JRC Makers-in-Residence Programme

Spirulina Solar Bioreactor

David Cotte--Birgé

2023

Contact information
Name: David Cotte--Birgé
Email: david.birge.cotte@gmail.com

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC134343

Ispra: European Commission, 2023

How to cite this report: Cotte—Birgé, D., *JRC Makers-in-Residence Programme: Spirulina Solar Bioreactor*, European Commission, Ispra, 2023, JRC134343.

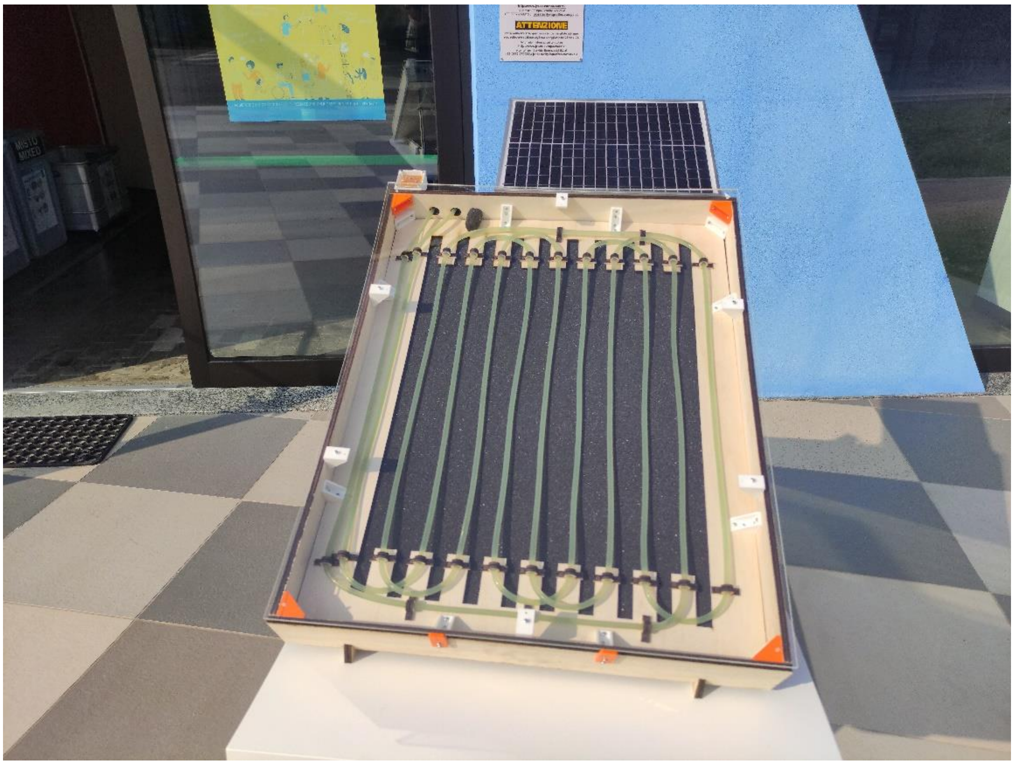
Contents

Abstract

Spirulina is a micro-algae that has gained significant attention in recent years due to its high nutritional content and potential as a sustainable food source. In this project the feasibility of growing Spirulina in urban environments using a solar-based bioreactor is explored. Traditionally, open ponds have been utilized for Spirulina cultivation, but this method requires significant land and may not be practical in urban areas. The use of electric photobioreactors is an alternative, but it may not be sustainable in terms of energy consumption. By utilizing a solar panel-shaped device outdoors, we can eliminate reliance on the grid and produce Spirulina within cities without adding to the carbon footprint (climate-neutral and smart cities EU mission). The work done in this Maker's residency suggest that solar-based bioreactors have the potential to offer a sustainable solution for urban Spirulina cultivation.

During the participation in the "JRC Makers-in-Residence programme", the author was able to create a functional prototype of a solar-based bioreactor for growing Spirulina. Over the course of nine days, the JRC Makerspace's equipment was used, including a laser cutter and a 3D printer, to build the solar-based bioreactor. With diligent effort and experimentation, the prototype successfully achieved its intended proof of concept purpose.

Figure 1: Bioreactor in action on a sunny day (23/03/2023) in front of the JRC Makerspace.



Acknowledgements

I would like to express my deep gratitude to Paulo for his unwavering support and assistance throughout the program. His dedication and willingness to help me with the prototype, materials and tools were instrumental in its successful completion, even amidst his lots of other responsibilities.

I would also like to extend my thanks to Ângela for the enjoyable moments we shared outside of work, discovering the local cuisine. Her company was much appreciated and made my time here even more memorable.

Additionally, I would like to thank the Makers in Residence programme and Vulca for providing me with the opportunity to work on this project, as well as access to the JRC Makerspace's equipment. The resources provided were invaluable in the development of the solar-based bioreactor.

Author

David Cotte--Birgé

David Cotte--Birgé is a French Maker living in an organic farm. He is specialized in prototyping bio and agri tech for sustainable production of food and bio-based materials. His last works include an automatic small-scale mushroom growing system, a peristaltic pump for microbiology works, a solar irrigation system for vegetable farming and micro-algae bioreactors

1 Introduction

1.1 Context

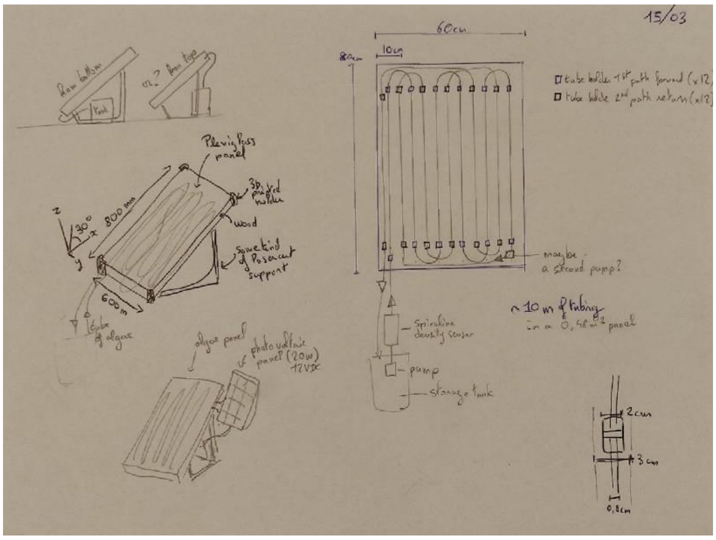
Spirulina is a micro-algae that has gained significant attention in recent years due to its high nutritional content and potential as a sustainable food source [1]. Its cultivation traditionally takes place in open ponds, which require significant land outside of urban areas. Also, the drying process of Spirulina after harvest needed to store it is energy-intensive and can lower the quality of the final product [2]. With the world's population projected to reach 9.7 billion by 2050, there is an increasing need for sustainable food production methods that can meet the growing demand while lowering the environmental footprint.

One potential solution is to cultivate Spirulina in urban environments, where space is limited but the demand for fresh, locally sourced food is high and transportation can more easily be carbon neutral. Electric photobioreactors have been used as an alternative to open ponds in cities, but they require a significant amount of electrical energy and may not be the most sustainable option [3].

1.2 Proposal

To address the challenge of sustainably growing Spirulina in urban environments, I decided to explore the potential of a solar-based bioreactor as an alternative method. This device can eliminate the need for electricity from the grid, making it an environmentally sustainable option for urban food production. The solar-based bioreactor has the shape of a traditional solar panel (see figure 2) that can harness the power of the sun to provide the necessary energy for Spirulina growth. The aim of this report is to document the process of creating a functional prototype of the solar-based bioreactor and evaluate its feasibility for Spirulina cultivation in an urban setting. By reducing reliance on the grid and utilizing a sustainable energy source, we can potentially minimize the carbon footprint associated with food production and increase access to fresh, locally sourced "plant based" protein.

Figure 2: Early drawing of the prototype.



2 Process

The JRC Makers-in-Residence programme had a total duration (on-site) of 2 weeks. During the first week, I focused my work on the mechanical / structural design of the solar-based bioreactor. Using the JRC Makerspace equipment, I started by laser cutting the side and back structure of the bioreactor's panel, using 10mm thick wood from the local hardware store. To keep the heat from the sun inside the panel, I used black insulation foam. The mounting brackets for holding the structure and tube holders for the tubing were manufactured using a 3D printer. A plexiglass sheet (5mm thickness) was placed on top of the panel to allow light and heat to enter inside the panel for the Spirulina to growth. The panel is 800mm by 600mm and holds around 10 meters of tubing (figure 3).

Figure 3: prototype being built inside the JRC Makerspace

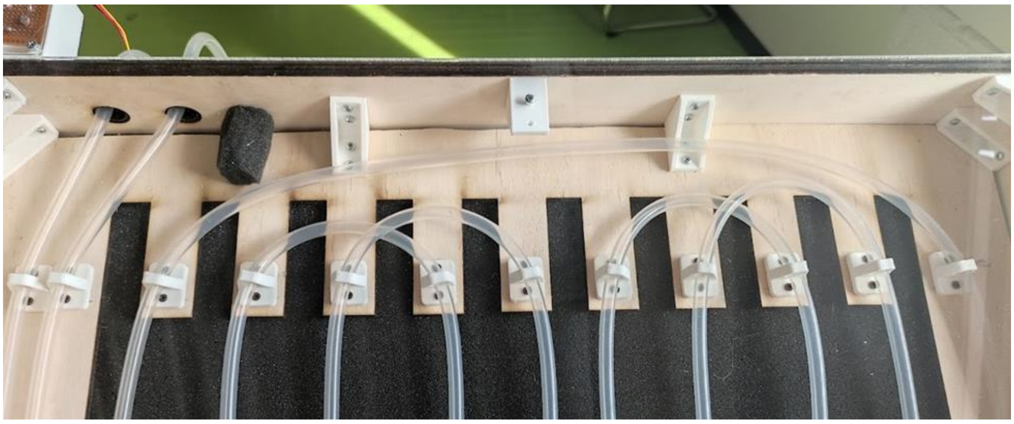
In the second week, I shifted my focus to the electronics, while still having some mechanical work to do, such as making a 30° angle support for the panel and mounting a 20-watt photovoltaic panel to the bioreactor's main structure / panel. The electronics were based around the ESP32 WiFi microcontroller [4], which is used to gather a large amount of data in an SD card, including:

- the temperature inside the panel (DS18B20 sensor [5]),
- the temperature inside the Spirulina water container (DS18B20 sensor),
- the temperature outside the panel (AHT21 sensor [6]),
- the sun's intensity (simple divider bridge using a resistor and a photoresistor in a 3d printed enclosure with transparent polycarbonate lid),
- the Spirulina density (using a TM6000 light intensity sensor [7] and a red LED in an opaque enclosure with the spirulina tube passing in between the sensor and the light source allowing to monitor the opacity of the spirulina media), and,
- the time of day (using ESP32 WiFi features to get the NTP time).

It also features multiple DC-DC converters for converting the voltage from the photovoltaic panel (around 22V) to usable voltages for the 12V pump and the 5V microcontroller.

While testing the panel during the second week, I found that the heat inside the panel rose to 63°C thanks to the logging from the electronics. At this temperature, the 3D printed tube holders started to deform. I replaced them with laser-cut pieces of wood. I also added a gap between the frame and the plexiglass sheet to allow hot air to escape, as Spirulina does not thrive at temperatures above 40°C. After adding the gap, the air temperature in the panel didn't go above 50°C.

Figure 4: Detail of the tubing system with melted 3d printed tube holders.



Overall, the design and implementation of the solar-based bioreactor has been successful, despite some minor setbacks described earlier. The device is functional and should be able to cultivate Spirulina using only solar power. The use of wood and 3D printing has made the device relatively low-cost and accessible (the 5mm plexiglass panel could be replaced by some thinner polycarbonate to lower cost). The ESP32 microcontroller has allowed for precise monitoring of the environmental conditions and data collection, which could potentially lead to further improvements in the design and implementation of solar-based bioreactors.

Figure 5: Schematics of the electronics.

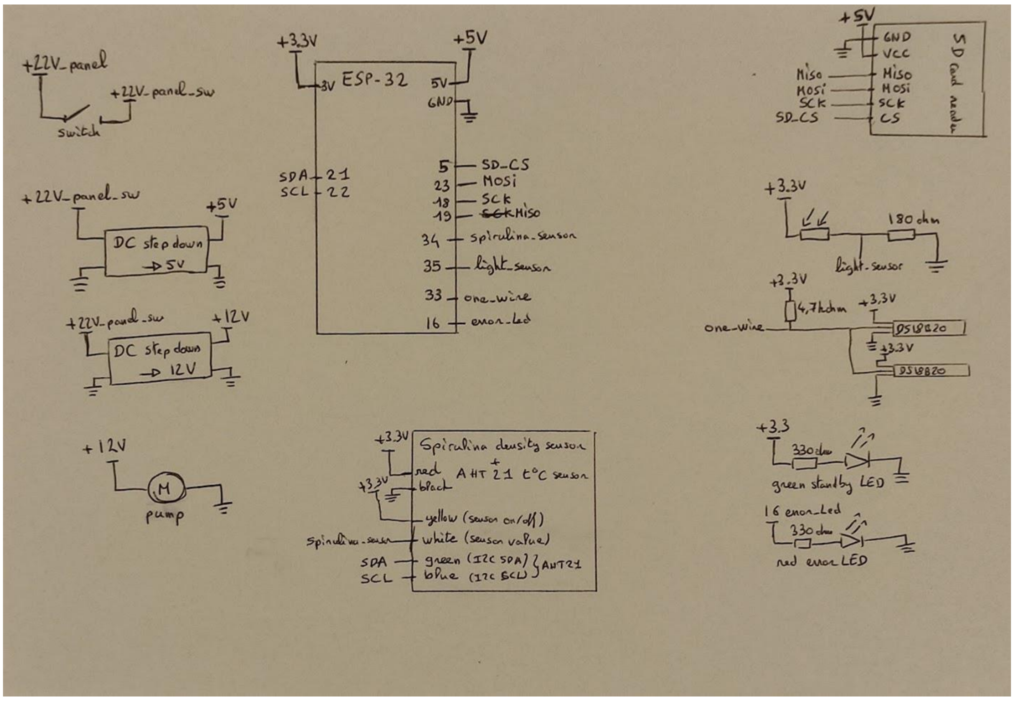
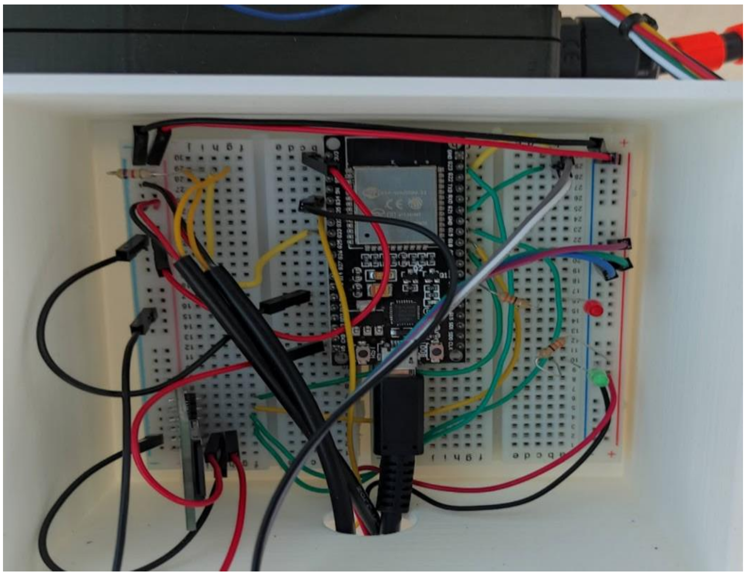


Figure 6: Physical wiring of the ESP32 in its 3D printed enclosure.



3 Results

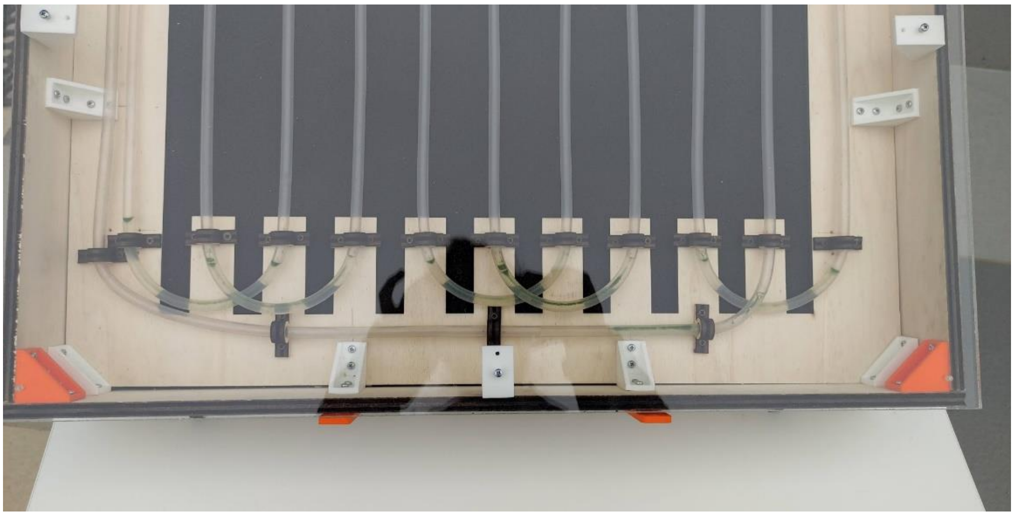
During the two weeks of the programme, I successfully built a functioning solar-based bioreactor prototype for growing spirulina. The prototype was able to use direct sunlight to heat the panel and allow the spirulina to grow through natural photosynthesis. However, I only managed to get the pump working on the penultimate day of the programme because of issues with DC converters. Then on the last day, the sky was cloudy and the photovoltaic panel did not receive enough power to operate the bioreactor. This unfortunately meant that, due to the building process taking up most of the time, I had little opportunity to collect and analyse data from the prototype. While the prototype did reach a temperature of 63°C inside the panel during testing, I had to make adjustments in order to prevent overheating and maintain an optimal temperature for spirulina growth. On the day before the last day, when the pump was working, the spirulina went to more than 30°C and had access to lots of light so it was in perfect conditions to produce biomass.

The prototype proved to be a successful design and implementation of a solar-based bioreactor for growing spirulina when in the right environmental conditions even if it could of course be optimized.

Further tests were conducted after my departure from the JRC Makerspace. In some of the days the conditions were great - for example on one day the outside temperature was between 20°C and 24°C and the algae water's temperature went from 20,5°C at 9am to 30°C at 4:30pm. Inside the panel the temperature fluctuated between 23°C and 60°C. On the contrary, on a hot (33°C) day the data showed dangerous temperatures for the algae: 43°C at 4pm. This kind of temperature inhibits growth, can lead to the death of the spirulina culture and must be prevented [8]. These lethal temperatures could be prevented in a future version (see section 4.2).

It's worth noting that due to the way the tubing is mounted inside the panel, it's difficult to fully purge the system of spirulina when it's not operating. As a result, some spirulina can remain inside the tubing which is not ideal because with time it can stick to the tubing and the cleaning is difficult.

Figure 7: Detail of the Spirulina media not able to be purged (bottom of panel)



Using the photos and videos I took during the programme, I was able to capture the entire process of designing and building this solar-based bioreactor prototype. I compiled over 5 minutes of video footage showcasing each step of the design and implementation process. This video serves as a valuable resource for documenting the work done during the program and can be used for educational purposes in the future. I also published a 6:40 minute commented version of the video on Youtube (https://youtu.be/ZI2rKLxdTVo).

4 Reflections

4.1 Main challenges

The project presented a few challenges that required some creative problem-solving. One of the main challenges was related with the temperature inside the panel. While it was important to maximize the amount of sunlight entering the panel to heat up the water for the spirulina to grow, I also had to ensure that the temperature did not exceed the limit of 40°C, beyond which the spirulina could not thrive. During testing the heat inside the panel went up from 20°C to 63°C in one hour. In addition to being deadly to the algae, it made the 3D printed plastic to deform and start to melt. This required a modification of the original design to replace the holders with laser-cut wooden pieces, which could withstand the higher temperatures. Another solution would be to 3D print the holders in a higher temperature resistance plastic material. I also added a gap between the wood structure and the plexiglass panel to allow hot air to escape.

Another challenge faced related to being able to run the pump from the photovoltaic panel, as the pump needs a stable 12V supply and the photovoltaic gives a variable 18 to 23V depending on the weather. The DC converter module initially used was not adequate and was destroyed in the testing process while also destroying one of the two pumps I brought. A higher quality 15-40V to 12V DC converter had to be bought to solve this issue.

I also faced challenges in obtaining enough power from the photovoltaic panel to run the bioreactor. The last day of the residency was a cloudy day. As a consequence, there was not enough sunlight to power the photovoltaic panel and to run the bioreactor. In any case, even if the bioreactor pump was running there would not have been enough sun to heat and grow the spirulina. This is one of the limitations of solar based bioreactors.

One other challenge encountered was the reliability of the SD card connexion and power supply of the ESP32. In certain occasions the bioreactor was functioning but not logging the data. To address this issue, it was added in the electronics and programmed in the software, a red LED continuously flashing when the SD card is not recognised. Also, a green LED was added to visually know if the ESP32 was running, especially in the end of the day when the power from the photovoltaic panel might not be enough for both the pump and the ESP32.

Table 1: Extract from data log from the SD card

Row number	Day of the week	Time	Light level	Panel temp (°C)	Spirulina temp (°C)	Outside temp (°C)	Spirulina density
145	4	10:59:44	2473	59.25	28.12	27.38	1051
146	4	11:02:32	2554	57.50	28.19	26.53	1041
147	4	11:05:20	2572	57.38	28.19	25.99	1036
148	4	11:08:08	2550	60.19	28.38	26.34	1040
149	4	11:10:56	2471	58.81	28.19	26.39	1041
150	4	11:13:44	2189	58.00	28.19	26.10	1037
151	4	11:16:32	2301	52.62	28.12	25.60	1033
152	4	11:19:20	2514	52.19	28.25	26.25	1041
153	4	11:22:08	2638	54.56	28.44	26.46	1043
154	4	11:24:56	2492	54.94	28.25	26.67	1044
155	4	11:27:44	2615	57.44	28.44	26.87	1046
156	4	11:30:32	2426	59.31	28.38	27.54	1055
157	4	11:33:21	2478	58.25	28.38	26.75	1045
158	4	11:36:09	2239	56.06	28.25	26.73	1044

4.2 What could be done next

There are several improvements that could be made to the solar-based bioreactor prototype.

One potential enhancement is the addition of a MOSFET to control the pump, ensuring it only runs when the temperature inside the panel or the water temperature is within the appropriate range for the spirulina to growth. Another MOSFET could also be added to control a small computer fan in the walls of the panel, allowing for more precise control over the extraction of the hot air. This would help maintain a consistent temperature inside the panel and prevent overheating.

Another potential improvement is to add more WiFi functionality to the prototype, allowing data to be logged to a remote server instead of relying on an SD card which needs manual collection of data. This would enable real-time monitoring and analysis of the bioreactor's performance, as well as the ability to remotely adjust its settings as needed.

In addition, the design could be optimized to increase the efficiency of the panel, such as exploring different tubing configurations to be able to pack more length of tubing in the same area or be able to completely empty the tubing. It would also be valuable to conduct further testing and data collection over a longer period of time to evaluate the long-term performance and feasibility of this solar-based bioreactor

Moreover, scaling up the design to a larger size could also be explored for real production use.

Another potential upgrade to the solar-based bioreactor could be the integration of automatic feeding and pH adjustment using peristaltic pumps and a PH sensor. By adding these features, the system could maintain the optimal conditions for spirulina growth without requiring constant manual monitoring and adjustment. The peristaltic pumps could be controlled by the ESP32 microcontroller based on sensor readings, ensuring a consistent and controlled environment for the spirulina.

5 Conclusions

In conclusion, the solar-based bioreactor prototype developed during the Makers in Residence programme demonstrated the feasibility of growing Spirulina in urban environments using renewable energy from the sun, but the testing time was not enough to capture sufficient data to know how much spirulina would be produced by such a device taking into account different weather. The device was constructed using commonly available materials, including wood, insulation, 3D printed plastics, a photovoltaic panel, and incorporated an ESP32 microcontroller to monitor and record data.

Overall, the functional prototype achieved its intended proof of concept purpose, and the use of photos and videos helped to document the design and construction process. The successful creation of a solar-based bioreactor demonstrates the potential for sustainable Spirulina cultivation in urban areas.

While constructing the bioreactor, I faced several challenges such as the melting of the 3D printed tube holders due to high temperatures and the difficulty of purging the tubing, which resulted in some Spirulina remaining inside when not operating.

Several potential improvements were identified during the development of the prototype, including the addition of MOSFETs to control the pump and fan, WiFi functionality for remote data logging, and peristaltic pumps for automatic feed and pH adjustment. With further development, a solar-based bioreactor could offer a viable solution for urban food production, providing a source of nutritious micro-algae while minimising the carbon footprint.

Overall, this open-source project serves as a starting point for further exploration and development of sustainable urban Spirulina cultivation. The solar-based bioreactor prototype provides a foundation for future advancements and improvements, and can serve as an inspiration for other makers and researchers in the field.

References

[1] Saranraj, P., and S. Sivasakthi. "Spirulina platensis–food for future: a review." *Asian Journal of Pharmaceutical Science and Technology* 4.1 (2014): 26-33.

[2] Desmorieux, Hélène, and Fabiola Hernandez. "Biochemical and physical criteria of Spirulina after different drying processes." *Proceedings of the 14th International Drying Symposium (IDS),* B. 2004.

[3] Soni, Ruma Arora, K. Sudhakar, and R. S. Rana. "Spirulina–From growth to nutritional product: A review." *Trends in food science & technology* 69 (2017): 157-171.

[4] https://www.espressif.com/en/products/socs/esp32

[5] https://datasheets.maximintegrated.com/en/ds/DS18B20.pdf

[6] http://www.aosong.com/userfiles/files/media/Data%20Sheet%20AHT21.pdf

[7] https://www.vishay.com/docs/81579/temt6000.pdf

[8] Kumar, Manoj, Jyoti Kulshreshtha, and Gajendra Pal Singh. "Growth and biopigment accumulation of cyanobacterium Spirulina platensis at different light intensities and temperature." *Brazilian Journal of Microbiology* 42 (2011): 1128-1135.

Additional Information

Video of an algae panel that inspired this project: https://youtu.be/64cEmjtwRgw

Free book on spirulina cultivation:

http://spirulinefrance.free.fr/Resources/Manuel%20du%202%20fevrier%202018.pdf

Video produced by the author about this project: https://youtu.be/ZI2rKLxdTVo

Github link with files and log data of the project: https://github.com/David-Birge-Cotte/SSB

List of figures

List of tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

@eu_science