Enhancing CO_2 Capture and Alternative Bioelectricity Generation using Algal Fuel Cells

A Comparative Study of *Arthrospira platensis* and *Chlorella pyrenoidosa*

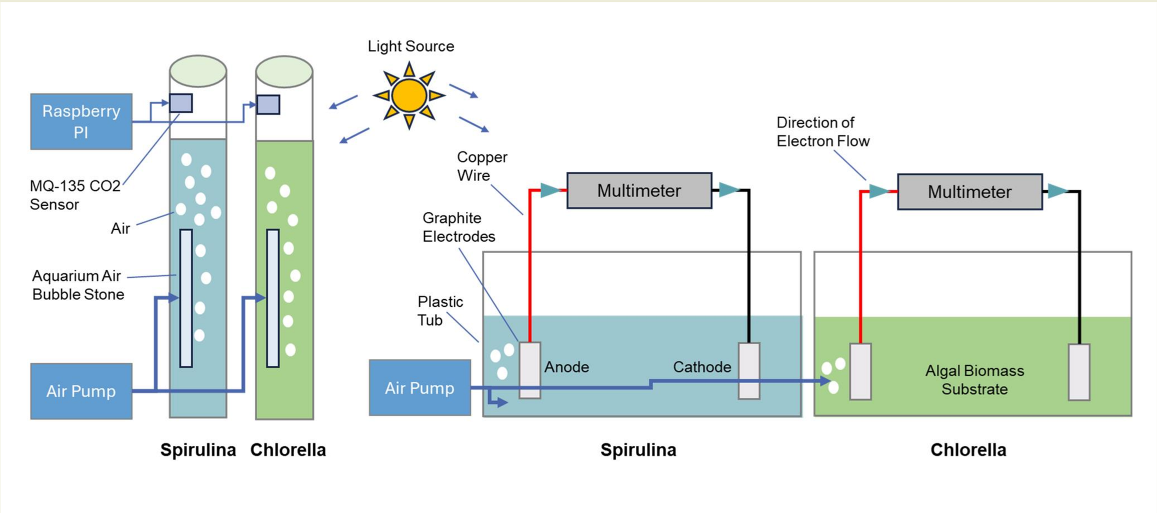
Abstract

- This research study compared the CO_2 capture and electricity generation capabilities of two microalgae to identify the most optimal species for large-scale implementation of carbon sequestration and bioenergy production facilities.
- This study is differentiated because it uses a continuous electronic gas sensor to track carbon capture efficiencies in the CO_2 scrubber.
- Another unique aspect of the design is that the algal fuel cell runs on biomass from the CO_2 scrubber, enabling a reusable method of bioenergy generation.
- The research results indicate Chlorella was 16% more efficient in capturing CO_2 and 70% more efficient in bioelectricity generation compared to Spirulina.
- The findings indicate Chlorella holds promise as a more effective microalgae for use in sustainable energy production and continuous carbon capture due to its higher efficiency and lower maintenance costs.

Selected References:

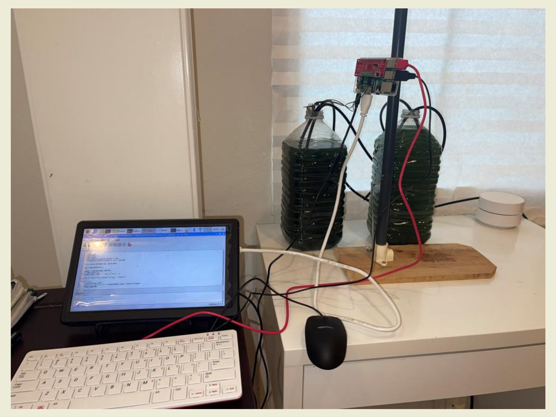
- Ciniciato, Gustavo P.M.K. et al. "Investigating the association between photosynthetic efficiency and generation of biophotoelectricity in autotrophic microbial fuel cells" , https://doi.org/10.1038/srep31193.
- Singh, Jyoti and Dolly Wattal Dhar, "Overview of Carbon Capture Technology: Microalgal Biorefinery Concept and State-of-the-Art", https://doi.org/10.3389/fmars.2019.00029.
- Kannan, Nethraa and Philip Donnellan "Algae-assisted microbial fuel cells: A practical overview", https://doi.org/10.1016/j.biteb.2021.100747.
- Rathinavel, Lavanyasri et al. "Algal microbial fuel cells—nature's perpetual energy resource" Microbial Fuel Cell Technology for Bioelectricity, https://doi.org/10.1007/978-3-319-92904-0_5.
- Onyeaka, Helen et al. "Minimizing carbon footprint via microalgae as a biological capture" , https://doi.org/10.1016/j.ccst.2021.100007.

Hypothesis

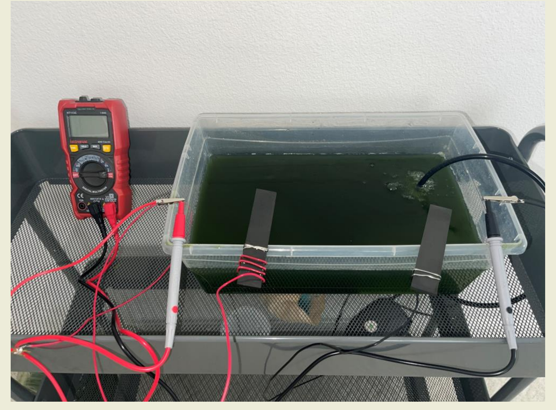


If **both algae types are grown under constant temperature, light and nutrient conditions, *then* Chlorella will be able to capture CO_2 at a higher efficiency and generate more electricity *because* of Chlorella's higher chlorophyll and lipid content.**

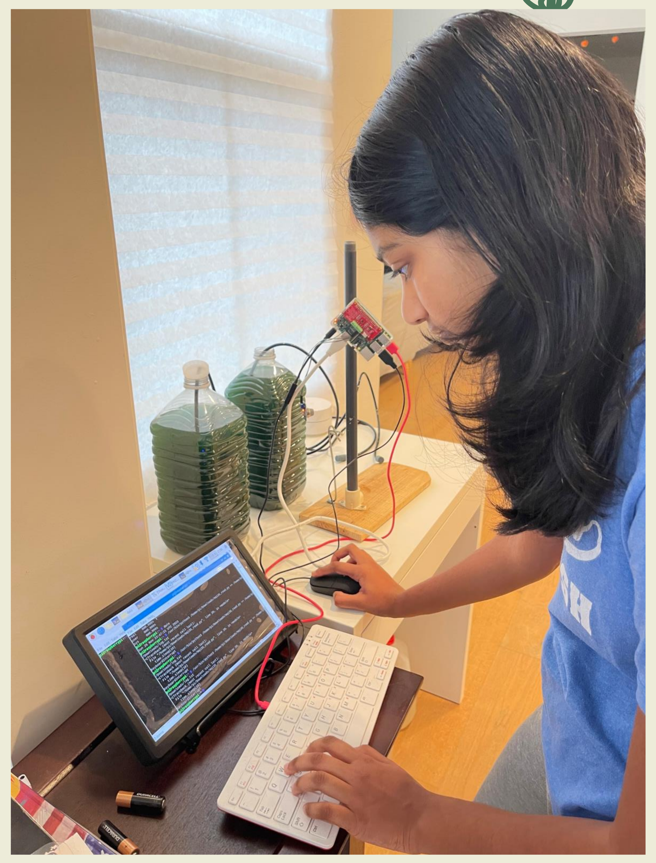
- Chlorella is a freshwater chlorophyte, or green microalgae that contains high amounts of chlorophyll.
- Chlorella pyrenoidosa can "tolerate high concentrations of CO_2, has high photosynthetic capacity, and can maintain high growth rate." (Farhad et. al, 2017).
- CO_2 is captured during photosynthesis, where the amount of chlorophyll plays an important role, leading me to believe Chlorella will perform better at carbon capture.
- Additionally, due to its higher lipid content, Chlorella may also be better at producing electrical energy in a fuel cell compared to Spirulina.



Algal CO_2 Scrubber



Algal Fuel Cell



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Procedure

Algae Cultivation:

1. Procure the algal species - *Arthrospira platensis* and *Chlorella pyrenoidosa*.
2. Transfer the algae culture and nutrient media into the culture vessel.
3. Feed both Spirulina and Chlorella at a constant rate of 1 ml/liter every week.

Algal CO_2 Scrubber:

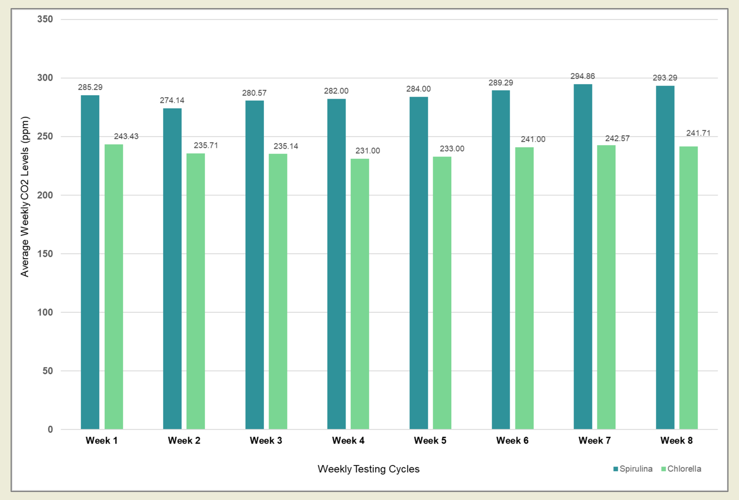
1. Immerse an aquarium stone connected to an air pump into culture vessel.
2. Pump air into the culture vessel to provide CO_2 for algae.
3. Setup the MQ-135 CO_2 sensor with Raspberry PI.
4. Write a Python program to read sensor data in parts per million (ppm) every 10 seconds.
5. At the end of the experiment, harvest the microalgae from the culture vessel.

Algal Fuel Cell:

1. Construct two fuel cells, one for Chlorella and one for Spirulina using algal biomass from the CO_2 scrubber.
2. Attach two copper wires to two graphite electrodes for the anode and cathode
3. Insert the electrodes into the fuel cell with the algae.
4. Connect the other end of the copper wires to a multimeter
5. Measure the voltage in millivolts (mV) once every 3 hours and note down the readings.

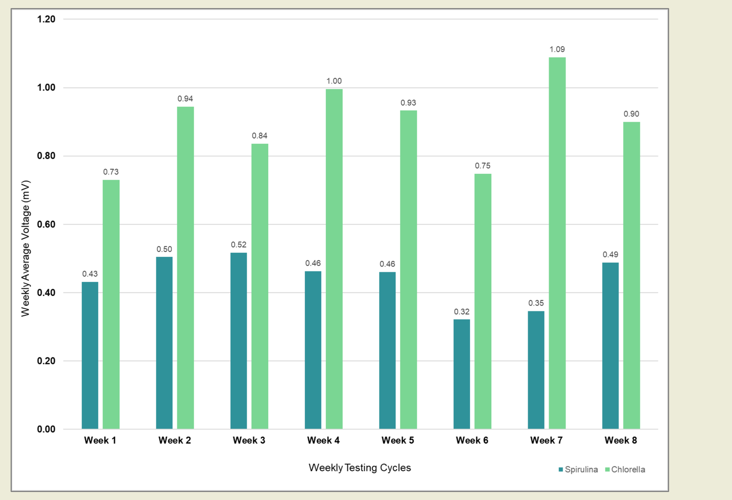
Results

Weekly average CO_2 capture efficiency (ppm)



Chlorella was **16% more efficient in capturing CO_2** compared to Spirulina. Since we are measuring the CO_2 levels in the culture vessel, the <u>lower values indicate higher CO_2 capture capability.</u>

Weekly average voltage generation (mv)

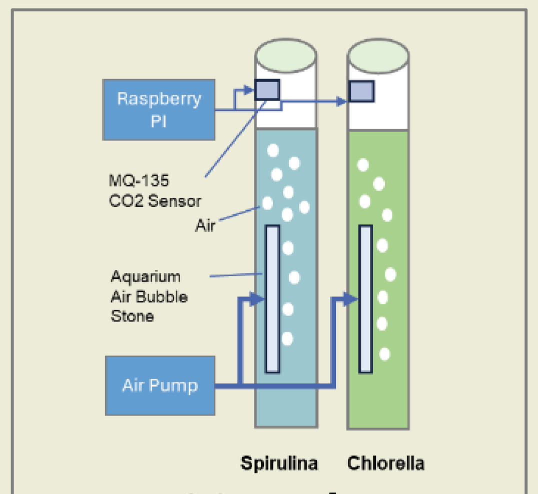


Chlorella was **70% more efficient in generating electricity** compared to Spirulina. Since we are measuring the voltage generated, the <u>higher values indicate better electricity generation capability.</u>

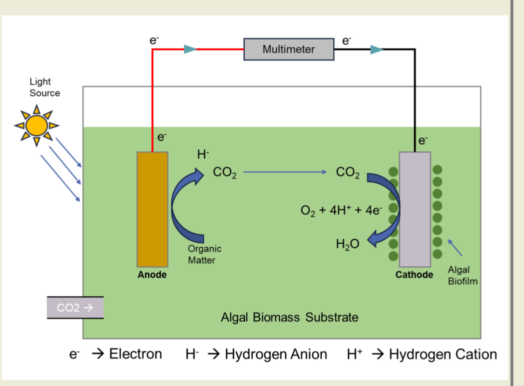
Key Observations:

- While Chlorella had a higher rate of electricity generation across all the eight testing cycles, it was observed that Spirulina voltage readings were more consistent across the testing cycles.
- This was an interesting finding and may indicate that Spirulina was more resistant to any variations in growth conditions.

Discussion



C3 cycle



Oxidation Process

- Microalgae photosynthesize through the Calvin-Benson-Bassham cycle, or the C3 cycle, where CO_2 and hydrogen carrier compounds are converted to carbohydrates.
- A key step in the C3 cycle is carboxylation, or carbon capture, where CO_2 is combined with a sugar called ribulose bisphosphate, producing two carbon molecules of phosphoglycerate.
- The carboxylation process is catalyzed by an enzyme called RuBisCO, which is inefficient in CO_2 capture. Microalgae have developed a CO_2 capture mechanism to overcome this inefficiency by transporting CO_2 to sub-compartments inside the cell that are active centers of RuBisCO, thus enabling significantly higher photosynthetic rates compared to terrestrial plants.
- Algal fuel cells operate by using the algal biomass, or organic matter produced by the microalgae during photosynthesis, which gets oxidized at the anode producing CO_2, hydrogen and electrons.

  $$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$$

- The advantage of a single-chambered fuel cell is that the CO_2 produced during oxidation can be reused by the microalgae for further photosynthesis and biomass growth, making it a renewable cycle.
- The electrons produced during the oxidation phase pass through the copper wire to the cathode, where they undergo reduction using the oxygen and hydrogen ions to produce electricity and water as a byproduct.

  $$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Conclusion / Next Steps

The results from my project **supported my initial hypothesis**. The Chlorella algae showed consistently higher energy output and carbon capture capability compared to Spirulina.

Potential Improvements:

- Sealing the algal containers would minimize the effect of the outside environment and improve accuracy of the readings.
- CO_2 was pumped manually using a bicycle pump. Adding an electronically timed air pump would provide constant CO_2 to the algae, increasing their growth rate.
- Setting up the LED light on an automatic timer could also ensure the same amount of light is provided to both algae.

Future Research/Applications:

- This technology can be implemented in remote areas, such as coastal desert lands in Morocco, Oman and South Africa, serving as an efficient and natural way to provide sustainable electricity.
- Algae could play an important role on Martian terraforming where 95% of the atmosphere is made up of CO_2.