Optimizing Microalgae Growth for the Production of Biofuel as a Green-Energy Source

Teagan Kilian

April 15, 2025

1 Introduction

It is no secret that scientists all over the world are scrambling to uncover the worlds next great, green energy source. The attention to the energy sector is clearly much needed; however, innovation is not coming quickly enough. The UN states that 60% of climate change-contributing greenhouse gas emissions are produced by energy consumption [9]. It is evident that humanity must quickly find an alternative energy source which is clean, reliable, and cheap. There are currently many green energy sources that have been integrated into the global energy grid such as solar photovoltaic power, wind energy, and hydroelectric power, to name a few. These energy sources provide a promising future outlook; yet, it is becoming increasingly clear that these technologies are far less cost-effective and efficient than what is required to truly mitigate the risk of irreversible climate damage.

In addition to the fore-mentioned green energy sources, microalgae based biofuel has great potential to transform the energy and fuel industry. Various species of marine algae are currently being raised on algae farms for their biomass to be processed into an energy source. Aligning with the re-occurring theme of most clean energy sources, algae has yet to be proven profitable. It is evident that growing algae takes relatively few resources and has a comparatively small environmental impact. With that being said, it is certainly worth inspecting how this industry can be transformed to increase its efficiency.

2 Algae as a Biofuel

Various types of microalgae have been considered an operational source of green energy. Some of the major reasons why algae is so interesting is because its cultivation does not take resources away from other necessary processes. What's more, the process of algae cultivation has many other favorable outcomes. Algae biofuel is considered to be a third generation biofuel. Third generation biofuels have the potential to be very efficient and environmentally friendly since they can produce higher outputs of energy with lower inputs [6]. Algae can be cultivated in existing shallow lagoons and ponds or biophotoreactors (PBR) on land that would not otherwise be used for food production [8]. The overall cultivation process of algae does not burgle resources from the farming and agriculture industries.

Furthermore, algae have been shown to be very effective in treating waste water. Algae require nutrients and fertilizer to grow; therefore, using wastewater in algae farms provides both a green source of fertilizer and a way of removing hazardous materials from the water. Algae have the ability to remove 80-100% of nutrients and heavy metals from the water they inhabit [8]. Notably, algae also survive by completing photosynthesis - removing carbon dioxide from the air in order to produce energy [6]. Algae not only have the potential to produce valuable energy, but the ability to transform waste and byproducts are not favorable for humans.

2.1 Microalgae

Algae are marine photoautotrophs that use fertilizer, CO2, and light to produce energy. Algae grows at very rapid rates and can be up to four times more efficient than terrestrial photoautotrophs in completing the process of photosynthesis [6]. There are over 25,000 known types of marine algae in the world which all have slightly different characteristics and environmental preferences in order to have peak performance [6]. For this reason, it is necessary to study specific species to determine the optimal condition for individual alga type. Some common algae used for biofuel production include *C. protothecoides*, *C. stigmatophora*, *C. vulgaris*, *Desmodesmus sp.*, *E. pseudoalveolaris*,*S. abundans*, *S obliquus*, and *T. chui*. As the algae progress in their life cycle, they uses the nutrients found in their environments to produce carbohydrates, lipids, and proteins [8]. The main factors that appear to influence the production of these materials are environmental temperature, PH of the water, available nutrients, and the type of reactor the algae are grown in.

2.2 Biofuel

Biofuel is the final product in the process of cultivating algae as an energy source. In this context, biofuel encompasses biodiesel, bioethanol, biomethane, and biobutanol - all of which have various individual applications [8]. Biofuels obviously vary in composition based on their source and the application they will be used for.

Certain characteristics of fuels are more favorable for particular uses. It would be optimal to hone the production of these fuels so they contain the molecules that give them the most favorable properties. For algae based biofuel specifically, it has been seen that the light available to algae colonies can impact the presence saturated fatty acids (SFAs). The increased presence of SFAs in algae relate to the cetane number (CN) of the fuel derived from those algae. The CN is a property of fuel which is directly correlated to efficient combustion by creating a more oxidative stable fuel which produces less nitrous oxide and has less of an ignition time delay [5]. This effect has been verified in a 2017 study by Rai and Gupta analyzing the CN of *S. abundans* which found that the experimental conditions (continuous illumination of the algae by white light with an intensity of 27 $\mu mol/(m^2 s)$) allowed the generated biofuel to have a CN of about 53.68. This value is above the minimum limit for this value in the US and Europe; therefore, would be acceptable as a biodiesel [5].

2.3 Current Challenges

Like many up and coming green energy sources, alga based biofuel remains costly due to low efficiency and complex processing [6]. One way to increase the efficiency of this biofuel process is to focus on cultivating microalgae that produce large amounts of biomass

- specifically, with high percentages of lipids. In this way, the fuel that is produced downstream will be more energy dense and therefore more cost-effective.

The use of sunlight as a light source has a few associated disadvantages. The primary concern is the lack of sun exposure in certain parts of the world and at certain times of the year due to seasonal changes or weather conditions [1]. Among the disadvantages, there is one clear advantage that sunlight has over any other alga-tailored light source: it is free. According to a review of the feasibility of microalgae grown using artificial light sources, the cost of lighting would need to be below 1.3 $kg/DW to make the process economically viable. At the time the article was written (2013) the lighting cost was calculated to be 16.1 $kg/DW [1].

Even if the economic cost of using artificial light sources can decrease enough in the near future, the environmental cost may not be enough to justify their use. Algae based biofuel is clearly an alternative energy source that is much more environmentally friendly than other non-renewable sources. Nonetheless, if artificial light sources are required to make algae fuel dependable, there are likely to be hidden environmental maladies in the cultivation process. As seen in figure 3, precious resources are lost at every step of the biofuel process. Using artificial light that is powered by a carbon dense energy source to produce an alternative clean energy source would be counterintuitive and the net carbon output would conclusively not be as low as one might assume.

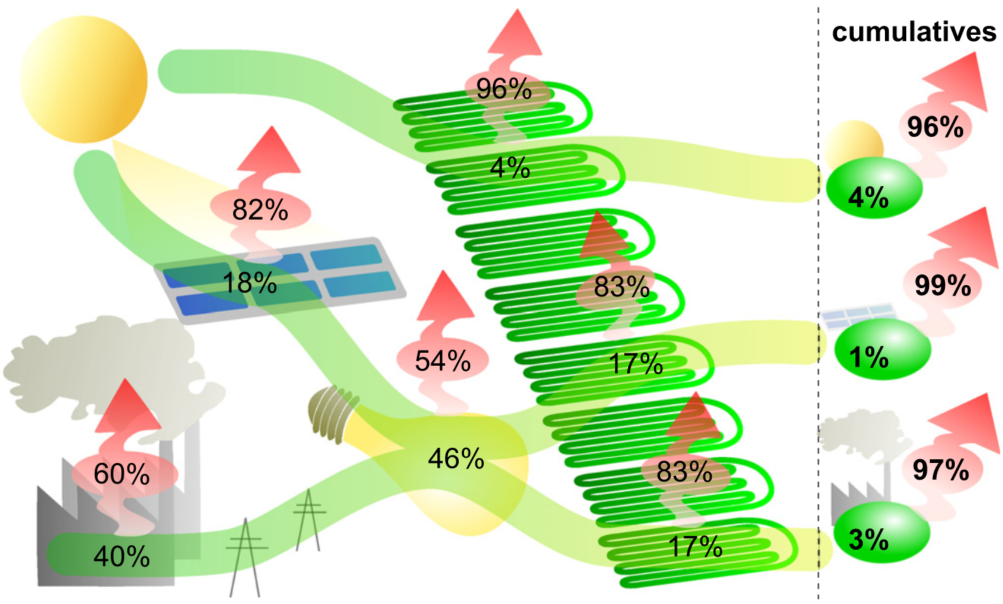

Figure 1: Monochromatic light being absorbed and reflected by an algae cell [1].

3 Light

Because algae are photoautotrophs, light plays a large role in the life cycle of these organisms. As previously stated, if algae based biofuel is ever to be seriously considered a viable green energy source, the optimal light source must be found for each alga species. Combining optimal lighting conditions with the correct growth environment and supplemental nutrients, may allow algae to become an energy source of the future.

Traditionally, sunlight has been used for the cultivation of photoautotrophic algae as it is free, abundant, and it is the light source that algae have adapted to. At first glance, sunlight seems to be the obvious choice of light source for this application; however, there are some drawbacks associated with it. Sunlight is only available for a given amount of time per day. When differing hours of daylight due to latitude and seasons or weather conditions are factored in, the daily duration of sunlight is quite limited. It is important to examine different artificial lighting schemes - in terms of wavelength, lighting duration, and intensity - and if they can out perform sunlight is the algae cultivation process.

3.1 Wavelength

One way to improve the efficiency of light sources used in algae cultivation is to discover which specific wavelengths the microalgae respond to best and provide them with a light source that has a spectrum which is honed to each species photosynthetic needs. A study carried out by P.S.C. Schulze et al. examined how light source and wavelength affect the algal biomass production of two species of algae: *N. oculata* and *T. chuii* [7]. The study investigated how well the algae grew under red, blue, and white LED and fluorescent light sources. Ultimately, it was found that both species grew better under the fluorescent light compared to those grown under the LEDs. Generally, light sources that emitted higher levels of red photons allowed algal growth rates to be higher. In terms of growth optimization, P.S.C. Schulze et al. determined that dichromatic light that included blue and red photons at the wavelength of about 390 to 450 nm and 660 nm, respectively, allow the algae to produce the most biomass [7]. The optimal wavelengths are denoted in Figure 2 which shoes that these wavelengths correspond to red and blue lights [4]. These results make sense due to the fact that both of these algal species are green in color; therefore, adding green light to their environmental conditions would not cause any additional light absorption. Figure 3 demonstrates how red light will be absorbed by an algae cell and green light will be reflected along with some blue light.

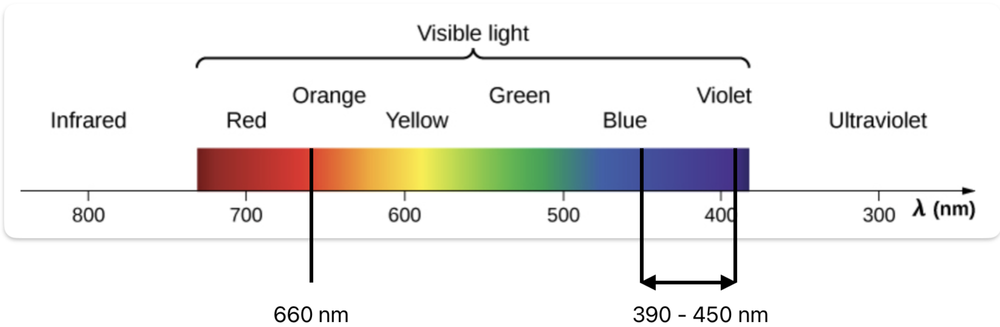

Figure 2: Ideal wavelengths for alga absorption [4].

Further, it has been found that the photosynthetic efficiency of microalgae grown while exposed to red light is 13% more efficient than that grown in natural sunlight [1]. The sun produces white light which has a broad wavelength spectrum and the algae are not able to take advantage of each of the colors of light available. This further proves that red photons are better absorbed by certain species of algae so, light sources with wavelengths in the red-range are the preferred lighting condition for algae farms. These

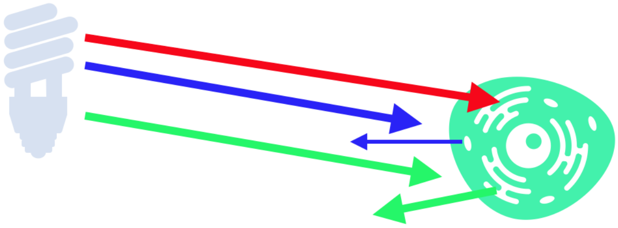

Figure 3: Monochromatic light being absorbed and reflected by an algae cell.

findings provide a guideline for the environmental design and function of algae farms. Having the correct lighting source can decrease the amount of energy that is lost to inefficiencies throughout the microalgae growth process. Improving efficiency is critical in producing the most environmentally friendly fuel source as possible.

3.2 Duration of Light Exposure

It may seem intuitive to assume that continuous light exposure will optimize the photosynthetic capacity of photoautotrophs; however, it is also important to retain the fact that algae have adapted to live on Earth which typically has an average of 12 hours of daylight and 12 hours of darkness per day [2]. M.P. Rai and S. Gupta examined this phenomenon in their 2017 study of various factors affecting the growth of *S. abundans* [5]. Using a light scheme of 16 hours of of light at an intensity of 40.5 $\mu mol/(m^2 * s)$ to 8 hours of darkness, the algae produced the highest level of biomass and lipids compared to lighting schedules of 24 hours of lightness, 24 hours of darkness, and 8 hours of lightness to 16 hours of darkness [5].

Clearly, there is some need for algae to experience darkness based on the evidence that optimal biomass production is not found when lighting conditions are constant over 24 hours. In fact, photosynthesis is a two step process - one of which occurs in the presence of light and the other in the absence of light. During the photochemical phase, light is used to produce ATP. In the biochemical dark phase, the ATP and other compounds that were produced in the previous phase are used to perform metabolic processes within the cells [5]. Since there are clearly some metabolic processes that must occur in the absence of light, it is essential that if artificial lighting is used, the lights are turned off for a certain period of time.

3.3 Intensity

The question of optimal light intensity for algal biomass production is very important because having less than optimal light intensity will not allow the algae to produce the highest yield. On the other hand, having light intensity that is too high will not produce any greater benefits while wasting the energy used to produce that extra intensity. Further, light that is too intense could damage the organisms and inhabit them from producing biomass all together. A study carried out by Nzayisenga et al. aimed to explore this exact issue and found the light intensity that produced the highest biomass production of four microalgae species [3]. The species in this study - *C. vulgaris*, *Desmodesmus sp.*, *E. pseudoalveolaris*, and *S. obliquus* - were grown in waste water in the Northern

Hemisphere. Each of the species had samples that were exposed to one of three light intensities: 50, 150, or 300 $\mu E/(m^2 * s)$. It was found that each of the species responded positively to the higher intensity values. Specifically, *Desmodesmus sp.* and *S. obliquus* responded to the more intense light by out-performing the other two species in terms of biomass growth [3].

M.P. Rai and S. Gupta observed that *S. abundans* responded the best to exposure to 40.5 $\mu mol/(m^2 * s)$ - allowing both the biomass and lipid production to reach a maximum. At this light intensity, the lipid content was 48% compared to 29.6% and 33% lipid content for this algal species grown at light intensities of 27 $\mu mol/(m^2 * s)$ and 54 $\mu mol/(m^2 * s)$, respectively [5].

This study only considered a few algal species which may not be viable in all algae farm locations. Therefore, the prescribed most efficient light intensity can not be applied to all algae species and experiments to determine how much light the algae should be exposed to must be conducted on a case by case basis.

4 Conclusion

All optimal parameters discussed previously are only relevant for the species that were specifically examined. Optimal conditions will clearly differ between species. In terms of wavelength specifically, it appears that artificial light sources beat sunlight in terms of productivity. Artificial light can also be better at providing the optimal duration of light exposure especially in situations where there is persistent cloud cover or few hours of sunlight in the winter months. With that being said, it is important to remember that algae has adapted to the natural cycles of the sun and therefore constant exposure to light would negatively impact the organisms ability to undergo photosynthesis. If artificial light sources are used, they must be placed on a periodic cycle that coincides with the species-specific optimal light-to-dark ratio.

The production of biofuel is invaluable to humanity moving toward a carbon neutral future. Algae based biofuel is certainly a viable venture in terms of a future renewable resource because its biomass can be processed in many ways to generate a multitude of fuel types for a multitude applications. Microalgae cultivation is especially interesting because it has the potential to produce a carbon deficit rather than just carbon neutrality. Because algae are photoautotrophs, they use carbon to as a part of their metabolic processes.

Currently, more exploration needs to be conducted on the matter of algae based biofuel because the process has yet to be economical on a major scale. If this feat is ever to come to fruition, some form of artificial light will need to be highly tuned to the needs of these organisms.

References

[1] Ward Blanken, Maria Cuaresma, René H Wijffels, and Marcel Janssen. Cultivation of microalgae on artificial light comes at a cost. *Algal Research*, 2(4):333–340, 2013.

[2] Lunar and Planetary Institute. Day and night - skytellers, n.d. Accessed: 2025-04-01.

[3] Jean Claude Nzayisenga, Xavier Farge, Sophia Leticia Groll, and Anita Sellstedt. Effects of light intensity on growth and lipid production in microalgae grown in wastewater. *Biotechnology for biofuels*, 13:1–8, 2020.

[4] OpenStax. *University Physics Volume 3*. OpenStax, 2022. Accessed: 2025-04-01.

[5] Monika Prakash Rai and Shivani Gupta. Effect of media composition and light supply on biomass, lipid content and fame profile for quality biofuel production from scenedesmus abundans. *Energy Conversion and Management*, 141:85–92, 2017.

[6] Sumathy Rengarajan, Mathiyazhagan Narayanan, and Ying Ma. A comprehensive review of current progress in biofuel production using marine algae biomass. *Biocatalysis and Agricultural Biotechnology*, page 103311, 2024.

[7] Peter SC Schulze, Hugo GC Pereira, Tamára FC Santos, Lisa Schueler, Rui Guerra, Luísa A Barreira, José A Perales, and João CS Varela. Effect of light quality supplied by light emitting diodes (leds) on growth and biochemical profiles of nannochloropsis oculata and tetraselmis chuii. *Algal research*, 16:387–398, 2016.

[8] Sakshi Tomar, Shruti Agarwal, Harshita Singh, Reetesh Kumar, Kamal A Qureshi, Mariusz Jaremko, Abdul-Hamid Emwas, and Pankaj Kumar Rai. Microalgae: a promising source for biofuel production. *Biocatalysis and Agricultural Biotechnology*, 53:102877, 2023.

[9] United Nations. Affordable and clean energy - sustainable development goal 7, n.d. Accessed: 2025-04-01.