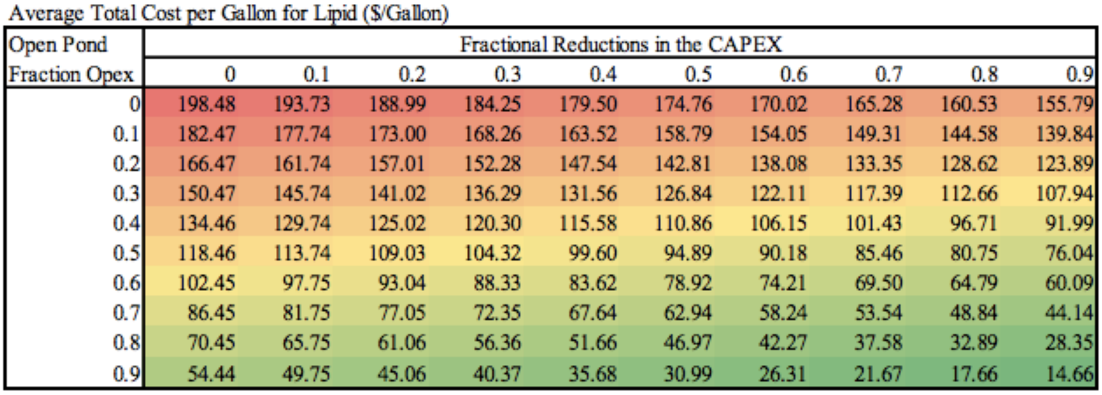
Ending Cash Reserves in Year 10 (M$s)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -9621.05 | -9398.75 | -9176.46 | -8954.16 | -8731.87 | -8509.58 | -8287.28 | -8064.99 | -7842.70 | -7620.40 |
| 0.1 | -8818.77 | -8596.78 | -8374.79 | -8152.80 | -7930.81 | -7708.81 | -7486.82 | -7264.83 | -7042.84 | -6820.84 |
| 0.2 | -8016.50 | -7794.81 | -7573.12 | -7351.43 | -7129.74 | -6908.05 | -6686.36 | -6464.67 | -6242.98 | -6021.28 |
| 0.3 | -7214.23 | -6992.84 | -6771.45 | -6550.06 | -6328.67 | -6107.28 | -5885.89 | -5664.50 | -5443.11 | -5221.72 |
| 0.4 | -6411.96 | -6190.87 | -5969.79 | -5748.70 | -5527.61 | -5306.52 | -5085.43 | -4864.34 | -4643.25 | -4422.17 |
| 0.5 | -5609.69 | -5388.90 | -5168.12 | -4947.33 | -4726.54 | -4505.76 | -4284.97 | -4064.18 | -3843.39 | -3622.61 |
| 0.6 | -4807.42 | -4586.93 | -4366.45 | -4145.96 | -3925.48 | -3704.99 | -3484.50 | -3264.02 | -3043.53 | -2823.05 |
| 0.7 | -4005.15 | -3784.97 | -3564.78 | -3344.60 | -3124.41 | -2904.23 | -2684.04 | -2463.86 | -2243.67 | -2023.49 |
| 0.8 | -3202.88 | -2983.00 | -2763.11 | -2543.23 | -2323.34 | -2103.46 | -1883.58 | -1663.69 | -1443.81 | -1223.93 |
| 0.9 | -2400.61 | -2181.03 | -1961.44 | -1741.86 | -1522.28 | -1302.70 | -1083.15 | -863.65 | -644.27 | -425.23 |

Table 3.10 Average Ending Cash Reserves in Year 10 for Scenario 2 Assuming Alternative Fractional Reduction in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.11 explains that the total cost (dollar/gallon) of lipid, while Table 3.12 is used to describe the marginal cost (dollar/gallon) of lipid for each of the fractional in CAPEX and OPEX in accordance to NAABB. With no reduction in CAPEX and OPEX present, the cost for lipid exceeds 200 dollars per gallon. Even with a 90 percent reduction in the OPEX it is not completely feasible as the cost of lipid still remains high at about 12 dollars per gallon. However when compared to scenario 1, scenario 2's improved technology allow for the marginal cost of lipid and the total cost (dollar/ton) of biomass is reduced.

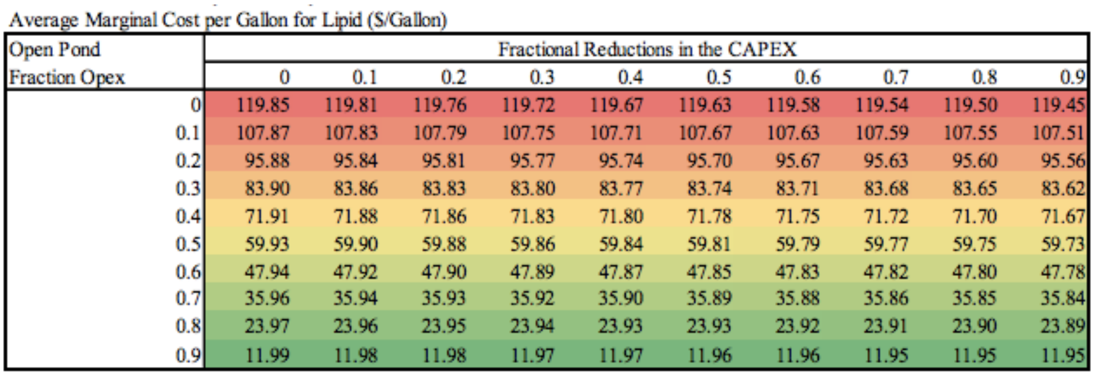


Average Total Cost per Gallon for Lipid ($/Gallon)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 198.48 | 193.73 | 188.99 | 184.25 | 179.50 | 174.76 | 170.02 | 165.28 | 160.53 | 155.79 |
| 0.1 | 182.47 | 177.74 | 173.00 | 168.26 | 163.52 | 158.79 | 154.05 | 149.31 | 144.58 | 139.84 |
| 0.2 | 166.47 | 161.74 | 157.01 | 152.28 | 147.54 | 142.81 | 138.08 | 133.35 | 128.62 | 123.89 |
| 0.3 | 150.47 | 145.74 | 141.02 | 136.29 | 131.56 | 126.84 | 122.11 | 117.39 | 112.66 | 107.94 |
| 0.4 | 134.46 | 129.74 | 125.02 | 120.30 | 115.58 | 110.86 | 106.15 | 101.43 | 96.71 | 91.99 |
| 0.5 | 118.46 | 113.74 | 109.03 | 104.32 | 99.60 | 94.89 | 90.18 | 85.46 | 80.75 | 76.04 |
| 0.6 | 102.45 | 97.75 | 93.04 | 88.33 | 83.62 | 78.92 | 74.21 | 69.50 | 64.79 | 60.09 |
| 0.7 | 86.45 | 81.75 | 77.05 | 72.35 | 67.64 | 62.94 | 58.24 | 53.54 | 48.84 | 44.14 |
| 0.8 | 70.45 | 65.75 | 61.06 | 56.36 | 51.66 | 46.97 | 42.27 | 37.58 | 32.89 | 28.35 |
| 0.9 | 54.44 | 49.75 | 45.06 | 40.37 | 35.68 | 30.99 | 26.31 | 21.67 | 17.66 | 14.66 |

Table 11 Average Total Cost of Algae Lipid for Scenario 2 Assuming Alternative Fractional Reductions in CAPEX and OPEX ($/Gallon)

(NAABB, 2013)



Average Marginal Cost per Gallon for Lipid ($/Gallon)

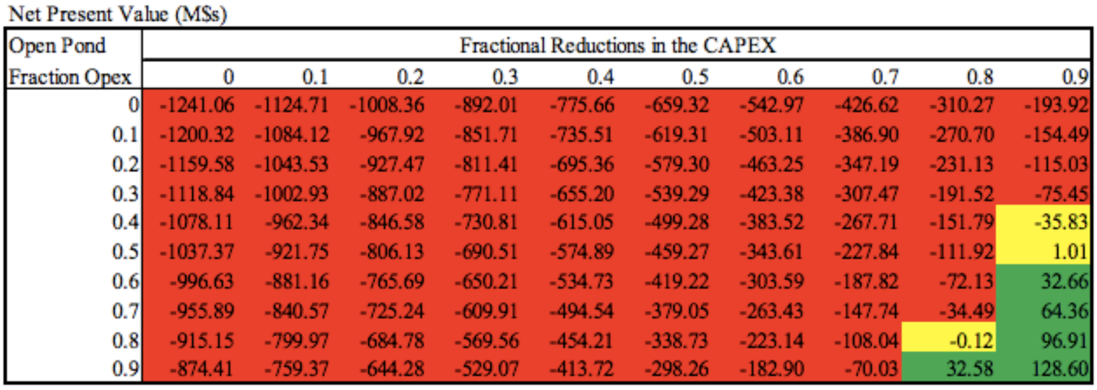
| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 119.85 | 119.81 | 119.76 | 119.72 | 119.67 | 119.63 | 119.58 | 119.54 | 119.50 | 119.45 |
| 0.1 | 107.87 | 107.83 | 107.79 | 107.75 | 107.71 | 107.67 | 107.63 | 107.59 | 107.55 | 107.51 |
| 0.2 | 95.88 | 95.84 | 95.81 | 95.77 | 95.74 | 95.70 | 95.67 | 95.63 | 95.60 | 95.56 |
| 0.3 | 83.90 | 83.86 | 83.83 | 83.80 | 83.77 | 83.74 | 83.71 | 83.68 | 83.65 | 83.62 |
| 0.4 | 71.91 | 71.88 | 71.86 | 71.83 | 71.80 | 71.78 | 71.75 | 71.72 | 71.70 | 71.67 |
| 0.5 | 59.93 | 59.90 | 59.88 | 59.86 | 59.84 | 59.81 | 59.79 | 59.77 | 59.75 | 59.73 |
| 0.6 | 47.94 | 47.92 | 47.90 | 47.89 | 47.87 | 47.85 | 47.83 | 47.82 | 47.80 | 47.78 |
| 0.7 | 35.96 | 35.94 | 35.93 | 35.92 | 35.90 | 35.89 | 35.88 | 35.86 | 35.85 | 35.84 |
| 0.8 | 23.97 | 23.96 | 23.95 | 23.94 | 23.93 | 23.93 | 23.92 | 23.91 | 23.90 | 23.89 |
| 0.9 | 11.99 | 11.98 | 11.98 | 11.97 | 11.97 | 11.96 | 11.96 | 11.95 | 11.95 | 11.95 |

Table 3.12 Average Marginal Cost of Algae Lipid for Scenario 2 Assuming Alternative Fractional Reduction in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)

### 3.2.2 Scenario 3 Results

Scenario 3 is based on a different extraction system. It is a comparison of the HTL-CHG extraction system to the wet solvent extraction system in scenario 1. NAABB explains that; "The average net present value for each fractional reduction in CAPEX and OPEX for Scenario 3 is summarized in Table 13. There are five combinations of CAPEX and OPEX reductions in Scenario 3 that return positive average net present values. For example, if CAPEX is reduced by 90% and OPEX is reduced by 60% a positive average net present value will be reached ($29.48 million). If investors greatly reduce CAPEX and OPEX they could see a return on their initial investment greater than the 10% discount rate" (NAABB, 2013)" Between scenario 1 and scenario 3, only the extraction system is different, while all other values are identical to scenario 1. In comparison to scenario 1, scenario 3 with HTL-CHG extraction system offers a much more economical value.



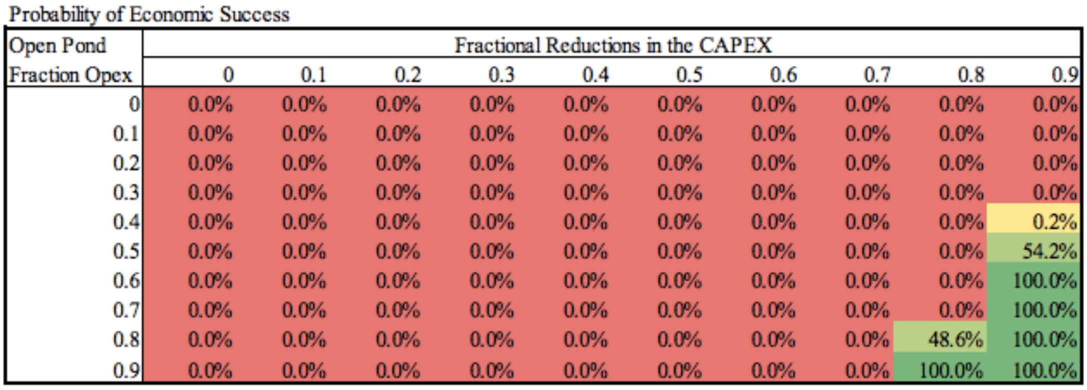
Net Present Value (M$s)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -1241.06 | -1124.71 | -1008.36 | -892.01 | -775.66 | -659.32 | -542.97 | -426.62 | -310.27 | -193.92 |
| 0.1 | -1200.32 | -1084.12 | -967.92 | -851.71 | -735.51 | -619.31 | -503.11 | -386.90 | -270.70 | -154.49 |
| 0.2 | -1159.58 | -1043.53 | -927.47 | -811.41 | -695.36 | -579.30 | -463.25 | -347.19 | -231.13 | -115.03 |
| 0.3 | -1118.84 | -1002.93 | -887.02 | -771.11 | -655.20 | -539.29 | -423.38 | -307.47 | -191.52 | -75.45 |
| 0.4 | -1078.11 | -962.34 | -846.58 | -730.81 | -615.05 | -499.28 | -383.52 | -267.71 | -151.79 | -35.83 |
| 0.5 | -1037.37 | -921.75 | -806.13 | -690.51 | -574.89 | -459.27 | -343.61 | -227.84 | -111.92 | 1.01 |
| 0.6 | -996.63 | -881.16 | -765.69 | -650.21 | -534.73 | -419.22 | -303.59 | -187.82 | -72.13 | 32.66 |
| 0.7 | -955.89 | -840.57 | -725.24 | -609.91 | -494.54 | -379.05 | -263.43 | -147.74 | -34.49 | 64.36 |
| 0.8 | -915.15 | -799.97 | -684.78 | -569.56 | -454.21 | -338.73 | -223.14 | -108.04 | -0.12 | 96.91 |
| 0.9 | -874.41 | -759.37 | -644.28 | -529.07 | -413.72 | -298.26 | -182.90 | -70.03 | 32.58 | 128.60 |

Table 3.13 Average Net Presernt Value for Scenario 3 Assuming Alternative Fraction Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.14 explains the probability of economical success of each different combination of fraction reduction in CAPEX and OPEX for scenario 3 algae farms. The combinations, which yield probability of economical success, are shown in green and yellow, with seven possible combinations that would grant greater than zero probability of economical success.



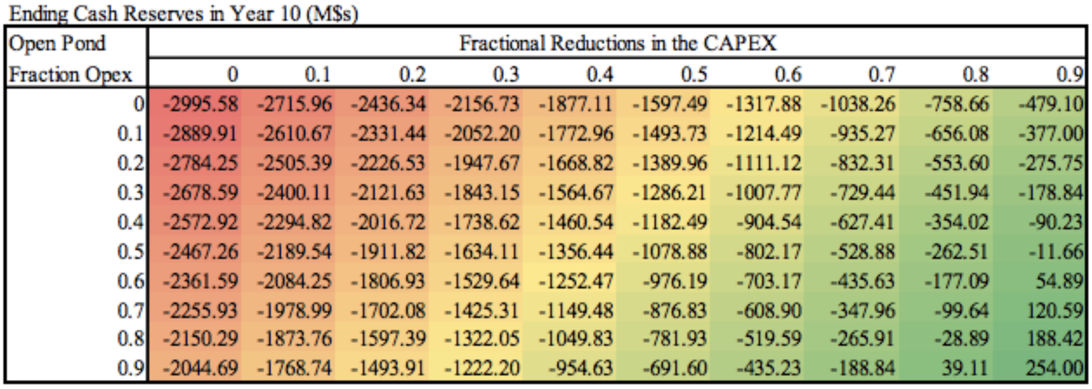
Probability of Economic Success

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.1 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.2 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.3 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 0.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% |
| 0.5 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 54.2% |
| 0.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| 0.7 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| 0.8 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 48.6% | 100.0% |
| 0.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |

Table 3.14 Probability of Economic Success for Scenario 3 Assuming Alternation Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.15 explains the average ending cash reserves for the different fractional reduction in CAPEX and OPEX for algae farms in scenario 3. There are five possible combination of fractional reduction that create a positive ending cash flow, which is mandatory that CAPEX be reduced by 90 percent and 60 or greater reduction in OPEX.



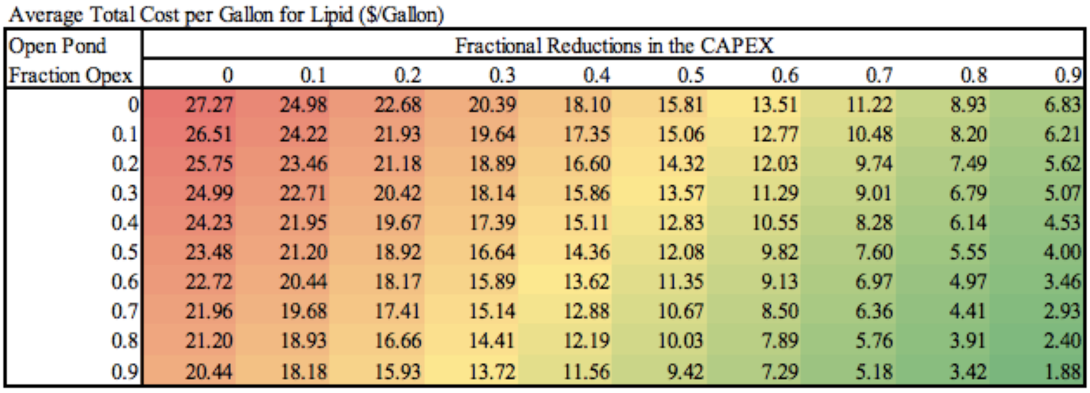
Ending Cash Reserves in Year 10 (M$s)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -2995.58 | -2715.96 | -2436.34 | -2156.73 | -1877.11 | -1597.49 | -1317.88 | -1038.26 | -758.66 | -479.10 |
| 0.1 | -2889.91 | -2610.67 | -2331.44 | -2052.20 | -1772.96 | -1493.73 | -1214.49 | -935.27 | -656.08 | -377.00 |
| 0.2 | -2784.25 | -2505.39 | -2226.53 | -1947.67 | -1668.82 | -1389.96 | -1111.12 | -832.31 | -553.60 | -275.75 |
| 0.3 | -2678.59 | -2400.11 | -2121.63 | -1843.15 | -1564.67 | -1286.21 | -1007.77 | -729.44 | -451.94 | -178.84 |
| 0.4 | -2572.92 | -2294.82 | -2016.72 | -1738.62 | -1460.54 | -1182.49 | -904.54 | -627.41 | -354.02 | -90.23 |
| 0.5 | -2467.26 | -2189.54 | -1911.82 | -1634.11 | -1356.44 | -1078.88 | -802.17 | -528.88 | -262.51 | -11.66 |
| 0.6 | -2361.59 | -2084.25 | -1806.93 | -1529.64 | -1252.47 | -976.19 | -703.17 | -435.63 | -177.09 | 54.89 |
| 0.7 | -2255.93 | -1978.99 | -1702.08 | -1425.31 | -1149.48 | -876.83 | -608.90 | -347.96 | -99.64 | 120.59 |
| 0.8 | -2150.29 | -1873.76 | -1597.39 | -1322.05 | -1049.83 | -781.93 | -519.59 | -265.91 | -28.89 | 188.42 |
| 0.9 | -2044.69 | -1768.74 | -1493.91 | -1222.20 | -954.63 | -691.60 | -435.23 | -188.84 | 39.11 | 254.00 |

Table 3.15 Average Ending Cash Reserves in Year 10 for Scenario 3 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.16 explains the total cost of lipid in dollars per gallon, and Table 3.17 shows the marginal cost in dollars per gallon of lipid for each of the fractional reductions in CAPEX and OPEX for farms in scenario 3. NAABB explains that; "When there is no reduction in CAPEX and OPEX the total cost for lipid is very high (more than $28/gallon) and remains high unless there are substantial reductions in the CAPEX and OPEX. For example, if CAPEX and OPEX are reduced 80% each ($4.08/gallon). When there is no reduction in CAPEX and OPEX the marginal cost for lipid is also extremely high ($5.54/gallon). However, with a 60% reduction in the OPEX the marginal cost for lipid becomes feasible at $2.18/gallon. At this reduction level, algal lipid production could become competitive with fossil fuels (NAABB, 2013)". Compared to scenario 1, scenario 3's total cost of lipid, marginal cost of lipid, and total cost of biomass can be decreased through the improvement of extraction systems.

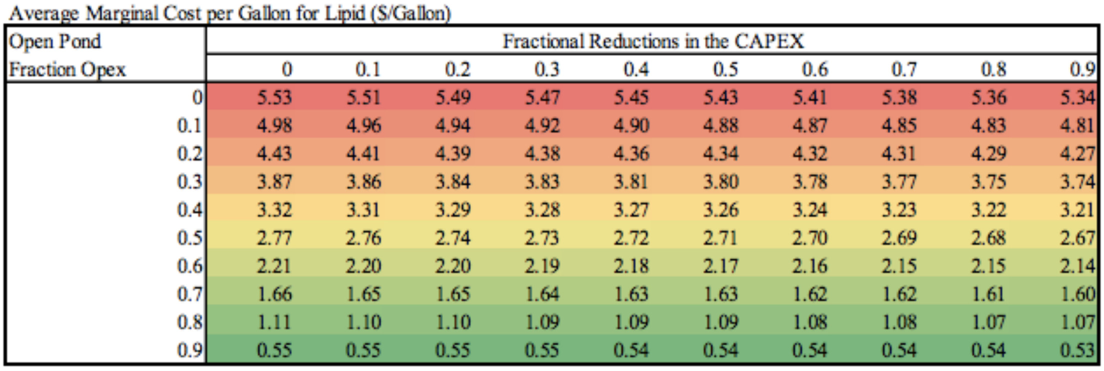


Average Total Cost per Gallon for Lipid ($/Gallon)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 27.27 | 24.98 | 22.68 | 20.39 | 18.10 | 15.81 | 13.51 | 11.22 | 8.93 | 6.83 |
| 0.1 | 26.51 | 24.22 | 21.93 | 19.64 | 17.35 | 15.06 | 12.77 | 10.48 | 8.20 | 6.21 |
| 0.2 | 25.75 | 23.46 | 21.18 | 18.89 | 16.60 | 14.32 | 12.03 | 9.74 | 7.49 | 5.62 |
| 0.3 | 24.99 | 22.71 | 20.42 | 18.14 | 15.86 | 13.57 | 11.29 | 9.01 | 6.79 | 5.07 |
| 0.4 | 24.23 | 21.95 | 19.67 | 17.39 | 15.11 | 12.83 | 10.55 | 8.28 | 6.14 | 4.53 |
| 0.5 | 23.48 | 21.20 | 18.92 | 16.64 | 14.36 | 12.08 | 9.82 | 7.60 | 5.55 | 4.00 |
| 0.6 | 22.72 | 20.44 | 18.17 | 15.89 | 13.62 | 11.35 | 9.13 | 6.97 | 4.97 | 3.46 |
| 0.7 | 21.96 | 19.68 | 17.41 | 15.14 | 12.88 | 10.67 | 8.50 | 6.36 | 4.41 | 2.93 |
| 0.8 | 21.20 | 18.93 | 16.66 | 14.41 | 12.19 | 10.03 | 7.89 | 5.76 | 3.91 | 2.40 |
| 0.9 | 20.44 | 18.18 | 15.93 | 13.72 | 11.56 | 9.42 | 7.29 | 5.18 | 3.42 | 1.88 |

Table 3.16 Average Total Cost of Algae Lipid for Scenario 3 Assuming Alternative Fractional Reduction in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)



Average Marginal Cost per Gallon for Lipid ($/Gallon)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 5.53 | 5.51 | 5.49 | 5.47 | 5.45 | 5.43 | 5.41 | 5.38 | 5.36 | 5.34 |
| 0.1 | 4.98 | 4.96 | 4.94 | 4.92 | 4.90 | 4.88 | 4.87 | 4.85 | 4.83 | 4.81 |
| 0.2 | 4.43 | 4.41 | 4.39 | 4.38 | 4.36 | 4.34 | 4.32 | 4.31 | 4.29 | 4.27 |
| 0.3 | 3.87 | 3.86 | 3.84 | 3.83 | 3.81 | 3.80 | 3.78 | 3.77 | 3.75 | 3.74 |
| 0.4 | 3.32 | 3.31 | 3.29 | 3.28 | 3.27 | 3.26 | 3.24 | 3.23 | 3.22 | 3.21 |
| 0.5 | 2.77 | 2.76 | 2.74 | 2.73 | 2.72 | 2.71 | 2.70 | 2.69 | 2.68 | 2.67 |
| 0.6 | 2.21 | 2.20 | 2.20 | 2.19 | 2.18 | 2.17 | 2.16 | 2.15 | 2.15 | 2.14 |
| 0.7 | 1.66 | 1.65 | 1.65 | 1.64 | 1.63 | 1.63 | 1.62 | 1.62 | 1.61 | 1.60 |
| 0.8 | 1.11 | 1.10 | 1.10 | 1.09 | 1.09 | 1.09 | 1.08 | 1.08 | 1.07 | 1.07 |
| 0.9 | 0.55 | 0.55 | 0.55 | 0.55 | 0.54 | 0.54 | 0.54 | 0.54 | 0.54 | 0.53 |

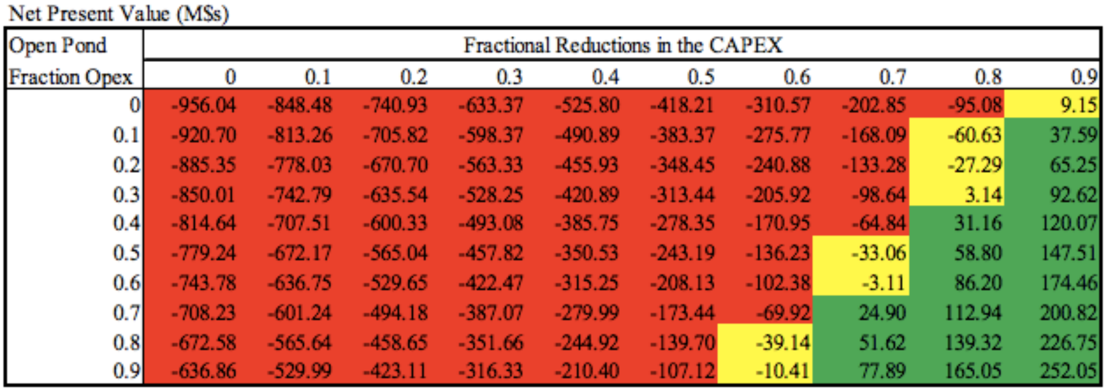
Table 3.17 Average Marginal Cost of Algae Lipid for Scenario 3 Assuming Alternative Fractional Reduction in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)

### 3.2.3 Scenario 4 Results

Scenario 4 is a comparison between with a different cultivation system. This scenario is based on the ARID cultivation system with harvesting and extraction technologies to the open pond cultivation system. The net present values for the fractional reduction in CAPEX and OPEX for scenario 5 is shown in Table 3.18. NAABB mentions that “there are 27 combinations of CAPEX and

OPEX reductions in Scenario 5 that return positive average net present values. For example, if CAPEX is reduced by 80% and OPEX is reduced by 50% a positive net present value would average $72.62 million. (NAABB, 2013)"



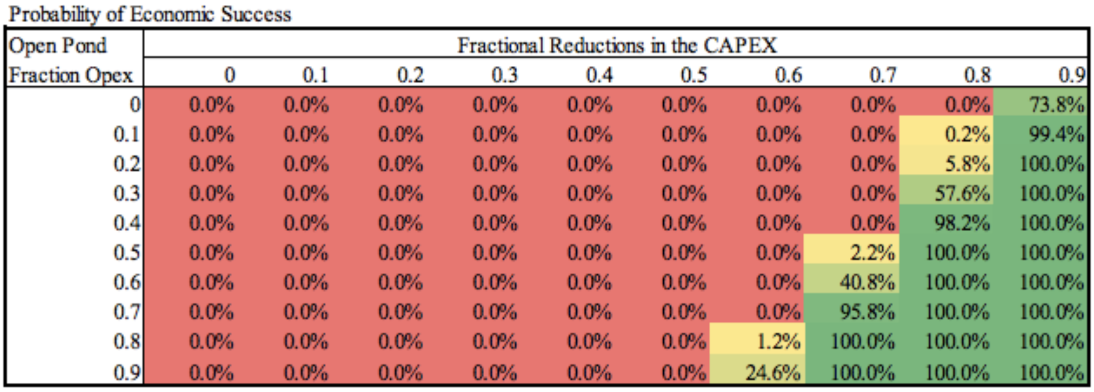
Net Present Value (M$s)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -956.04 | -848.48 | -740.93 | -633.37 | -525.80 | -418.21 | -310.57 | -202.85 | -95.08 | 9.15 |
| 0.1 | -920.70 | -813.26 | -705.82 | -598.37 | -490.89 | -383.37 | -275.77 | -168.09 | -60.63 | 37.59 |
| 0.2 | -885.35 | -778.03 | -670.70 | -563.33 | -455.93 | -348.45 | -240.88 | -133.28 | -27.29 | 65.25 |
| 0.3 | -850.01 | -742.79 | -635.54 | -528.25 | -420.89 | -313.44 | -205.92 | -98.64 | 3.14 | 92.62 |
| 0.4 | -814.64 | -707.51 | -600.33 | -493.08 | -385.75 | -278.35 | -170.95 | -64.84 | 31.16 | 120.07 |
| 0.5 | -779.24 | -672.17 | -565.04 | -457.82 | -350.53 | -243.19 | -136.23 | -33.06 | 58.80 | 147.51 |
| 0.6 | -743.78 | -636.75 | -529.65 | -422.47 | -315.25 | -208.13 | -102.38 | -3.11 | 86.20 | 174.46 |
| 0.7 | -708.23 | -601.24 | -494.18 | -387.07 | -279.99 | -173.44 | -69.92 | 24.90 | 112.94 | 200.82 |
| 0.8 | -672.58 | -565.64 | -458.65 | -351.66 | -244.92 | -139.70 | -39.14 | 51.62 | 139.32 | 226.75 |
| 0.9 | -636.86 | -529.99 | -423.11 | -316.33 | -210.40 | -107.12 | -10.41 | 77.89 | 165.05 | 252.05 |

Table 3.18 Average Net Present Value for Scenario 5 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.19 explains the probability of economical success for scenario 5. There are a total of 27 combination of reductions in CAPEX and OPEX that yields a greater than zero probability of economical success.



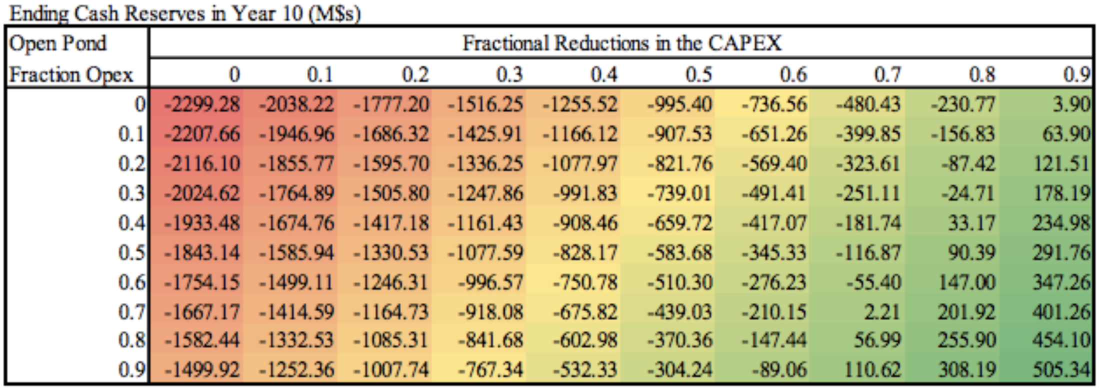
Probability of Economic Success

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 73.8% |
| 0.1 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% | 99.4% |
| 0.2 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5.8% | 100.0% |
| 0.3 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 57.6% | 100.0% |
| 0.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 98.2% | 100.0% |
| 0.5 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.2% | 100.0% | 100.0% |
| 0.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 40.8% | 100.0% | 100.0% |
| 0.7 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 95.8% | 100.0% | 100.0% |
| 0.8 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.2% | 100.0% | 100.0% | 100.0% |
| 0.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 24.6% | 100.0% | 100.0% | 100.0% |

Table 3.19 Probability of Economic Success for Scenario 5 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.20 is a representation of the average ending cash reserves for each fractional reduction in CAPEX and OPEX for algae farm is in scenario 5. There seems to be a positive average ending cash, but requires a large reduction in CAPEX.



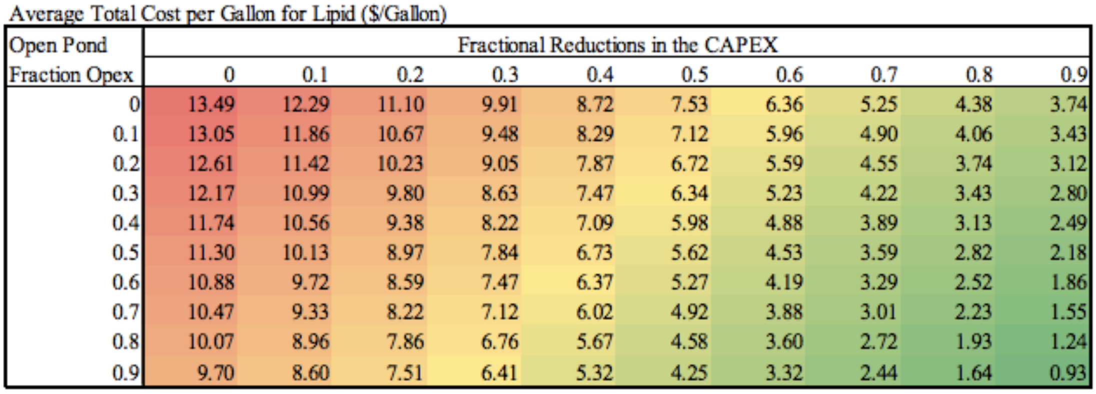
Ending Cash Reserves in Year 10 (M$s)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | -2299.28 | -2038.22 | -1777.20 | -1516.25 | -1255.52 | -995.40 | -736.56 | -480.43 | -230.77 | 3.90 |
| 0.1 | -2207.66 | -1946.96 | -1686.32 | -1425.91 | -1166.12 | -907.53 | -651.26 | -399.85 | -156.83 | 63.90 |
| 0.2 | -2116.10 | -1855.77 | -1595.70 | -1336.25 | -1077.97 | -821.76 | -569.40 | -323.61 | -87.42 | 121.51 |
| 0.3 | -2024.62 | -1764.89 | -1505.80 | -1247.86 | -991.83 | -739.01 | -491.41 | -251.11 | -24.71 | 178.19 |
| 0.4 | -1933.48 | -1674.76 | -1417.18 | -1161.43 | -908.46 | -659.72 | -417.07 | -181.74 | 33.17 | 234.98 |
| 0.5 | -1843.14 | -1585.94 | -1330.53 | -1077.59 | -828.17 | -583.68 | -345.33 | -116.87 | 90.39 | 291.76 |
| 0.6 | -1754.15 | -1499.11 | -1246.31 | -996.57 | -750.78 | -510.30 | -276.23 | -55.40 | 147.00 | 347.26 |
| 0.7 | -1667.17 | -1414.59 | -1164.73 | -918.08 | -675.82 | -439.03 | -210.15 | 2.21 | 201.92 | 401.26 |
| 0.8 | -1582.44 | -1332.53 | -1085.31 | -841.68 | -602.98 | -370.36 | -147.44 | 56.99 | 255.90 | 454.10 |
| 0.9 | -1499.92 | -1252.36 | -1007.74 | -767.34 | -532.33 | -304.24 | -89.06 | 110.62 | 308.19 | 505.34 |

Table 3.20 Average Ending Cash Reserves in Year 10 for Scenario 5 Assuming Alternative Fractional Reductions in CAPEX and OPEX (M$s).

(NAABB, 2013)

Table 3.21 explains the total cost of lipid (dollar/gallon), while Table 3.22 explains the marginal cost (dollars/gallon) of lipid for each of the fractional reduction in CAPEX and OPEX. When no reduction is present, the total cost of lipid is higher than 15 dollars per gallon, but would be significantly lowered with the reduction of CAPEX and OPEX.

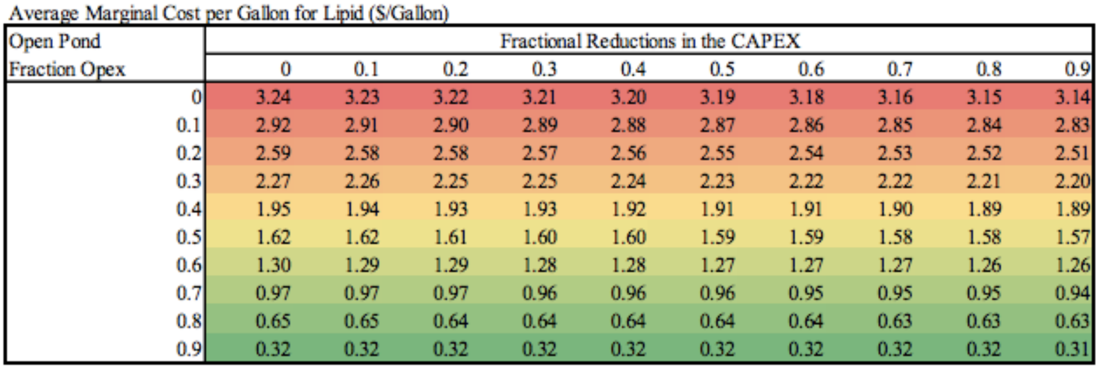


Average Total Cost per Gallon for Lipid ($/Gallon)

| Open Pond | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fraction Opex | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 13.49 | 12.29 | 11.10 | 9.91 | 8.72 | 7.53 | 6.36 | 5.25 | 4.38 | 3.74 |
| 0.1 | 13.05 | 11.86 | 10.67 | 9.48 | 8.29 | 7.12 | 5.96 | 4.90 | 4.06 | 3.43 |
| 0.2 | 12.61 | 11.42 | 10.23 | 9.05 | 7.87 | 6.72 | 5.59 | 4.55 | 3.74 | 3.12 |
| 0.3 | 12.17 | 10.99 | 9.80 | 8.63 | 7.47 | 6.34 | 5.23 | 4.22 | 3.43 | 2.80 |
| 0.4 | 11.74 | 10.56 | 9.38 | 8.22 | 7.09 | 5.98 | 4.88 | 3.89 | 3.13 | 2.49 |
| 0.5 | 11.30 | 10.13 | 8.97 | 7.84 | 6.73 | 5.62 | 4.53 | 3.59 | 2.82 | 2.18 |
| 0.6 | 10.88 | 9.72 | 8.59 | 7.47 | 6.37 | 5.27 | 4.19 | 3.29 | 2.52 | 1.86 |
| 0.7 | 10.47 | 9.33 | 8.22 | 7.12 | 6.02 | 4.92 | 3.88 | 3.01 | 2.23 | 1.55 |
| 0.8 | 10.07 | 8.96 | 7.86 | 6.76 | 5.67 | 4.58 | 3.60 | 2.72 | 1.93 | 1.24 |
| 0.9 | 9.70 | 8.60 | 7.51 | 6.41 | 5.32 | 4.25 | 3.32 | 2.44 | 1.64 | 0.93 |

Table 3.21 Average Total Cost of Algae Lipid for Scenario 5 Assuming Alternative Fractional Reductions in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)



Average Marginal Cost per Gallon for Lipid ($/Gallon)

| Open Pond<br>Fraction Opex | Fractional Reductions in the CAPEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 3.24 | 3.23 | 3.22 | 3.21 | 3.20 | 3.19 | 3.18 | 3.16 | 3.15 | 3.14 |
| 0.1 | 2.92 | 2.91 | 2.90 | 2.89 | 2.88 | 2.87 | 2.86 | 2.85 | 2.84 | 2.83 |
| 0.2 | 2.59 | 2.58 | 2.58 | 2.57 | 2.56 | 2.55 | 2.54 | 2.53 | 2.52 | 2.51 |
| 0.3 | 2.27 | 2.26 | 2.25 | 2.25 | 2.24 | 2.23 | 2.22 | 2.22 | 2.21 | 2.20 |
| 0.4 | 1.95 | 1.94 | 1.93 | 1.93 | 1.92 | 1.91 | 1.91 | 1.90 | 1.89 | 1.89 |
| 0.5 | 1.62 | 1.62 | 1.61 | 1.60 | 1.60 | 1.59 | 1.59 | 1.58 | 1.58 | 1.57 |
| 0.6 | 1.30 | 1.29 | 1.29 | 1.28 | 1.28 | 1.27 | 1.27 | 1.27 | 1.26 | 1.26 |
| 0.7 | 0.97 | 0.97 | 0.97 | 0.96 | 0.96 | 0.96 | 0.95 | 0.95 | 0.95 | 0.94 |
| 0.8 | 0.65 | 0.65 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.63 | 0.63 | 0.63 |
| 0.9 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.31 |

Table 3.22 Average Marginal Cost of Algae Lipid for Scenario 5 Assuming Alternative Fractional Reductions in CAPEX and OPEX ($/Gallon).

(NAABB, 2013)

A direct comparison cannot be made between scenario 4 and other scenarios due to the different in reduction fractions and technologies, it is still comprehensible that scenario 4 shows economical feasibility potential.

## Drawback and Limitations

Algal biofuels, like many other cultured biofuels has its limitations. Firstly, there is a need for controlled conditions. Algae need to be grown under specific conditions relating especially to temperature of the water it is to be sustained in. This increase algae production cost quite greatly as temperature control in open pond systems would require a lot of equipment, preparation, and capital.

There is also the problem with Cold Flow, meaning that algal biofuel tend to perform poorly compared to other fuels when temperature is lower. However this can be overcome by mixing algal biofuel with other fuels to create a blend, which would allow for the alleviation of Cold Flow. GMO is not new but to have the most efficient algae for biofuel production, there are researchers using genetically modified strains of algae. This is quite costly, and may be harmful the surrounding environment if not contained properly. Although algal biofuel is considered as zero emission, its production is still carbon dependent.

## Recommendations

Algae as a source of biofuel are a vey good candidate in terms of space management and environmental protection factors. This technology although still very much expensive and may not be economically feasible with certain types of algae farming, it is however beneficial

## Conclusion

In conclusion the presence of algae biofuel is still very limited and for it to be considered economically viable for the mass market much more research effort is needed to put in place. Although there are multiple entities that are pushing this technology forward it is still not possible for smaller farmers or business owners to easily set up an algae farm and produce biofuel for profit as easily compared to some other more traditional biofuel materials, as mentioned earlier, such as corn or switch grass. Further more, business models have shown that algae bio plants might even be economically invalid as they might not produce a sufficient amount of return in investment, but with dedication and certain methods it can be implemented and become economically viable as well as environmentally friendly with less land use and less impact in terms of space competition for food crops, and other farm. Other benefit from algae bio plants are that they are viable in arid areas, and could be done in places where other crops might not be able to grow.

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