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ALGAE: THE SOLUTION AGAINST CLIMATE CHANGE?

INTRODUCTION

Climate change is one of the biggest challenges of our time and is associated with rising average temperatures and extreme weather events. Resulting heatwaves combined with long periods of drought were linked to Australian bushfires of unprecedented magnitude last year.[1] The UN estimates that burning fossil fuels accounts for 76% of our greenhouse gas emissions (mainly carbon dioxide – CO_2) which is the main cause for climate change.[2] Despite the knowledge about the detrimental effects of fossil fuels on the climate, it has been predicated by the International Energy Agency (IEA) that they will still account for 77% of all fuels used by 2040.[3] It is therefore critical to develop novel effective ways to reduce the atmospheric CO_2 burden and to decrease further greenhouse gas emissions.

Algae are believed to be an excellent option for greenhouse gas control as they absorb large amounts of CO_2 and their biomass can be converted into sustainable ecofriendly fuel. While in the past the mass culture of algae has been restricted by difficult to control rapid algae growth and production conditions, recent advancements in technology have made it possible to scale up production.[4] Algae could therefore become an effective solution against climate change.

BACKGROUND

Algae are a diverse group of aquatic organisms ranging from large seaweed (macroalgae) to microscopic organisms (microalgae). Algae are a fundamental part of many ecosystems, providing the foundation for aquatic food chains. Algae can grow in almost all types of water, including brackish, sea and wastewater, which are unsuitable for agricultural cultivation.[5] Images of algae and a diagram of an algae spirogyra cell can be seen in figures 1, 2 and 3.

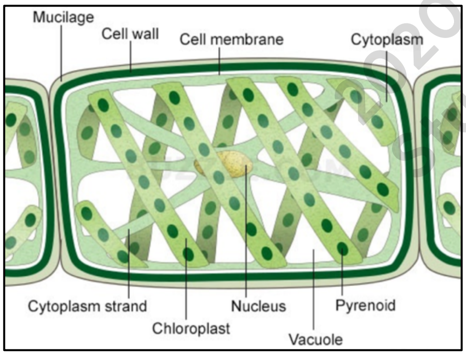

Figure 1. Algae Spirogyra cell diagram
(QS study, 2020. *Labeled Diagram Of Spirogyra*. [image] Available at: <https://www.qsstudy.com/biology/describe-with-labelled-diagram-the-structure-of-spirogyra> [Accessed 1 July 2020].)

Figure 2. Algae Spirogyra under a light microscope (x 40)
*(*Aytar, E., 2020. *Spirogyra Sp. Algae Under Microscopic View X40 - Chlorophyta.* [image] Available at: <https://www.dreamstime.com/spirogyra-sp-algae-under-microscopic-view-chlorophyta-image179352431> [Accessed 1 July 2020].)

Figure 3. Algal bloom (Windsor Lake 2019)
*(*Sanchez, H., 2020. *Blue-Green Algae At Windsor Lake On Friday, July 19, 2019*. [image] Available at: <https://www.cpr.org/2019/08/29/whats-up-with-the-algae-blooms-in-colorado-and-why-are-they-so-hard-to-track/> [Accessed 1 July 2020].)

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[1] United Nations Sustainable Development. 2020. *Climate Change*. [online] Available at: <https://www.un.org/sustainabledevelopment/climate-change/> [Accessed 28 June 2020].
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[5] Marimuthu, D. and Jayaraman, A., 2018. Isolation and Growth Characterization of the Fresh Water Algae Chlorosarcinopsis Eremi on Different Growth Media. *Journal of Pure and Applied Microbiology*, 12(1), pp.389-392.

Most algae are photosynthetic organisms. Thus, utilize light energy to convert inorganic CO_2 and water into organic biomass and oxygen, through a process known as photosynthesis.[6]

The chemical reaction for photosynthesis can be seen below.

$$6CO_2 + 6H_2O \xrightarrow{Photosynthesis} C_6H_{12}O_6 + 6O_2$$

Most algae are classified as autotrophic, as they have the capability of converting inorganic carbon into a nutrient source. They are also classified as phototrophic due to their dependence on light.

ALGAE APPLICATIONS AGAINST CLIMATE CHANGE

Carbon sequestration

Carbon sequestration is the process of capturing and storing atmospheric CO_2. The global biosphere absorbs nearly two billion tonnes of CO_2 annually, which accounts for nearly 1/3 of all CO_2 emissions.[7] This has created particular interest in biological means of CO_2 sequestration.[8] Algae sequester CO_2 naturally during photosynthesis and approximately half of the algae biomass dry weight consists of carbon which is derived from CO_2.[9] The approximate molecular formula of microalgae dry biomass is $CO_{0.48}H_{1.83}N_{0.11}P_{1.01}$.[10] This means that for about every kg of algae dry mass gained, 1.83kg of carbon dioxide is bound.[11] Thus, photoautotrophic algae have the potential to be used to sequestrate CO_2 out of the atmosphere.[12] Microalgae are of particular interest for researchers as they double their biomass every 24 hours and during their exponential growth phase can even double in mass as quickly as every 3.5 hours.[13] Due to their rapid growth and uncomplicated cellular structures, microalgae have a CO_2 fixation efficiency which is 10–50 fold higher than that of terrestrial plants.[14]

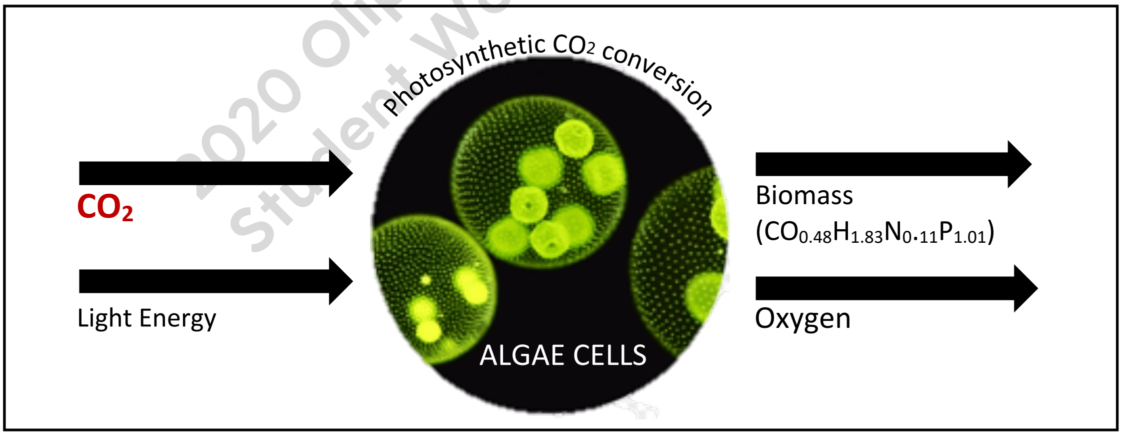

Figure 4. Photosynthetic conversion of CO_2 into microalgae biomass
Adapted from: Kativu, E., 2014. *Carbon Dioxide Absorption Using Fresh Water Algae And Identifying Potential Uses Of Algal Biomass.* [online] Core.ac.uk. Available at: <https://core.ac.uk/reader/39669356> [Accessed 20 July 2020].

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Microalgae culture and bioreactors

Large scale microalgae culture has been successfully achieved with green algae species such as *chlorella*, and *spirulina.*[15] Microalgae are cultivated on land in large ponds, or in enclosed photobioreactors. Open ponds are the most common means of cultivating algae as they are fairly simple to construct and are low cost.[16] However, they face a variety of limitations, including low biomass conversion or loss of CO_2.[17] Therefore, for effective CO_2 sequestration and to maximise algae growth, photobioreactors had to be developed. Photobioreactors contain large volumes of algae in a typically enclosed environment and vertical arrangement, which is maintained to maximise algal photosynthesis. There are several different types of bioreactors, including plate photobioreactors, tubular photobioreactors and bubble column photobioreactors, all of which require human monitoring to maximise the algae's exposure to light energy and maintain ideal growth conditions.[18]

Large scale algae production has been technically challenging, due to the variety of factors limiting algae culture such as light and pH (see table 1), as well as rapid, difficult to control growth.[19] However, recently the company Hypergiant from Texas, USA, developed an artificial intelligence (AI) bioreactor which not only uses AI to maximise algal growth by maintaining optimum temperatures and light intensities but also monitors algal development without human intervention through computer learning.[20] An image of the Hypergiant bioreactor can be viewed in figure 5. Bioreactors such as the Hypergiant bioreactor allow the culture of algae in a controlled large-scale system for CO_2 sequestration and synthesis of products such as biofuel.[21]

Table 1. Factors limiting microalgae growth

Operational factors	Barriers to growth such as inappropriate dilution rate, depth, harvest frequency and addition of bicarbonate, and shear produced by mixing
Biotic factors	The presences of pathogens (viruses, bacteria and fungi) and competition from other algae.
Abiotic factors	Light, temperature, pH, salinity, presence of toxic chemicals, oxygen and, concentration and bioavailability of nutrients.

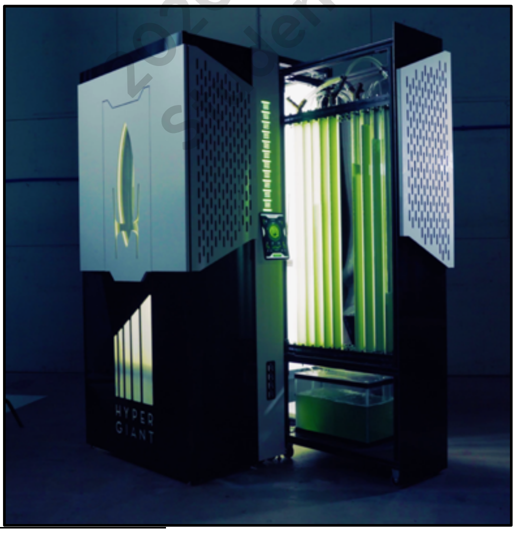

Figure 5. Hypergiant AI Algae Bioreactor
(Hypergiant,2020. HYPERGIANT EOS BIOREACTOR. [image] Available at: <https://www.hypergiant.com/green/> [Accessed 1 July 2020].)

[15]Kativu, E., 2014. *Carbon Dioxide Absorption Using Fresh Water Algae And Identifying Potential Uses Of Algal Biomass.*. [online] Core.ac.uk. Available at: <https://core.ac.uk/reader/39669356> [Accessed 20 July 2020].
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Fuel generation

Microalgae are great candidates for sustainable production of biofuels. Production of biofuels from algae relies on the lipid content of the organisms. The main fuel produced from algae is biodiesel.[22] During the biodiesel production process raw oil is extracted from the biomass created by algae through expression, ultrasonic method or chemical solvents such as benzene or hexene which cause the cells to break down and release the oil.[23] The oil then undergoes a conversion process into fuel, known as transesterification.[24] Transesterification is the reaction of a triglyceride (fat) with an alcohol to form esters and glycerol. A triglyceride has a glycerine molecule at its base with three long chain fatty acids attached.[25] The fatty acids react with the alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide, to form the biodiesel and crude glycerol.[26] The algae biodiesel cultivation circle can be seen in figure 5.

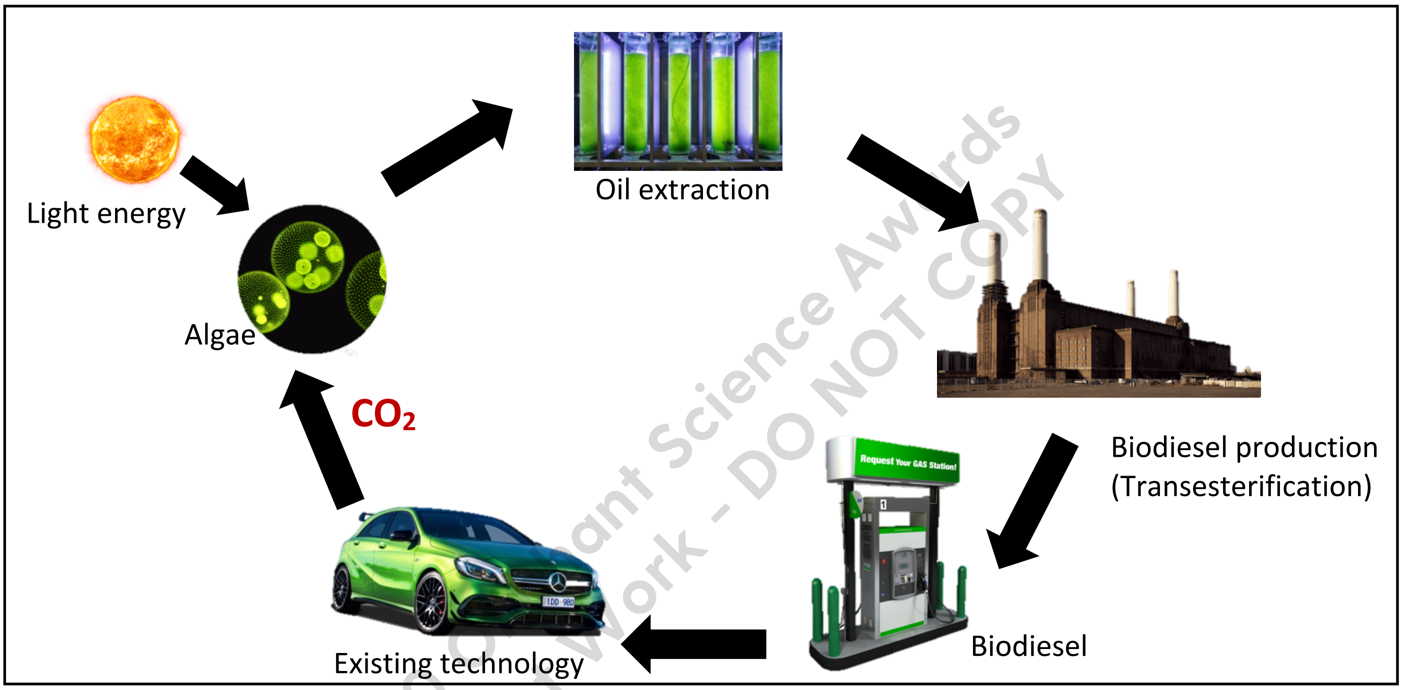

Figure 5. Algae biodiesel circle
Adapted from: Phillips, B., 2018. *Algae As Energy: A Look To The Future - Climate, Energy, And Society - College Of Liberal Arts - Auburn University*. [online] Cla.auburn.edu. Available at: <https://cla.auburn.edu/ces/energy/algae-as-energy-a-look-to-the-future/> [Accessed 21 July 2020].

Biodiesel when combusting under optimal conditions compares favourably to petrol diesel, producing less carbon dioxide per kilogram combusted.[27] However, one issue with biodiesel can be the emission of nitric oxide which is poisonous and can contribute to acid rain.[28]

Algae can also be used to produce a second fuel, hydrogen, which outweighs biodiesel in ecological sustainability.[29] Biohydrogen is considered clean and sustainable as its combustion only results in H_2O as end-product, as can be seen below.[30]

$$2H_2 + O_2 \xrightarrow{Cobustion} 2H_2O$$

[22] Nandan, S., 2020. Biofuel Production Technology from Bioenergy Crop-Algae Biofuel. *SSRN Electronic Journal*.
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Biological hydrogen is produced as a by-product of algal metabolic pathways. There are three potential mechanisms of biohydrogen production in algal cells: 1. Direct bio-photolysis, 2. Indirect bio-photolysis and 3. Dark fermentation. The three processes can be seen below.

$$1.\, 2H_2O + light\ energy \rightarrow 2H_2 + O_2$$

$$2.\, 6H_2O + C_6H_{12}O_6 + light\ energy \longrightarrow 12H_2 + 6CO_2$$

$$3.\, C_6H_{12}O_{12} + 2H_2O \rightarrow 2C_2H_4O_2 + 4H_2 + 2CO_2$$

1.Bio-photolysis 2. Indirect bio-photolysis 3. Dark fermentation

Though many algae species show the potential to produce hydrogen under certain conditions, the harvesting of hydrogen as a fuel from algae is in the early stages of development and there are still technical issues regarding the optimization of the process and collection of the end product during synthesis.[31]

DISCUSSION

Carbon combustion for energy production produces more than 24 gigatons of CO_2 annually.[32] As a result, atmospheric CO_2 concentrations have risen from 295 parts per million (ppm) to 380 ppm over the last 100 years, and have been the cause of global warming and climate change.[33] The Intergovernmental Panel on Climate Change of the United Nation has therefore set the aim to reduce CO_2 emission levels by 25% from 2010 until 2030 and reach net zero emissions by 2050.[34] However, CO_2 emissions continue to rise, and the greatest concentration of CO_2 in the atmosphere in human history was measured in May 2020.[35] Although greenhouse gas emissions are projected to drop by about 6 per cent in 2020 due to travel bans and economic slowdown as a result from the COVID-19 pandemic, this improvement will only be temporary.[36] Climate change will therefore not stop.[37]

The application of algae as a means of carbon capture could be a suitable solution against rising CO_2 emissions.[38] Algae when used in conjunction with an AI-powered bio reactor are up to 400 times more efficient in removing CO_2 from the atmosphere than trees.[39] Therefore, carbon-capture with algal bioreactors would potentially enable cities to become CO_2 neutral or even negative.[40] Furthermore, algae are known to grow in high CO_2 concentration environments and methods have been developed for the integration of flue-gas from power plants with algae production for the capture and utilization of CO_2.[41] Moreover, unlike terrestrial plants algae can be cultivated vertically and fairly compactly, thus providing the opportunity for algae carbon sequestration in densely populated cities. This was shown last year when the

[31]Nandan, S., 2020. Biofuel Production Technology from Bioenergy Crop-Algae Biofuel. *SSRN Electronic Journal*.
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company EcoLogicStudio installed 'urban curtains' in London.[42] The curtains consists of thin vertical arrays of algae and have been shown to be as effective as seven fully grown trees.[43] They plan on having the 'urban curtains' installed in 5 other locations by the end of 2020.[44]

Microalgae are showing huge potential as a sustainable source of biofuels. It is expected that if fossil fuels are used to the extent they are today, that they will be depleted in just under 50 years.[45] The production and use of biofuels is therefore encouraged. However, many of the leading sources of biofuel, such as sugar cane and corn, require large areas of arable land for their production.[46] For this reason the biofuel industry is facing severe criticism due to its competition with food production, which can be a significant issue in developing countries which are struggling to keep up with agricultural demand.[47] The negative impact of traditional biofuels is compounded by the fact that it often entails the removal of native vegetation, natural CO_2 scrubbers, thus making the production of conventional biofuels carbon positive.[48] Therefore, attempting to meet all of our energy demands using conventional biofuels, is not sustainable. Algae therefore represent a key substitute to current conventional biofuels.[49] Algae can be grown on unproductive land and are much more efficient in their production than conventional biofuels (algae culture produces about 19000 L of biodiesel per equivalent acre compared to soy which produces only about 220 L per acre).[50] Moreover, algae fuel production is carbon neutral as the same amount of CO_2 is sequestered as it is released through the combustion of algae biofuels.[51]

Hydrogen from algae has immense potential as a completely green fuel only producing water vapor when combusted, thus being a carbon negative fuel source.[52] While hydrogen production from algae is currently not possible on large scale due to quantitative issues, recent research has shown an increase of hydrogen yield by 60% when combining the unicellular green algae Chlamydomonas reinhardii with E. coli bacteria.[53] The increased hydrogen production caused by higher respiration rates in the bioreactors during symbiotic growth has led to the potential application of this system as a hydrogen-based fuel source.[54]

While the application of algae and photobioreactors for carbon sequestration could be the basis of a sustainable green future, there are still obstacles to overcome. The main factor limiting the widespread implementation are the costs.[55] To make the algae industry economically feasible, the production of algae needs to be upscaled and combined with the production of novel commercial algae products, such as biofuels, animal feeds and human dietary supplements. This would create an income stream and reduce the attributed cost of the algae production.[56]

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CONCLUSIONS

Algae absorb large amounts of CO_2 and their biomass can be converted biofuels, but their application has been constrained in the past due to technical limitations and costs. Latest scientific developments, such as AI photobioreactors, are now allowing large-scale implementation of algae culture for carbon capture and production of sustainable ecofriendly fuel. The upscaling of algae culture will make it more economically feasible and advance the development of additional fuel sources from algae, such a biohydrogen. Algae therefore now have the great potential to become an effective solution against climate change.

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