Sheffield Hallam University

Development of a Novel Bioreactor Table for Algae Cultivation and Water Filtration

Michelle Chimwanda
Dept. of Engineering & Mathematics
Sheffield Hallam University
Sheffield, United Kindom
Michelle.Chimwanda@student.shu.ac.uk

Priyanka Vishwas Rane
Dept. of Engineering & Mathematics
Sheffield Hallam University
Sheffield, United Kindom
PriyankaVishwas.V.Rane@student.shu.ac.uk

Abdul Manan
Dept. of Engineering & Mathematics
Sheffield Hallam University
Sheffield, United Kindom
AbdulManan.Manan@student.shu.ac.uk

Rashmiben Ajay Patil
Dept. of Engineering & Mathematics
Sheffield Hallam University
Sheffield, United Kindom
RashmibenAjay.A.Patil@student.shu.ac.uk

Aung Paing Hein
Dept. of Engineering & Mathematics
Sheffield Hallam University
Sheffield, United Kindom
AungPaing.P.Hein@student.shu.ac.uk

***Abstract*— This paper introduces a novel bioreactor table designed for water filtration and carbon capture. Incorporating innovative design, the bioreactor offers a sustainable solution for bioprocessing. Market analysis guides product design for optimal market fit.**

Keywords*—*bioreactor, water-filter, carbon capture, design, market

I. Introduction

This paper introduces Flora Oasis, a novel bioreactor table designed to combat rising carbon dioxide levels by simultaneously capturing carbon and cultivating food through algae. Leveraging the high nutritional value and ease of cultivation of algae, Flora Oasis integrates advanced materials and manufacturing processes to optimize efficiency and sustainability in bioprocessing. Through a comprehensive methodology encompassing design, manufacturing, and sustainability analysis, this research addresses the pressing need for the reduction of alarmingly high CO_2 levels in the atmosphere (Betts et al., Year).

II. Literature Review

Recent advancements in indoor microalgae cultivation systems have focused on modular designs to optimize growth conditions (Aurélio, 2011; Andersen, 2015). These systems allow precise control over environmental factors such as temperature, light intensity, and nutrient supply, promoting high microalgae yields (Romagnoli et al., 2020; Kuan Yong Wai et al., 2016). Researchers have also emphasized the selection and engineering of microalgae strains with desirable traits for various applications, including food, biofuel, and pharmaceuticals (Prokop et al., 2015).

While innovations like The Coral and The Bloom showcase the potential for household microalgae cultivation (Hyunseok-An; Alg & You), our paper aims to introduce a novel bioreactor table designed specifically for algae cultivation, water filtration and carbon capture. Unlike existing systems, our bioreactor table offers a dual-functionality system, utilizing algae growth to both filter water and capture carbon dioxide. By leveraging innovative design concepts and sustainable materials, our bioreactor table aims to optimize bioprocessing efficiency while minimizing environmental impact.

III. Methodology

A. Team Structure and Collaboration

The team structure was guided by the Belbin Team Role Test for balanced skill distribution. In addition, the T-shaped skills model was applied to enable cross-functional participation. Regular weekly meetings ensured effective communication and coordination.

B. Market Research for Water Capacity

Market research compared (see figure 1) the GBP per litre of water capacity of existing bioreactors to our target volume of 30 litres. Our goal was to offer a lower price per litre than competitors while ensuring a high algae growth capacity, high carbon sequestration all while providing cost-effectiveness. This analysis guided our pricing strategy to remain competitive in the market.

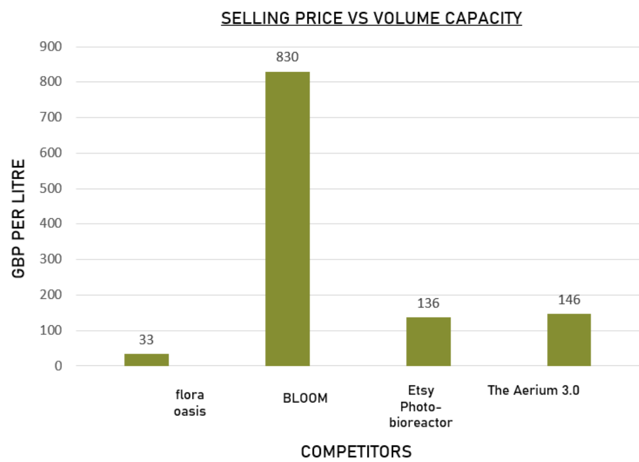
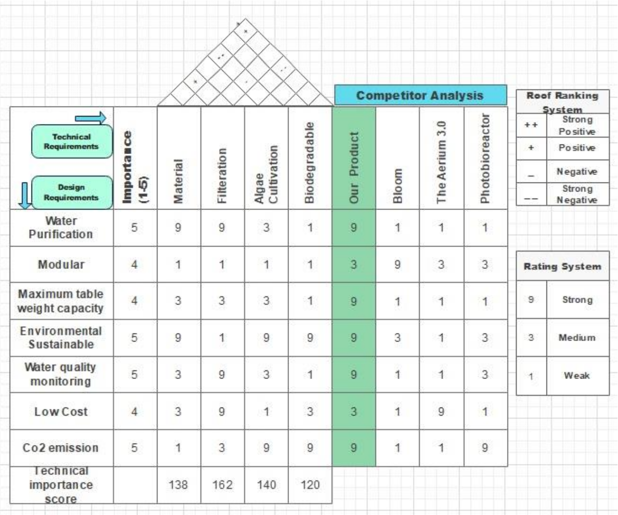


Fig. 1. Showing grapgh of cost per liter in GBP vs competitiors and table

C. House of Qualities

The House of Quality (HOQ) is essential for guiding the design process by identifying key features and prioritizing them according to customer needs. Through extensive market research, critical features for the bioreactor table, including cost, water filtration effectiveness, sustainability, and modularity. We then utilized the HOQ to assign importance ratings to these features and evaluate how well our design met each requirement. This systematic approach ensured that our bioreactor table addressed the most crucial customer needs effectively.



Technical Requirements / Design Requirements	Importance (1-5)	Material	Filteration	Algae Cultivation	Biodegradable	Our Product	Bloom	The Aerium 3.0	Photobioreactor
						Competitor Analysis			
Water Purification	5	9	9	3	1	9	1	1	1
Modular	4	1	1	1	1	3	9	3	3
Maximum table weight capacity	4	3	3	3	1	9	1	1	1
Environmental Sustainable	5	9	1	9	9	9	3	1	3
Water quality monitoring	5	3	9	3	1	9	1	1	3
Low Cost	4	3	9	1	3	3	1	9	1
Co2 emission	5	1	3	9	9	9	1	1	9
Technical importance score		138	162	140	120				

Roof Ranking System	
++	Strong Positive
+	Positive
–	Negative
––	Strong Negative

Rating System	
9	Strong
3	Medium
1	Weak

Fig. 2. Showing House of Qualities

D. Table Design

The design process began with a focus on low capacity, initially targeting 1-2 litres of wet algae growth. However, it evolved (see figure 3) into the concept of a table that fosters algae growth, with the final design accommodating a larger volume of 30 litres. This transformation was inspired by a fish table. Engineering calculations played a pivotal role in shaping this design, considering factors such as water pressure, table capacity, and material strength.

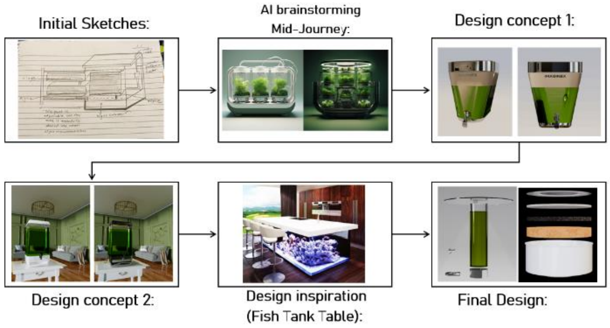


Fig. 3. Showing design flow for Flora Oasis Table

Pascal's law (see equation 1) was instrumental in determining the water pressure exerted on the tank walls. The stress analysis equations were employed to ensure the tank's structural integrity. The formula for stress (see equation 2) in a material under pressure was utilized (Kotrasova et al., 2021).

$$P = \rho \cdot g \cdot h$$
$$P = 1270\text{kg/m3} \times 9.81\text{m/s2} \times 0.71\text{m}$$
$$P \approx 8913.81Pa \tag{1}$$

Where P is the pressure, ρ is the density of water (1270 kg/m33), g is the acceleration due to gravity (9.81 m/s22), and h is the height of the water column (0.71 m).

$$\sigma = \frac{P \cdot r}{t}$$
$$\sigma = \frac{8913.81Pa \times 0.115m}{6.6\times10^{-3}m} = 1.21\ MPa \tag{2}$$

Modularity was implemented through the removable table top, allowing for customization with different shapes and sizes upon request. PLA (Polylactic Acid) was opted for the table top, known for its biodegradability, and stainless steel for the harvesting and environment control system housing. The standard bar table height (0.91m) and a round table top diameter (0.91) to seat four people were chosen for practicality and usability (Dimensions.com, 2024).

The design (see figure 4) incorporates a light system for low light conditions and a monitoring system for pH, temperature, and algae growth. Additionally, it includes an aeration system, which may or may not require an external pump. A removable tap, connected to the tank by NRB coupling, prevents water leakage when the tap is removed.

Fig. 4. Showing Front and Side view of fully assembled table with wet Alage inside

E. Market Research for Material

A a poll was conducted using the website StrawPoll to determine material for aesthetic considerations, with 109 participants from 21 countries. White and silver showed a strong tie in preference. The majority of participants were from the UK. Despite limited direct market research, the target market is Australia.

Fig. 5. Showing Votes for favourtie colour over time

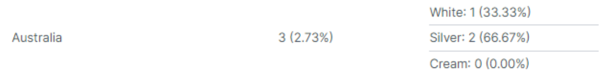


Fig. 6. Data for number of voters in Australia

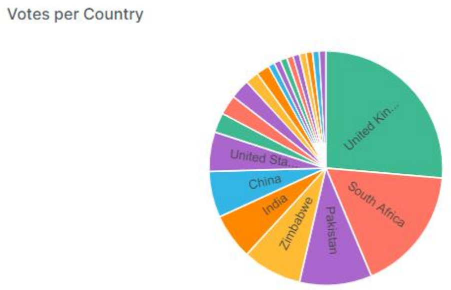


Fig. 7. Pie charting showing Distribution of Countries that voted

F. *Filter Design*

The design of Flora Oasis water filters for the bioreactor table is based on the need to grow microalgae using clean water. From research, no bioreactor on the market was found with this functionality making this feature a unique selling point.

The filter is also replaceable and detachable from the table, therefore ensuring easy maintainability and sustainability. It is also important that the filter is removable after pouring water into the tank, to prevent blocking light from the algae as it is critical condition for the algae cultivation process. The outer container of the filter layers, is made of biodegradable polylactic acid (PLA) and is designed to be collected and refilled with the inner filtering materials after its use capacity is fulfilled .

The water filter consists of four **layers (see figure 8),** each designed to target specific impurities. The top layer, made of filter cloth with water openings, mechanically removes visible impurities while being biodegradable. Following is a foam layer of polyurethane foam, also biodegradable, which traps larger particles and sediments (Teodosiu et al., 2014). Beneath is a granulated activated carbon layer that effectively removes organic contaminants and heavy metals, utilizing regenerated carbon. The final layer consists of ion exchange resin beads, which soften water and are reusable, enhancing the filter's sustainability (Rajeshkumar et al., 2021) (Liu et al., 2021). Due to sustainable regeneration, activated carbon material properties are suitable for sustainable water treatment by extending the life cycle and reducing emissions from activated carbon (dos Santos & Daniel, 2020).

Fig. 8. Example of a figure caption. (*figure caption*)

A subscription-based model (see table I) is the best fit for the filters as they must be replaced regularly and it allows a collection strategy for the materials to be recycled and reused for other filters (Evans et al., 2017).

TABLE I. WATER FILTER PRICING

Water Filter Subscription Packages (GBP)		
Monthly	***6 Months***	***Annual***
30	162	306

[a] The longer the subscription period the bigger the discount

G. *Manufacturing and Sustainablitiy Analysis*

The manufacturing process for the bioreactor table involves the integration of sustainable materials and practices. The table's tank and top, both made of Poly-Lactic Acid (PLLA), are injection moulded, ensuring precision and minimizing waste. The magnets connecting the table top and tank are crafted from recycled neodymium, further reducing environmental impact. Additionally, the algae harvesting and condition control system casing, as well as the algae tray, are constructed from stainless steel, primarily through sand casting, ensuring durability and recyclability. The tray is specifically designed for manufacture (see figure 9) with minimal waste material, optimizing material usage and reducing environmental impact. This choice of materials and manufacturing methods aligns with the commitment to sustainability.

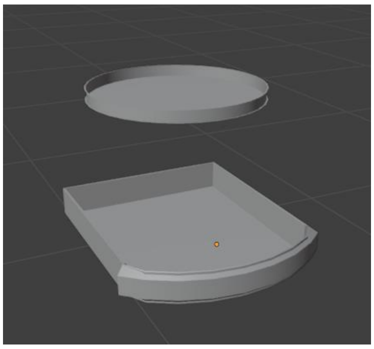


Fig. 9. Example of a figure caption. (*figure caption*)

To further assess the environmental impact, a lifecycle assessment (LCA) was conducted. The LCA evaluated the table's environmental footprint from raw material extraction to disposal, considering factors such as energy consumption, emissions, and waste generation. Additionally, logistics were optimized by choosing to manufacture the table in China and targeting the Australian market due to its favourable climate for algae growth and cost-effective logistics. This strategic decision minimizes transportation emissions and supports local economies while leveraging Australia's ideal conditions for bioprocessing. Overall, by incorporating sustainable materials, utilizing recycled components, and conducting a lifecycle assessment, the bioreactor table meets high standards of environmental responsibility while effectively targeting its intended market.

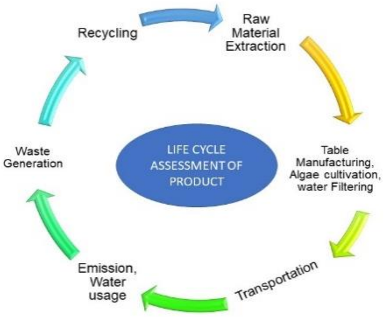


Fig. 10. Visualisng Elements of Lifecyle assesemet

Spirulina production and CO_2 sequestration efficiency were calculated using the Grow Organic Spirulina calculator. With a 30-liter capacity, it produced 0.0018 kilogramme of Spirulina every day, meeting CO_2 sequestration criteria (Gammer, 2017). Over ten years, it is predicted to trap 11.826 kg of CO_2, indicating potential for carbon reduction and sustainability goals, as well as a significant step towards environmental stewardship. Looking at table II the estimated emissions per table is 12.3162 meaning the product may absorb 96% of the CO_2 emitted to produce it within its minimum expected lifespan of 10 years.

TABLE II. CO2 EMISSION PER TABLE PRODUCTION

Raw Materials/Table Unit	***Weight (Kg)***	***CO2 emissions (KG Of co2 per KG Of Material)***
PLLA	4.6740	1.3000
Neodymium	0.2046	12.000
Stainless Steel	1.2000	2.7500
Total Emission		12.3162

[b.] Total emissions for the raw material of 1 table

H. *Marketing and Business Plan*

The marketing and business plan capitalizes on the growing interest in algae culture technology (Berg-Nilsen, 2006). Flora Oasis targets urban dwellers seeking eco-friendly solutions. Primarily, the is aim to attract environmentally conscious individuals, particularly young professionals and families, as our primary market segment. Secondary markets include research labs, business offices, and educational institutions (Berg-Nilsen, 2006). The breakdown of unit economics (see figure 11) was structured to prioritize manufacturing quality at 41%, minimizing packaging and logistics costs at 2% each, and allocating 10% for effective marketing strategies. This distribution ensures efficient resource allocation to maximize product quality and market reach.

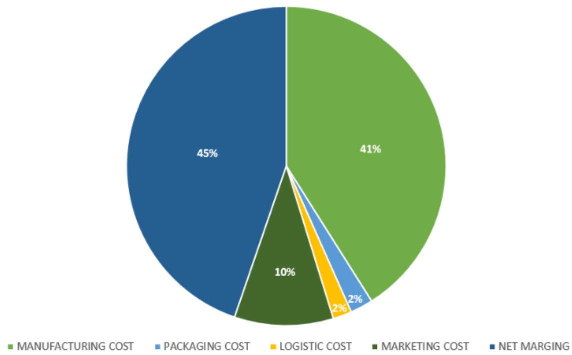


Fig. 11. Showing Unit of Economics

To effectively launch the product, the following strategies:

- Collaborative initiatives with yoga studios, meditation centres, and health retreats to promote eco-awareness and holistic living (Eberhardt, 2024). This strategy aligns with Australia's increasing focus on wellness and sustainable living practices.
- Partnerships with wellness influencers to promote the Algae Reactor as a component of a healthy lifestyle (Eberhardt, 2024). Australian influencers will help us reach our target demographic more effectively.
- Live workshops and demonstrations across Australian cities to showcase the capabilities of the Algae Reactor (Algal Biology Toolbox Workshop Summary Report, 2016). These events will cater to the Australian market's interest in hands-on experiences and sustainability.
- Participation in Australian exhibitions and events related to renewable energy and biotechnology to showcase the technology and network with potential clients (Algal Biology Toolbox Workshop Summary Report, 2016). This aligns with Australia's focus on renewable energy and innovation.

Fig. 12. Marketing Campaign Designed for Australian Market

This marketing strategy aims to generate brand awareness and demonstrate the benefits of Flora Oasis (Eberhardt, 2024), effectively connecting with the Australian demographic.

IV. DISCUSSION

In future iterations, detailed schematics for the harvesting and environmental control system can be developed. Additionally, creating a physical prototype will allow better analysis of the design and gather user feedback. Deeper market analysis can be conducted in Australia to tailor the product to local preferences, and optimize logistics for efficient manufacturing in China and shipping to Australia.

V. CONCLUSION

In conclusion, the development of the bioreactor table represents an innovative step towards sustainable algae cultivation and water filtration solutions. Through comprehensive research and creative design strategies , we have created a high potential product with the capacity to be disruptive. Moving forward, continued development and adaptation will ensure the bioreactor table remains at the forefront of eco-friendly technology, contributing to a greener future and lower global carbon dioxide in the atmosphere.

REFERENCES

1. Algal Biology Toolbox Workshop Summary Report. (2016). Retrieved from https://www.algaltoolbox.com/report.
2. Andersen, R.A. (2015). Algal culturing techniques. Amsterdam Etc.: Elsevier.
3. AurélioM. (2011). Biofuels engineering process technology. Intech.
4. Berg-Nilsen, S. (2006). Algae culture technology: A promising and forward-looking business area. Journal of Algal Business Research, 12(3), 45-53.
5. Betts, R. A., Jones, C. D., Knight, J. R., Pope, J. O., & Sandford, C. (Year). Climate and climate change: Mauna Loa carbon dioxide forecast for 2024. Atmospheric CO2 rise predicted to exceed IPCC 1.5°C scenarios. [PDF file]. Retrieved from https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/forecasts/co2-forecast#:~:text=In%202024%2C%20we%20predict%20this,for%20over%202%20million%20years
6. dos Santos, P. R., & Daniel, L. A. (2020). A review: organic matter and ammonia removal by biological activated carbon filtration for water and wastewater treatment. International Journal of Environmental Science and Technology, 17(1), 591–606. https://doi.org/10.1007/s13762-019-02567-1
7. Eberhardt, C. (2024). Promoting eco-awareness through collaborative initiatives: A case study of yoga studios and health retreats. Marketing Today, 35(2), 67-78.
8. Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A., & Barlow, C. Y. (2017). Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. Business Strategy and the Environment, 26(5), 597–608. https://doi.org/https://doi.org/10.1002/bse.1939
9. Gammer, N. (2017, January 5). How much spirulina can I harvest per day – Free harvesting calculator! Retrieved from https://grow-organic-spirulina.com/blog/how-much-spirulina-can-i-harvest-per-day-free-harvesting-calculator-included/
10. Hyunseok-An, Alg & You.
11. Kotrasova, K., Kormanikova, E., & Harabinova, S. (2021). Pressure and stress analysis of liquid-filled cylindrical tank. DOI: 10.22541/au.161073302.24116477/v1
12. Kuan Yong Wai, Hao Tan Yong, Wan Poong Sze, & Eem Lim Phaik. (2016). Response of microalgae in a changing climate and environment. Malaysian Journal of Science. Series B, Physical & Earth Sciences, 35(2), 169–191.
13. Liu, Z., Haddad, M., Sauvé, S., & Barbeau, B. (2021). Alleviating the burden of ion exchange brine in water treatment: From operational strategies to brine management. Water Research, 205, 117728. https://doi.org/https://doi.org/10.1016/j.watres.2021.117728
14. Prokop, A., Bajpai, R. K., Zappi, M. E., & Springerlink (Online Service. (2015). Algal Biorefineries: Volume 2: Products and Refinery Design. Springer International Publishing.
15. Rajeshkumar, G., Arvindh Seshadri, S., Devnani, G. L., Sanjay, M. R., Siengchin, S., Prakash Maran, J., Al-Dhabi, N. A., Karuppiah, P., Mariadhas, V. A., Sivarajasekar, N., & Ronaldo Anuf, A. (2021). Environment friendly, renewable and sustainable poly lactic acid (PLA) based natural fiber reinforced composites – A comprehensive review. Journal of Cleaner Production, 310, 127483. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.127483
16. Romagnoli, F., Ievina, B., Perera, W. A. A. R., & Ferrari, D. (2020). Novel Stacked Modular Open Raceway Ponds for Microalgae Biomass Cultivation in Biogas Plants: Preliminary Design and Modelling. Environmental and Climate Technologies, 24(2), 1–19.

17. Teodosiu, C., Wenkert, R., Tofan, L., & Paduraru, C. (2014). Advances in preconcentration/removal of environmentally relevant heavy metal ions from water and wastewater by sorbents based on polyurethane foam. 30(4), 403–420. https://doi.org/doi:10.1515/revce-2013-0036
18. Dimensions.com Icon. (2024). Dimensions.com. Retrieved from https://www.dimensions.com