Enclosed-system indoor algae production as a biofuel using artificial LED light

Worldwide, demand for fossil fuels is expected to outstrip supply, creating a peak where prices continue to rise and supply can no longer meet demand. Fossil fuels are also largely responsible for anthropogenic climate change, so that in order to maintain our current standard of living, sustainable alternatives are needed.

Biofuels could be a sustainable fossil fuel alternative. They sequester as much carbon during growth as they release in combustion, giving them potential to be carbon neutral. Because plant matter grows quickly, they are renewable on short scales and extremely scaleable to meet future demand. Because of decreasing fossil fuel supply, prices will rise, making biofuels a more affordable alternative. Even now, if social and environmental costs of fossil fuels are considered, biofuel may be less costly.

A variety of crops can be turned into biofuel, some of which are food crops. These include corn, sugar cane, and soybean, among others. Some other biofuel sources include oil palm, switch grass, and algae. Algae are a promising new biofuel, since they can have up to 300 times soybean yields. These yields are achieved largely because of its quick growth period and high oil content. Algae can also be grown in saltwater or even wastewater, conserving freshwater resources.

Traditionally, algae are grown in open and raceway ponds, but these have issues associated with them. Open ponds are land-use intensive, weather dependent, and easily contaminated. Raceway ponds, while more efficient than open ponds, are more expensive, while still easily contaminated and weather dependent. Artificial light bioreactors are a promising new algae growth method using a more controlled environment in order to optimize growth rates. In this project, we propose to attempt to grow algae cost-effectively in a small-scale bioreactor.

Our enclosed artificial light system could be more efficient than traditional methods for several reasons:
• In the Pacific Northwest, we have access to cheap, clean hydro-electricity, making artificial lighting more feasible.
• With artificial lighting, algae can grow in a controlled environment regulating CO2, temperature, and light conditions, and possibly running 24/7.
• The LEDs we plan to use only consume 9 watts of electricity, and have been optimized to produce ideal light for photosynthesis.

We hope that these advantages will allow our productivity to be higher than most commercial systems.

Our proposed design uses two ten-gallon tanks stacked vertically inside a mirror-lined plywood box. A CO2 tank enhances CO2 levels in the top tank, where the young algae need it most. These
young algae can’t handle bright light, so they don’t receive direct light; instead, the light shines from the bottom of the box, where the more mature algae can grow more quickly in bright light. The mirrors then reflect the light throughout the box, so that sufficient light reaches the younger algae in the top tank.

The future possibilities of bioreactors are enormous. People one day could have algae bioreactors in their garage, possibly even using the CO₂ that their car emits to grow algae. On a larger scale, all U.S. transportation fuel needs could be met by growing algae on less than 11% of existing crop-land. On top of being a superb fuel for transportation, 30-70% of algae biomass is unused in oil production, and this residual biomass could be used as animal feed in that it is high in carbohydrates and protein. Algae biofuel also has the enormous potential to decentralize and localize fuel production. This could be achieved by capture of CO₂ from vehicles and local growing and processing of algae. This would further lower the carbon footprint of biofuel transportation compared to oil that is shipped around the world.

Because algae can be carbon neutral, they have the potential to greatly reduce global warming. In order to avoid major warming, steps need to be taken now. Since newer technologies like clean electricity are not yet fully in place, we need something that can be implemented now, using no new technologies. Biofuels could be the immediate temporary solution, and algae fuel is the most productive biofuel.

An advantage that biofuels have over other technologies like hydrogen and electric cars is that very little modification is needed to make a vehicle run on biofuel. Being able to use current vehicles is a huge reduction in waste, reducing the need to get rid of old vehicles. This key point could also make biofuels excellent transition fuels as we move away from heavy fossil fuel use towards clean electricity and other sustainable technologies. Biofuels use currently available technologies, so no major infrastructure changes are required.

The major challenge facing algae production today is cost. Currently, a liter of algae biodiesel from a bioreactor costs about $2.80, in order to compete with $100/barrel fossil fuel oil, that cost will need to decline to $0.69 per liter. This, however, is not considering costs of CO₂ pollution among other impacts of fossil fuels. If subsidies and social costs were considered, the price gap would be much smaller.

No matter the outcome of our experiment, it would provide a starting point for future experiments. If our system succeeds, and is cost-effective, further study of our system in different scales would be the next step. Through further study, we could determine how to maximize yields, harvest more efficiently, and improve the construction and design of our system. If our system is not cost-effective, the next step would be more research into alternative methods. These could include improving open-pond efficiency, study of different types of bioreactors, and other alternative uses of algae. If our results are inconclusive, the next step would be more research into our method. This could be achieved by increasing sample size, eliminating possible biases, and repeating our study in order to strengthen conclusions.
Bibliography


   This paper makes the case that biodiesel derived from traditional oil crops cannot realistically satisfy “even a small fraction of the existing demand for transport fuels,” but that microalgae can produce considerably more lipid oil content per ton dry mass per hectare than food crops, and therefore can meet transportation fuel needs for the U.S. Comparisons between raceway ponds, tubular photobioreactors, and economics of biodiesel production are demonstrated.

   This paper is peer reviewed and we considered it the most complete and thorough explanation ranging from the potential of algae to how to make biodiesel that we had found from all of our readings. Also, this is the most cited paper on microalgae biodiesel production in the journal Biotechnology Advances.


   This is the website that sells SolarOasis products.

   The CEO of SolarOasis wrote a summary of the effects of their LED’s on algae growth stating that the light is very overwhelming at first and a light filter may be required. As a result we designed our system to take this into account and we have provided indirect light in the initial exponential growth phase (top tank). A hint by the CEO was suggested to run the light bars 24 hours, 7 days a week.


   This is the company’s webpage describing their patented 9 watt LED light bar.

   We found that through analyzing their patent that this company had by far and away had the most advanced system for photosynthesis optimized LED plant grow lights. These lights also equally work for algae growth. If we attempted to make our own LED grow lights that optimized photosynthesis we would have violated their patents and spent considerably more money than just buying their already manufactured grow lights.


   This article explains a company’s claim that they can capture CO₂ from a cars tailpipe and then empty the CO₂ into a photobioreactor. Although unsupported the company claims to capture a high percentage of a car’s CO₂ emissions.
We thought this idea supported our research into a home algae bioreactor system, and listed this as a potential CO₂ mitigating resource for the bioreactor.


This paper’s purpose is a response from other researchers that microalgae are inferior to terrestrial oil crops as net producer of renewable energy. Yusuf Chisti claims and demonstrates in this paper that microalgae can meet 100% of U.S. transportation fuel needs with microalgae biofuels on just 11% of U.S. cropping land.

This paper’s response to criticism from other researchers provided the equations that Yusuf Chisti’s previous research and this paper’s contents was based on such as: Total annual energy yield, Net energy yield, Effect of oil content of algal biomass and the biogas quality on total energy yield, Transport energy demand. This gave us the confidence that Chisti is one of the premier researchers/experts on the potential of microalgae as a biofuel.
Project title: Enclosed-system indoor algae production as a biofuel using artificial LED light.

Project dates: Begins: 01/15/2012 Ends: 02/18/2012

Academic term: Winter quarter

Amount requested: $833.35

**Project director** (i.e., the student who will serve as primary contact for the project; please provide current information about where you can be reached)

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**Faculty advisor(s)**

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Mail Stop: Lab 2

**Project description:**

Our investigation starts with a scientific and economic question: is it possible to grow algae for biofuel in a closed system in the Pacific Northwest—with limited sunshine and cheap electricity—competitively with large scale open raceway pond systems in the Southwest U.S.? We would like to use energy efficient LED grow lights that plants and algae have been shown to thrive with in enclosed environments.

Algae need sunshine, equal parts water and CO₂ (oxygenetic photosynthesis), and some trace minerals. We are not at this point interested in the conversion of algae into biodiesel. Our goals are (1) algae concentration, (2) growth rate and (3) lipid content analysis. These three metrics are critical to the determination of whether our system of production is competitive with the current most effective industry practices.
Our proposed system is a hybrid of two current practices, bioreactors and raceway ponds, both of which are mostly situated in sunny locales. Our initial construction plan is to use two fish tanks stacked on top of each other in an enclosed box, using mirrors to maximize light reflection. By stacking the fish tanks, we will be able to provide an optimum amount of light for each tank as well as using gravity to cycle algae from the top tank to the bottom one. For the CO₂ we will use a compressed tank to feed the gas into tubes lining the bottoms of the fish tanks and bubble up through the algae, to serve as a growth agent and agitator. We also plan to use passive recirculation of CO₂ to maintain containment in the box.

The optimum wavelengths of LED light for plant growth have been researched, and a patent-holding company produces LED grow lights that we would place at the bottom or side of the bottom tank. These LED lights have been shown to be too strong for the initial growth period, phase I, of the algae but are great after about the first 24 hours. Our plan is to grow the algae in the upper tank with reflected light, then drain the algae into the second tank with direct LED lighting for phase II, the next 24 hours. Algae have been shown to start growth and achieve harvest size in just 48 hours (in photo bioreactors) with ideal temperatures approximately 23°C.

Our first hypothesis is that in order to compete with raceway pond systems we will need to use energy extremely efficiently since we do not have the advantage of free solar energy. We believe this can be achieved with our design. Our LEDs would consume only 9 watts of electricity, and what little heat they give off will be put to work creating convection currents as an agitator for the algae. They may not provide enough heat on their own, so an agitator may also be necessary.

Our mirrors would reflect the light around the box, distributing light effectively and avoiding damage to young vulnerable algae. CO₂ will also be maintained at an elevated level within the box.

**Timeline:**

- **January 15th** -- Begin obtaining materials
- **January 22nd** -- Begin construction
- **January 29th** -- Begin first test
- **January 31st** -- Conclude first test
- **February 2nd** -- Complete drying and data collection
- **February 3rd** -- Begin second test
- **February 5th** -- Conclude second test
- **February 7th** -- Complete drying and data collection
- **February 8th** -- Begin third test
- **February 10th** -- Conclude first test
- **February 12th** -- Complete drying and data collection
- **February 18th** -- Complete data analysis

**Product and use of research:**

Algae are increasingly being accepted as the single greatest renewable feedstock for the production of biodiesel and other products. Algae can theoretically produce up to 100 times more oil per acre than conventional crops such as rapeseed, palms, and soybeans (http://rsif.royalsocietypublishing.org/content/7/46/703.full). Algae can be grown on land that is
not suitable for other established crops, and it grows 20 to 30 faster than food crops, without affecting human food markets (http://www.reuters.com/article/2009/02/10/us-biofuels-algae-idUSTRE5196HB20090210?pageNumber=2&virtualBrandChannel=0).

Currently, algae-based biodiesel is not economically competitive with other forms of biodiesel. Open pond algae to biodiesel fuel prices are $9.84/gal and the photo bioreactors fuel prices are $20.53/gal. Research into reducing costs of production is ongoing. Our investigation would try a new method of algae growth in attempt to reduce costs, and the system would be left on the Evergreen campus for continuing research by other students.

**How the project fits academic work:**

Our current program, Energy Systems and Climate Change, is largely focused on energy. We have looked at how energy is harvested, used, and misused. One promising source of alternative renewable energy is biofuel, but only if done correctly. We have learned about fossil fuel use and its contributions to environmental degradation and global climate change.

This project fits our academic work well because it builds on research that we have read about. It would give us an opportunity to take our learning out of the textbook and in to the field. Not only will this help us academically, it will also help other students understand what we are researching. Through discussions with other classmates, they will be able to engage in our project and build a greater understanding of the program material.

**How the project fits Evergreen career:**

Jaal Mann: I have been fascinated with environmental studies for a long time, taking classes related to it in high school, community college, and now Evergreen. It was not until now, however, that I had a chance to actually contribute my own original research to the field. This project would give me an opportunity to begin to change my role in science from an observer to a participant. With this project I could apply skills that I have learned both before and since coming to Evergreen to advance the fascinating field of biofuel research. I plan on continuing at Evergreen next year in the Masters of Environmental Studies program, and this project would provide a fantastic basis for further research there.

Michael Karch: I am a business student at Evergreen and I am personally interested in science in general. I would love to be able to be involved with research that could lead to an environmental solution that would also have a business fulfillment. Algae have caught my interest due to the urgency of environmental problems. There needs to be an alternative solution to oil. Algae have the dual capacity to both consume CO₂ and help with the transition off of fossil fuels. There needs to be more work done with algae, and I am strongly interested in the pursuit of a combination of science research and business collaboration to reduce production cost.

**How we will hold to Evergreen's core teaching and learning values:**

This project would adhere strongly to The Evergreen State College’s important values of collaborative learning, personal engagement, and linking theory with practical applications. This project would provide hands-on experience for us in a topic related to our areas of interest, and
would be extremely engaging as well as educational. We would collaborate as a team, and build on each other’s knowledge to complete a project that neither of us could have done alone.

We have learned about many different theories regarding sustainability, energy, and (more specifically) biofuels. This project would allow us to put this theory into practice, and provide a valuable teaching resource for Evergreen in the future. After completion of the project, it could remain on Evergreen’s campus as a way to help engage and teach others about the practical applications of their learning.

**Project significance:**

Algae biofuel is a promising energy source for the future. Other types of biofuels can be energy and land-intensive, and therefore have more drawbacks than algae. Currently, most large-scale algae operations are in open ponds because they are cheaper to build. Open ponds, however, have some serious drawbacks. They take up a lot of land since they have to be shallow for light to penetrate, they can be easily contaminated, and they can only operate seasonally and in certain areas with favorable climates. The closed system proposed in this project would be a different approach which would hopefully make up for any increased cost with increased yields.

In the Pacific Northwest we have cheap energy due to hydropower, but much less sunlight than many areas. For those reasons, it is a perfect place for indoor closed-system algae cultivation. An indoor closed-system could be operated 24/7, 365 days per year. This gives it a tremendous advantage over an open-pond system. The impact of our research would be to show whether or not an indoor closed-system bioreactor could cost-effectively be used to create fuel for a household and/or larger scale operation.

In the future, more research will be done on alternative energies, and algae biofuel is likely to be an essential one. Because biodiesel made from algae can be used in conventional diesel engines, it is an excellent stepping stone in the transition to a clean-energy society. Because of the increasing price of fossil fuels, biofuel popularity will continue to increase, and our project would help ensure that investments in new biofuel projects go towards the most efficient and effective ones.
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