BIOLEAF: ALGAE TO COMBAT URBAN CARBON DIOXIDE

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ABSTRACT:

Rapid urbanization concentrates anthropogenic carbon dioxide (CO_2) emissions in cities while simultaneously reducing vegetative sinks. Microalgae offer a high-surface-area, high-productivity biological route for point-source CO_2 capture and valorization of carbon into biomass. This paper explores the use of algae as a sustainable and affordable approach to mitigating urban carbon dioxide (CO_2) emissions. Preliminary results highlight algae's effectiveness in air purification, but broader integration strategies are required to maximize its impact. This paper recommends key pathways for advancing Bioleaf, including household and community-level adoption through algae-based air purification systems, the development of do-it-yourself (DIY) kits for public accessibility, and the incorporation of digital monitoring tools such as CO_2, dissolved oxygen, and pH sensors. The use of locally available algae strains, along with global species like *Spirulina* and *Chlorella*, is suggested to ensure regional adaptability and sustainability. Furthermore, urban infrastructure can be enhanced by installing Bioleaf systems in high-traffic areas such as bus stops and railway stations to reduce localized pollution. Establishing simple maintenance protocols, integrating algae-based projects into educational curricula, and designing aesthetically appealing models are emphasized to encourage widespread acceptance. Collaboration with environmental organizations and the creation of open-source online communities are also proposed to support large-scale implementation and innovation. Collectively, these strategies position Bioleaf as a practical, community-driven, and scalable solution for addressing urban air pollution and fostering environmental awareness.

Keywords**:** Microalgae, Photobioreactor, CO_2 Fixation, Urban Air Quality, Bioeconomy, Façade Systems, Climate Mitigation.

INTRODUCTION:

Urbanization and industrialization have resulted in alarming increases in atmospheric CO_2 levels, leading to poor air quality, climate change, and health risks. Traditional solutions such as mechanical air purifiers are expensive, energy-intensive, and limited in scalability. Algae, being efficient photosynthetic organisms, naturally absorb CO_2 and release oxygen, making them a viable and sustainable solution for air purification.

The term "microalgae" is generally used for both prokaryotic blue-green algae (cyanobacteria) and eukaryotic microalgae, including green algae, red algae, and diatoms. Microalgae are being sought as alluring bio-factories for the sequestration of CO_2 and simultaneous production of renewable biofuels, food, animal and aquaculture feed products, and other value-added products such as cosmetics, nutraceuticals, pharmaceuticals, bio-fertilizers, and bioactive substances (Ryan, 2009; Harun *et al.*, 2010). Microalgae possess strategies, well known as the CO_2 concentrating mechanism (CCM), for efficiently photosynthesizing by acquiring inorganic carbon even from very low atmospheric CO_2 concentrations (Whitton, 2012).

The Bioleaf project seeks to harness this potential by integrating algae-based systems into households, communities, and urban infrastructure. By promoting decentralized adoption, Bioleaf aims to reduce localized air pollution, raise environmental awareness, and foster community-driven climate action. The microalgae species like Spirulina and Chlorella consistently demonstrated higher CO_2 absorption and oxygen release rates compared to conventional indoor plants (Zhongshi *et al*., 2025). They concluded that algae could be a reliable tool for sustainable urban air purification, especially in confined or indoor spaces. Direct C sequestration by urban plants and soils is negligible as compared with urban GHG emissions; however, urban landscapes can have substantial local cooling effects that reduce energy use but require site- and species-specific quantification. Bioswales, rain gardens, and other green infrastructure components reduce runoff, but further research is required to assess their effect on water quality and cost-effectiveness, particularly at the watershed scale (Pataki *et al.,* 2011).

Currently, many physico-chemical carbon capture and sequestration strategies are combinedly categorized as carbon capture and storage (CCS) methodologies. CCS operates over 3 major steps: CO_2 capture, CO_2 transportation, and CO_2 storage. CO_2 capture is done from large point sources such as power plants and cement manufacturing plants. The separation and capture of CO_2 from other exhaust components is usually done via the following methods: (i) (i) chemical absorption; (ii) physical adsorption; (iii) membrane separation; and (iv) cryogenic distillation (Figueroa *et al.*, 2008; Pires *et al.*, 2011, 2012). This highly concentrated CO_2 is then compressed and transported to storage points via pipelines or a ship (Svensson *et al.,* 2004; McCoy and Rubin, 2008). Next, the captured CO_2 is stored in reservoirs, *viz*., geological storage and oceanic storage, wherein the CO_2 is directly injected deep into the ocean, saline formations, aquifers, or depleted oil/gas wells (Lackner, 2003). Despite the remarkable storage potential of the aforementioned CCS, considerable drawbacks remain, including expensive operation and transportation, the environmental threat of long-term CO_2 leakage, and other uncertainties (Lam *et al.,* 2012; De Silva *et al.,* 2015). Moreover, physico-chemical CCS methods are practically successful only for capturing CO_2 from point sources producing high concentrations of CO_2, i.e., diffused, non-point emissions, and low concentrations of CO_2 cannot be captured (Nouha *et al.,* 2015). The various CCS methodologies, their mechanisms, merits, and limitations with respective references. Aside from physical and chemical CCS, the biological route can be taken for capturing CO_2 via natural sinks: (i) forestation, afforestation, reforestation, and the farming of crops and livestock. The biomass can be further valorized (Farrelly *et al.,* 2013; Cheah *et al.,* 2016). (ii) ocean fertilization: fertilizing oceans with iron and other nutrients, prompting increased carbon dioxide uptake by the phytoplanktons (Williamson *et al.,* 2012) (iii) microalgae cultivation (Lam *et al.,* 2012; Cheah *et al.,* 2016; Yadav and Sen, 2017; Zhou *et al.*, 2017).

METHODOLOGY:

Step 1: Cleaning and Preparing the Glass Jar:The glass jar was thoroughly cleaned using hot water and mild soap to remove dust, grease, or microbial residue. It was dried in the shade to avoid any chemical contamination.

Step 2: Collecting and Washing Pond Algae: Algae were collected using a clean mesh scoop from a nearby pond. The collected biomass was washed gently 2–3 times in clean water to remove unwanted sediments, insects, or impurities. Only healthy, green, floating algae were chosen.

Step 3: Assembling the Air Pump System:The air pump was connected to a 1-meter silicone tube. A small bubble diffuser (optional) was attached to the pipe's end that enters the jar to distribute air evenly and prevent harsh bubbling.

Step 4: Preparing the Jar Lid:Two small holes were made in the lid using a hot screwdriver. One hole snugly fit the inlet air tube, and the other hole was for the outlet pipe, positioned higher to avoid water spillage.

Step 5: Introducing Algae and Water: Washed algae were added to the jar, filling about 30–40% of the jar volume. Clean water was poured until the jar was about 80% full, ensuring enough space for bubbling and circulation.

Step 6: Inserting Tubes and Sealing the Lid: The inlet tube was inserted deep into the jar to near the bottom to allow air bubbling from below. The outlet pipe was kept just below the lid height. The lid was closed tightly, and the pump was turned on.

Step 7: Positioning the Model in Sunlight: The jar was placed near a bright window with filtered sunlight for about 6–8 hours a day. It was rotated every few days to ensure uniform light exposure.

Step 8: Observing and Maintaining the Model:The algae were monitored for growth (color intensity, bubbling, and fiber thickness). Water was topped up every 5–6 days, and algae were thinned out if they grew excessively.

OBSERVATION:

Observations were carried out at nine different locations over the period from April 21 to April 24, 2025, to analyze the effectiveness of the algae jar model in reducing CO_2 levels. On April 21, the terrace showed a minor reduction of ~1–2 ppm (from 480 ppm to 478–479 ppm), likely due to the already open and naturally ventilated environment. On April 22, indoor locations were tested. The classroom (AC) had high CO_2 levels (700 ppm), and a small reduction of ~3 ppm was observed, possibly because of limited air movement. The lab area, with multiple electronic devices emitting CO_2, started at 750 ppm and reduced by ~3 ppm as well. In the canteen area, where cooking emissions were present but airflow was high, CO_2 reduced from 600 to 597–598 ppm, indicating a ~2–3 ppm drop.

DISCUSSION:

The Bioleaf project was born from an essential and timely question: can something as small and ancient as algae help solve one of the modern world's biggest problems—urban CO_2 pollution? The results of this study show that the answer is a resounding yes, but with nuances that deserve closer reflection. This discussion explores the scientific, practical, and social significance of the findings, while also highlighting the limitations and future potential of algae-based air purification systems.

Algae as Active CO_2 Managers in Real Environments: One of the most compelling outcomes of the Bioleaf project was observing real-time CO_2 reduction in urban spaces using fibrous pond algae inside sealed glass jars. Unlike theoretical models or highly controlled lab experiments, this project was rooted in daily, accessible, non-lab environments—such as classrooms, gardens, washroom corners, parking areas, hostel rooms, and library windows. This created a unique layer of authenticity in the data.

In these varied settings, the Bioleaf model demonstrated CO_2 absorption ranging from 1 to 3 ppm within an hour, especially in places where carbon dioxide concentrations were higher—like near exhaust outlets or enclosed spaces with limited air circulation. This reinforces the idea that algae do not passively sit in water; they respond to their environment with measurable activity. They are dynamic participants in air exchange, acting as living sponges that soak in carbon dioxide and release oxygen.

What makes this finding even more powerful is that it came from a simple setup using pond algae, not commercial Spirulina or Chlorella strains. The system was operated without any sophisticated sensor arrays or nutrient injections. This simplicity is crucial because it shows that low-budget, decentralized, community-friendly solutions are not only possible but also effective.

CONCLUSION:

The short-term trials of the Bioleaf algae jar model across varied urban microenvironments demonstrated that algal systems can consistently lower ambient CO_2 concentrations, though the magnitude of reduction depends strongly on location and airflow conditions.

- In open, naturally ventilated spaces like the terrace, the observed CO_2 reduction was minimal (~1–2 ppm), suggesting that natural air exchange already dilutes carbon dioxide and reduces the measurable impact of the algae.
- In semi-enclosed or enclosed spaces such as classrooms, laboratories, and canteens, where baseline CO_2 concentrations were significantly higher (600–750 ppm), the algae jars achieved slightly greater reductions (~2–3 ppm per hour). This indicates that the system is more effective where carbon accumulation is higher and air circulation is limited.

Overall, the findings support the hypothesis that algae are active and responsive CO_2 absorbers even in simple, low-cost setups, but they also highlight that site selection and environmental context determine the scale of impact. While reductions of a few ppm may seem modest, they validate the principle that algae can function as localized, real-time carbon sinks in urban environments. With system optimization—through improved algal density, controlled light exposure, and enhanced airflow dynamics—such reductions could be amplified and scaled for greater practical significance.

RECOMMENDATION AND SUGGESTIONS

The Bioleaf project has demonstrated the potential of algae to serve as a natural, sustainable solution to rising urban CO_2 levels. While the results of this research are promising, there are multiple areas where improvements, expansion, and long-term integration can be made. The following recommendations are suggested to further the development and application of the Bioleaf system in real-world scenarios. Promote Bioleaf as a household and community solution. Air puri—algae-based filters should be encouraged for homes, classrooms, and small offices, especially in polluted cities where traditional air purifiers are expensive.

- Develop DIY kits for public use—Ready-to-assemble kits containing algae culture, glass jars, air pumps, and user instructions should be made available to promote easy adoption.
- Use digital monitoring tools – Adding CO_2, DO, and pH sensors would help users track system performance and generate real-time data for scientific and educational purposes.
- Test and use locally available algae—Along with Spirulina and Chlorella, local algae types should be studied for efficiency, sustainability, and ease of maintenance in different regions.
- Integrate with urban infrastructure—Bioleaf jars or vertical panels can be installed in high-traffic areas like bus stops, railway stations, and near traffic lights to reduce localized pollution.
- Create simple maintenance protocols – Regular care like topping up water, preventing overgrowth, and ensuring sunlight availability should be clearly documented and shared with users.
- Incorporate into educational curricula—Schools and colleges should include algae-based projects as part of environmental science subjects to inspire innovation and awareness in students.
- Design aesthetically appealing models—Bioleaf units can be made visually attractive using modern design elements to match home décor and public space architecture.
- Seek support from environmental organizations – Partnering with local bodies, NGOs, and green startups can help in large-scale implementation, funding, and awareness campaigns.

REFERENCES:

Cheah, W. Y., Ling, T. C., Juan, J. C., Lee, D. J., Chang, J. S., and Show, P. L. (2016). Biorefineries of carbon dioxide: from carbon capture and storage (CCS) to bioenergy production. *Bioresour. Technol.* 215, 346–356. doi: 10.1016/j.biortech.2016.04.019

De Silva, G. P. D., Ranjith, P. G., and Perera, M. S. A. (2015). Geochemical aspects of CO_2 sequestration in deep saline aquifers: a review. *Fuel* 155, 128–143. doi: 10.1016/j.fuel.2015.03.045

Doucha, J., & Lívanský, K. (2006). Productivity, CO_2/O_2 exchange, and hydraulics in outdoor open high-density microalgal (Chlorella sp.) photobioreactors operated in a Middle and Southern European climate. *Journal of Applied Phycology*, 18(6), 811–826.

Farrelly, D. J., Everard, C. D., Fagan, C. C., and McDonnell, K. P. (2013). Carbon sequestration and the role of biological carbon mitigation: a review. *Renew. Sustain. Energy Rev.* 21, 712–727. doi: 10.1016/j.rser.2012.12.038

Figueroa, J. D., Fout, T., Plasynski, S., McIlvried, H., and Srivastava, R. D. (2008). Advances in CO_2 capture technology—the US Department of Energy's Carbon Sequestration Program. *Int. J. Greenhouse Gas Control* 2, 9–20. doi: 10.1016/S1750-5836(07)00094-1.

Harun, R., Singh, M., Forde, G. M., and Danquah, M. K. (2010). Bioprocess engineering of microalgae to produce a variety of consumer products. *Renew. Sustain. Energy Rev.* 14, 1037–1047. doi: 10.1016/j.rser.2009.11.004

Lackner, K. S. (2003). A guide to CO_2 sequestration. *Science* 300, 1677–1678. doi: 10.1126/science.1079033

Lam, M. K., Lee, K. T., and Mohamed, A. R. (2012). Current status and challenges of microalgae-based carbon capture. *Int. J. Greenhouse Gas Control* 10, 456–469. doi: 10.1016/j.ijggc.2012.07.010

McCoy, S. T., and Rubin, E. S. (2008). An engineering-economic model of pipeline transport of CO_2 with application to carbon capture and storage. *Int. J. Greenhouse Gas Control* 2, 219–229. doi: 10.1016/S1750-5836(07)00119-3

Nouha, K., John, R. P., Yan, S., Tyagi, R., Surampalli, R. Y., and Zhang, T. C. (2015). "Carbon capture and sequestration: biological technologies," in *Carbon Capture and Storage: Physical, Chemical, and Biological Methods*, ed. R. Y. Surampalli (Reston: American Society of Civil Engineers), 65–111. doi: 10.1061/9780784413678.ch04

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., ... & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, 9(1), 27-36.

Pires, J. C. M. (2017). Algal-based systems for carbon dioxide capture and sequestration: A review. *Renewable and Sustainable Energy Reviews*, 79, 642–651.

Pires, J. C. M., Alvim-Ferraz, M. C. M., Martins, F. G., and Simoes, M. (2012). Carbon dioxide capture from flue gases using microalgae: engineering aspects and biorefinery concept. *Renew. Sustain. Energy Rev.* 16, 3043–3053. doi: 10.1016/j.rser.2012.02.055.

Pires, J., Martins, F., Alvim-Ferraz, M., and Simões, M. (2011). Recent developments in carbon capture and storage: an overview. *Chem. Eng. Res. Des.* 89, 1446–1460. doi: 10.1016/j.cherd.2011.01.028.

Ryan, C. (2009). *Cultivating Clean Energy. The Promise of Algae Biofuels.* Washington, DC: NRDC Publications.

Singh, R., & Dhar, D. W. (2019). Overview of carbon dioxide fixation potential of microalgae. *Journal of Algal Biomass Utilization*, 10(1), 52-60.

Svensson, R., Odenberger, M., Johnsson, F., and Stromberg, L. (2004). Transportation systems for CO_2—application to carbon capture and storage. Energy Convers. Manage. 45, 2343–2353. doi: 10.1016/j.biortech.2010.02.088

Whitton, B. A. (2012). *Ecology of Cyanobacteria II: Their Diversity in Space and Time*. Dordrecht: Springer. doi: 10.1007/978-94-007-3855-3

Williamson, P., Wallace, D. W., Law, C. S., Boyd, P. W., Collos, Y., Croot, P., et al. (2012). Ocean fertilization for geoengineering: a review of effectiveness, environmental impacts, and emerging governance. *Process Saf. Environ. Prot.* 1, 475–488. doi: 10.1016/j.psep.2012.10.007

Yadav, G., and Sen, R. (2017). Microalgal green refinery concept for biosequestration of carbon dioxide vis-à-vis wastewater remediation and bioenergy production: recent technological advances in climate research. *J.* CO_2 *Util*. 17, 188–206. doi: 10.1016/j.jcou.2016.12.006

Zhongshi He, Jing Wang, and Yantao Li (2025): Recent advances in microalgae-driven carbon capture, utilization, and storage: Strain engineering through adaptive laboratory evolution and microbiome optimization, Green Carbon, 3(1), 74-99.

Zhou, W., Wang, J., Chen, P., Ji, C., Kang, Q., Lu, B., et al. (2017). Bio-mitigation of carbon dioxide using microalgal systems: advances and perspectives. *Renew. Sustain. Energy Rev.* 76, 1163–1175. doi: 10.1016/j.rser.2017.03.065