More than Just Clean Energy: A Research Paper Exploring the Possibilities of Micro-Algae Based Biofuel Production as Part of a Solution to Problems Related to Anthropogenic Global Warming

By: Malikai Bass

A hard look into algae based biodiesel production by an East Tennessee State University reveals huge potential benefits in carbon negation, water filtration, and economic viability that may make it part of the Global Energy Future.

Malikai Bass is an undergraduate student at East Tennessee State University. He is majoring in Education, as well as, participating in an English honors program. His long term goals include attending George Washington University's museumology graduate program, opening a middle grades science and math museum, and writing children's books.

Table of Contents

Introduction: Why We Need an Energy Revolution

Currently it is a point in time where humanity as a whole must make significant changes regarding how we produce and use energy. The scientific consensus is that the environmental cost of our current energy is too high and will inevitably lead to environmental instability. According to Bill Nye, an American scientist and educator, we are reaching a tipping point soon we will be unable to recover from this cost. Therefore, according to Nye, we must immediately "take our foot off of the accelerator" and reduce the amount of carbon dioxide we are releasing into the atmosphere. (Nye).

Other sources claim we are already well past that tipping point; in fact, Michael Lemonick wrote 8 years ago that we had crossed it. In his view, it is already far too late and the environmental consequences of our carbon emissions cannot be undone. Michael Lemonick's *Scientific American* article went on to explain that the amount of carbon dioxide in the atmosphere is causing potentially irreversible changes in the atmosphere. Even if those who claim we are too far gone are correct, there is no harm in taking an optimistic approach; either we can save the planet, or we can stop the conditions from worsening.

Humans are contributing a lot of carbon dioxide into the atmosphere by burning fossil fuels—the methods we use for transportation, industrial manufacturing, and deforestation which inhibits the natural way carbon dioxide is removed from the atmosphere. This carbon is the source of the environmental consequences.

"Taking our foot off of the accelerator" means looking for an alternative, cleaner way to supply energy as well as being more responsible in our energy usage. We must lessen our

dependence on fossil fuels in order to brighten our future and that of the planet. Fossil fuel is a category of traditional fuel sources including petroleum, natural gas, and coal. These sources mostly coming from fossilized plants and animals are carbon based and nonrenewable.

One promising alternative is biofuels. Biofuels are an alternative to traditional diesel and petroleum made from biomass, usually plant based materials. One promising candidate for biodiesel is algae, which has a variety of benefits. Algae is actually the name of a large and diverse group of nonflowering plants. They contain chlorophyll, a chemical byproduct used to store energy, but lack leaves, stems, roots and many other things considered characteristic of plants.

Due to algae's unique composition and life cycle it has many benefits as a potential energy source. It can reduce the overall amount of carbon in the atmosphere, filter fertilizer runoff out of water, and be a hyper-local domestic fuel source.

Carbon Dioxide and Algae: A Complex Relationship

Algae needs only a few simple and readily available resources to grow. These include sunlight as an energy source, water, nitrogen and phosphorous, and carbon dioxide. Carbon dioxide is one of the main requirements for algae, as it is for most plants. One of the reasons for the low cost of algae-based biofuels is the over-abundance of carbon dioxide. (Lemonick).

Algae reduces the levels of atmospheric carbon dioxide. This reduction is the first benefit of algae production. Carbon dioxide is a greenhouse gas, and it contributes to the greenhouse effect. The greenhouse effect exists as a result of the relationship between sunlight and the Earth. When sunlight reaches the Earth not all of it is absorbed. Some of it is reflected as Infrared radiation. Most of this infrared radiation escapes into space, or at least it used to. Greenhouse

gasses trap the light inside Earth's atmosphere. This is what insulates the earth, like windows on a greenhouse. This means that the carbon dioxide in our atmosphere keeps infrared radiation from escaping. In theory, this is a benefit since it is what keeps the earth warm enough to support life.

More carbon dioxide means a stronger greenhouse effect and a stronger greenhouse effect leads to a warmer Earth. Yet, not all of the carbon humans release into the atmosphere stays there. Some of it ends up dissolving in the ocean. This raises the oceans pH levels and negatively impacts ocean creatures and habitats.

Algae decreases carbon in the atmosphere because algae take in more carbon to grow than algae-based biodiesel release when they are burned. This makes algae "carbon negative". Algae, therefore, is part of a group of technologies called "Negative Emission Technology" or NET. Switching to NETs is extremely important for climate stabilization[1] (Moreira). BECCS which stands for Bio-Energy Carbon Capture[2] and Storage, a subset of NETS and includes algae, is the most viable option. BECCS combines biomass production by photosynthesis, bioenergy conversion, and carbon capture to create energy without releasing carbon dioxide into the atmosphere (Moreira).

Algae can also be used to stop carbon dioxide from traditional energy production from being released into the atmosphere. Algae can be "fed" the carbon from power plants. The carbon dioxide produced by power plants can be captured and transported to algae production facilities. At the facilities, it can be used by the algae instead of being released into the atmosphere. (Svoboda).

[1] According to research done for an article published in volume 215 of Bioresource Technology (a peer reviewed scientific journal) Negative Emission Technology is the easiest way to reduce greenhouse gases. (Moreria)
[2] Carbon capture is done by heating it into a supercritical fluid and storing it for later use.

This is mutually beneficial for the industries involved as it increases algal growth and decreases carbon emissions. It also benefits the environment. In the event of a "carbon tax" which is being currently suggested by several scientists and economists, the carbon negative nature of algae might decrease the production costs and allow it to be even more economically competitive. Algae biofuel production centers could sell the rights to supply carbon to the facility (Doshi).

While supplying carbon dioxide to algae is easy and a potential benefit, not all of algae's requirements appear that simple at first glance. However, Algae and water have a unique and symbiotic relationship within the context of American industry and infrastructure.

Algae and Water: A Symbiotic Relationship.

The second benefit of algae is slight more complex: algae growth requires a relatively enormous amount of water. Algae is not a terrestrial plant. Therefore, it must be grown either in open ponds or large tanks of water. According to the National Academy of Science's 2012 report, it could take up to 123 billion liters of water for 39 billion liters of algal fuel. However, water used for algal growth can easily be recycled for other uses (Stecker).

Algae requires water rich with phosphorous and nitrogen. According to the NAS report it could take up to 15 million metric tons of nitrogen and 2 million metric tons of phosphorous to produce enough energy to fulfill the United States energy needs. The National Academy of Science found these amounts to be extremely concerning, because nitrogen and phosphorous, commonly used in fertilizer, can cause serious problems when they are present in excess in natural waterways (Stecker).

Fertilizers used by the agriculture industry soak through the soil into groundwater storage[3]. The water cycle then carries this polluted water into rivers, lakes, streams, and even the ocean. The nitrogen and phosphorous present in the fertilizer cause algae in these environments to grow far faster than the ecosystem can support. These "algal blooms" or growth spikes are detrimental to the food chain and overall balance in these environments. Some are even harmful to humans because they produce elevated toxins and encourage bacterial growth that can make people sick if they come into contact with the polluted water, consume fish, shellfish, or seaweed from that environment, or drink contaminated water. (EPA.gov).

A 2016 study at Rice University examined algae production for biodiesel as a possible solution to fertilizer run-off. In the words of study co-author Evan Siemann, a professor of bioscience at Rice University, "Wastewater treatment facilities currently have no cost-effective means of removing large volumes of nitrates or phosphorus from treated water, so algae production with wastewater has the potential of solving two problems at once" (Rice University).

The study took place in 12 open topped 600-gallon tanks in July 2013. The tanks were fed with wastewater that had been run through clarifiers to remove sewage and suspended solids. Tanks contained various forms of algae, and in order to determine which was best at water purification, these included oil-rich algal strains, mixed cultures, and even fish that "preyed upon algae-eating zooplankton" (Rice University).

The study found that the optimal case for algae production[4] was also the optimal case for water purification. "Monocultures with no fish and no cross-contamination was the case where we saw optimal performance" according to Seimann. Algal growth was "prolific" and "easy"

[3] 30 percent of all of the freshwater on earth is groundwater.
[4] *Chlorella* the strain most commonly used for algae growth at the time of the study, removed the most nitrogen and phosphorous.

according to the research. The algae removed “more than 90 percent of nitrates” and “more than 50 percent of phosphorus” from the contaminated water.

Therefore, algae based filtration systems in dams, water treatment plants, and well systems are an efficient and cheap way of filtering out fertilizer runoff. However, there are still several other benefits to algae production and biodiesel.

Other Benefits and Advantages

One of the advantages of algae as a fuel source is that it can be grown in a much wider variety of places than terrestrial biofuel feedstocks, for example, cities or deserts (Svoboda). Because algae can be grown in tanks instead of fields or on fertile land, algae biofuel production does not use resources needed for agriculture.

In addition, because algae can be grown in cities, there is no pipeline network required. This makes it much safer and more reliable than petroleum. There is no danger of oil spills or pipe explosions.

Domestic fuel production in the United States will also help our national economy. If we can get rid of our dependence on foreign oil, more money will circulate in the United States. Since it takes less money to produce algae-based biofuel than import fossil fuels this will also decrease national spending. Producing algae-based biofuel will also create jobs.

Algae has a strong case as a superior source for biodiesel. It has numerous benefits including environmental and economic benefits. Yet, Biodiesel from any source has its own advantages. Biodiesel performs several unique jobs that allow it to be a great supplement with wind and solar for completely clean energy.

Algae-based biodiesel's benefits therefore include having a carbon-negative nature, a low cost, and the ability to filter water. Additionally, biofuel has benefits as well.

Biofuel: Basics and Benefits

According to biodiesel.org, an information website run by the National Biodiesel Board, "Biodiesel is a renewable, clean-burning diesel replacement". "Clean burning" means that when burned it does not release harmful or inorganic substances. Biodiesel releases only a small amount of carbon dioxide and water vapor[5].

Most biodiesel is an oil like substance produced through a chemical process called transesterification[6]. In transesterification animal fat or vegetable oil is separated into two parts, glycerin (a byproduct used in other products such as soaps) and "Methyl Esters" (Biodiesel.org). It can be made from several different feedstocks including soybean, cottonseed, palm, peanuts and rapeseed (Knothe). It can also be made using recycled waste oils.

Biodiesel has many advantages besides being clean burning. While there are several sources for biodiesel, there is one that stands far above the rest: algae.

Biodiesel from Algae and Lipid Extraction.

According to experts interviewed by Elizabeth Svoboda for her article "The Greenest Green Fuel", algae is the cleanest and most efficient biodiesel fuel source. There are several different ways to turn algae into biofuel. However, according to a 2015 article regarding methods for algae production, a traditional and inexpensive method of creating biofuel from land-based

[5] According to the chemical equations for the combustion of Ethanol and Butanol (the end forms of biodiesel) the only byproducts are Hydrogen Dioxide and Carbon Dioxide. (Biodiesel.org)

[6] Transesterification: A chemical process by which triglyceride lipid fat molecules can be shattered into four molecules using methanol and caustic soda as a catalyst. (Biodiesel.org)

biomass, an oil press cannot be used effectively on algae. This is due to algae's small cell size, complex cell membrane, and thick rigid cell wall (Ranjith). Therefore, most alternative methods utilize strong chemicals and/or long periods of time to separate the oil from the rest of the algae.

According to research done by M. Mubarak for Algal Research Journal, lipid extraction is a key process in algae-based biodiesel production, but it is also very costly. Lipid extraction is the process by which the fat-based oils are removed from the algae. These oils are where the algae store energy produced by photosynthesis. Lipid accumulation accounts for 25-75% of the dry weight of algae (Mubarak). This is a benefit of algae since it is the lipids that are processed into biofuel.

There are two categories of methods for lipid extraction: mechanical and chemical (Mubarak). The chemical methods are very expensive. Some chemical-based methods utilize toxic chemicals, such as methane, chloroform, and n-hexane, which can have negative effects on the environment and humans exposed to them. Another method called "Supercritical Fluid Extraction[7]" utilizes carbon dioxide gas as a solvent, which while non-toxic, on its own is inefficient (Muburak). There are also complications involved with chemical methods, such as removing the chemicals from the lipids after extraction and making sure the lipids are not damaged by the solvents.

Mechanical methods utilize presses, ultrasounds, and microwaves to extract the lipids. However, these are less effective due to the thick cell wall. On average, they remove less than three-quarters of the theoretical maximum lipids from the algae (Muburak). This leads to a lower energy yield and a higher cost than chemical-based methods. However, there are significant

[7] The carbon dioxide gas is super-heated until it becomes a fluid, it is then used to separate the lipids from the rest of the algae.

advances being made in how we process algae. One of those advances is a methodology called combined algae processing, or CAP.

Combined Algae Processing: Methodology and Benefits

Researchers at the National Renewable Energy Laboratory have developed a method that circumvents the problems involved in traditional processing method. They use combined algae processing named because it combines several other techniques including supercritical fluid extraction and fermentation. (Biofuels.org) In combined algae processing, the algae are first processed whole. This whole algae pre-treatment makes lipid extraction easier and also ferments part of the algae into ethanol. According to the NREL, this process creates ethanol from sugars in the algae without compromising the lipids (Casey).

Combined algae processing, according to the National Renewable Energy Laboratory, gives algae the ability to compete with petroleum on an economic level. It does so by increasing the maximum energy yield and simplifying the refining process. CAP and similar methods bring the total cost per gallon to less than 2 dollars (Nyugen). The average price of regular[8] gasoline in the United States is two dollars and twenty-one cents according to CNN.com, as of November 2016. Algae-based biofuel is already cheaper than gasoline, without governments subsidies or other potential cost-cutting support. According to CNNMoney, the average cost of Diesel is well over four dollars a gallon. This means algae-based biodiesel is less than half the cost of traditional diesel. Algae also has the potential to be a cheaper source of jet fuel (Doshi).

[8] Non-premium leaded gasoline actually contains up to 15 percent ethanol.

Combined algae processing also increases the energy yield and efficiency of algae to about 126 Gallons of Gasoline Equivalent (GGE)[9] per ton (Casey). This is 88% of the theoretical maximum. This is also 32% more than the energy yields from lipid only processing.

The energy for algae-based biodiesel is actually a form of solar energy using the algae as "batteries" or storage. Therefore, photosynthesis is the limiting factor shared by all biomass. The amount of energy via light available to a plant is called the PAR or photosynthetically available radiation[10] (Gerpen). Plants convert various amounts of that energy into biomass. For most plants, that's about 1/27 of the theoretical maximum, but for algae, it is about 10/27 of the theoretical maximum. That works out to roughly 6,000 gallons per acre optimistically (Gerpen).

The most productive terrestrial biodiesel stock is palm oil. Factories are able to produce roughly 600 gallons of palm oil-based biodiesel per acre. Even without combined algae processing algae can reliably produce more than 2000 gallons per acre (Gerpen). Early estimates using combined algae processing are around 3,000 gallons per acre, and this is over three times the amount produced by palm oil, the leading terrestrial biofuel feedstock.

Biodiesel: A Necessary Part of the Solution

Biodiesel can do provide power in situations that solar and wind cannot. For instance, wind turbines include a mechanical engine that starts the rotation before the wind takes over. Currently, these engines are fueled by traditional diesel. This allows them to produce more energy, however, the consequences of diesel negate some of the benefits of wind power.

[9] Based on Energy yield of fuel equivalent.
[10] Light is a form of energy transportation. Photosynthetically Available Radiation is the total amount of energy in light.

While electronic cars, solar powered buses, and even electronic trains are all available alternatives to traditionally petroleum-powered transportation, not everything we currently use petroleum for can be replaced with solar or the wind. Jet fuel cannot be replaced with batteries or solar panels. Nonland-based transportation requires unique fuels and safety precautions, however, with algae-based biodiesel, we can meet those needs safely. The exploration of both space and the deep sea also are impossible with only wind, tidal, or solar power.

Conclusion and Summary

Humanity will eventually pay the cost for our carbon emissions, if we are not already. A liquid fuel source is essential to current technology and industrialization. Yet, our current energy system causes large amounts of carbon dioxide to release into the atmosphere. A liquid fuel source is essential to current technology and industrialization. However, if we are going to incorporate any sort of diesel into a clean energy solution, we should take care that we are doing so in the cleanest, most efficient, and most economic manner possible. Algae has no environmental consequences, does not negatively affect agriculture, can filter dangerous agricultural waste from water, and is also cheaper than every available alternative and traditional liquid fuel source.

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