Chapter

CO_2 Capture for Industries by Algae

Vetrivel Anguselvi, Reginald Ebhin Masto, Ashis Mukherjee and Pradeep Kumar Singh

Abstract

The increased usage of fossil fuels has led to increase in the concentration of CO_2, which is a greenhouse gas responsible for global warming. Algae-based CO_2 conversion is a cost-effective option for reducing carbon footprint. In addition, algae-based CO_2 mitigation strategy has the potential to obtain valuable products at the end of the process. In the present study, freshwater algal species were isolated and identified for CO_2 capture, such as *Hydrodictyon*, *Spirogyra*, *Oscillatoria*, *Oedogonium*, and *Chlorella*. The algal strains were screened based on different parameters like fast growth rate, high rate of photosynthesis, strong tolerance to the trace constituents of other gases (gaseous hydrocarbons, NOx, SOx, etc.), high temperature tolerance, and possibility to produce high value products, etc. The study involves integrated methods for utilizing 90–99% CO_2 from a natural gas processing industry (GAIL India, Ltd.) as well as 13–15% of CO_2 from flue gas of thermal power plants (*Chandrapura* and Santaldih *Thermal Power Station*) as carbon nutrient source along with the additional nutritional supplements. A 400-ml and 25-l flat panel photo-bioreactor (PSI Photo-bioreactors) was used for CO_2 capture. After CO_2 capture, the algal biomass was used to extract value-added products such as amino acid rich feed, algal oil, algal pellets, etc.

Keywords: algae, CO_2, flue gas, capture, petrochemical industries, thermal power station

1. Introduction

Greenhouse gas emissions by industries and human activities make the planet warmer. CO_2 emitting industries are contributing a major role in the increase of greenhouse gases in the atmosphere for several decades. The largest source of greenhouse gas emissions from human activities in the world is burning fossil fuels for electricity, heat, transportation, and domestic uses. Carbon sequestration, capturing, and storing carbon emitted from the global energy system could be a major tool for reducing atmospheric CO_2 concentration. The conventional CO_2 sequestration processes like geological sequestration are highly power intensive and therefore expensive. While chemical and physical means exist to capture CO_2 from smoke stack emissions, the cost of utilizing these technologies would result in a significant increase in the cost of power. The need for CO_2 management, in particular capture and storage, is currently an important technological, economical, and global issue

and will continue to be so until alternative energy sources diminish the need for fossil fuels. As microalgae grow in aqueous environments, directly passing CO_2-rich gases through this medium is a very efficient way of capturing the CO_2 in those streams.

Algae-based carbon di-oxide (CO_2) sequestration has gained more interest due to its capability to utilize CO_2 as carbon source, higher photosynthetic efficiency, high CO_2 fixation capacities and optimal culture condition, higher growth rates than conventional crop plants and biomass produced can be used as a feedstock for other value added products such as biofuel and chemicals [1]. In recent years, cultivation of microalgae has received renewed attention on account of its possibility as a feasible CO_2 sequestration technology. Under phototrophic growth conditions, microalgae absorb solar energy, and assimilate CO_2 from air and nutrients from aquatic habitats. One kilogram of algal dry cell weight utilizes around 1.83 kg of CO_2. As per the available literature, an area of 1 Acre (4000 m^2) shall be able to capture about 2.7 tons/day of CO_2 [2]. Algae are receiving wide attention as a source of biomass protein for use in animal feeds and foods [3, 4]. In addition, algae-based CO_2 mitigation strategy has the potential to obtain valuable products from the algal biomass that can be used to generate revenues, thereby making this route feasible. This route could also provide solutions to another major problem viz. high dependency on fossil fuels.

As microalgae grow in aqueous environments, directly passing CO_2-rich gases through this medium is a very efficient way of capturing the CO_2 in those streams. Algae-based CO_2 conversion offers a cost-effective option toward reducing our carbon footprint. In addition, algae-based CO_2 mitigation strategy has the potential to obtain valuable products at the end of the process. Thus, any value addition achieved through such route could also provide solutions to the other major problem viz. high dependency on fossil fuels. Microalgae utilize CO_2 for photosynthesis. Algae-based CO_2 capture is one of the viable options for anthropogenic CO_2 conversion. While microalgal cultivation is expensive, microalgae biomass can be utilized to produce a variety of high value commercial products (algal fuel, protein-rich algal food, animal feed, algae-based medicines, etc.) that can be used to generate revenues, thereby making this route feasible.

At present, more number of researches work is in progress globally to develop and commercialize algae-based carbon conversion technology. Large companies of United States such as Duke Energy, the third largest electric power holding company, are working on various aspects of carbon conversion technology. Government policies, especially in the US and Europe, are also supporting the growth of algae-based carbon conversion technologies. If the challenges associated with algae-based carbon capture technology are addressed successfully, the technology will present a solution not only to the global warming problem, but also to reduce the fossil fuel demand.

2. Experimental study on CO_2 capture for petrochemical industry and thermal power plants

2.1 Isolation, identification, and selection of the high CO_2-tolerant algal strains

In the present study, freshwater algal species were isolated and identified for CO_2 capture, such as *Hydrodictyon*, *Spirogyra*, *Oscillatoria*, *Oedogonium* and *Chlorella* from freshwater taken from pond in the coal mining area of Dhanbad, Jharkhand, India. The blue-green microalgae, *Oscillatoria*, were used for CO_2 capture study. The stock culture and inoculum were grown in BG11 medium [3] in the required condition. The inoculum was pre-cultured aseptically in 500-ml Erlenmeyer flasks with 200 ml of

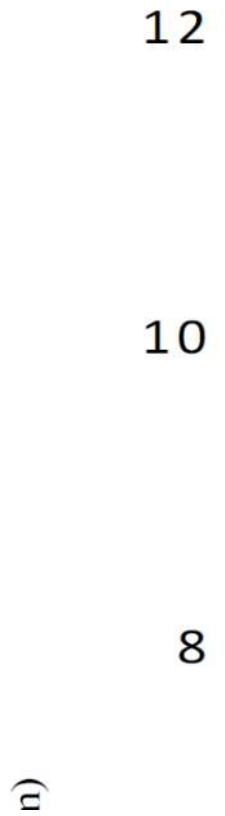

Figure 1.
Scanning electron micrograph of the filament of Oscillatoria.

BG11 medium. The flasks were placed in a 28°C illuminated incubator for 7 days under a 12-h light/12-h dark photoperiod and a light density of 40 μE m^{-2} s^{-1}. The BG-11 medium was used for algal culture with the composition of (g/L): $K_2HPO_4.3H_2O$ 0.04, $NaNO_3$ 1.5, $CaCl_2.2H_2O$ 0.036, $MgSO_4.7H_2O$ 0.075, ferric ammonium citrate 0.006, Na_2EDTA 0.001, citric acid 0.006, Na_2CO_3 0.02, pH 7.0. B The identification was done on the basis of the morphological characters of the algae (**Figure 1**).

2.2 Optimization of process parameters for CO_2 conversion

After pre-cultivation, the algal inoculum reached exponential growth phase. One gram of the algal inoculum was collected using centrifugation (4000×*g*, 4°C, 15 min). The collected algal cells were washed twice with sterile distilled water, and then inoculated into the growth medium. Microalgae growth and composition are affected by several process parameters. Different process parameters were optimized such as pH, light and temperature, nutrient media, culture condition, inoculum volume, inoculum concentration, etc.

2.3 CO_2 capture in photo-bioreactor

Exhaust gas from natural gas processing industry and thermal power plants were collected and analyzed for its composition (**Tables 1** and **2**) (Gas analyzer and GC). Selected species of microalgae were inoculated in a bioreactor and studied for CO_2 capture. Further, a novel "fibrous matrix photo-bioreactor" designed and used for algal culture and CO_2 capture. Novel bioreactor designed and used in the process is having in-built organic fibrous matrix for support of the filamentous algae growth, rapid proliferation, and easy recovery (**Figure 2**).

S. no	Test parameter	Unit	Result
1	Nitrogen	Mole %	0.20
2	Methane	Mole %	0.71
3	Ethane	Mole %	0.20
4	Hydrogen sulfide	ppm	60
5	Amine content	ppm	ND
6	Moisture content	Mole %	1.50
7	Carbon dioxide	Mole %	97.384

Table 1.
Composition of exhaust gas from natural gas processing industry, GAIL (PATA).

Gas	Santaldih TPS	Chandrapura TPS
	Amount (%)	
CO_2	11.93	10–12
O_2	3.96	4–6
SO_2	0.99	Trace
NO_2	0.99	Trace
N_2	82.13	85

Table 2.
Composition of exhaust gas from thermal power plants.

Figure 2.
Light microscope photo of a filament of Oscillatoria.

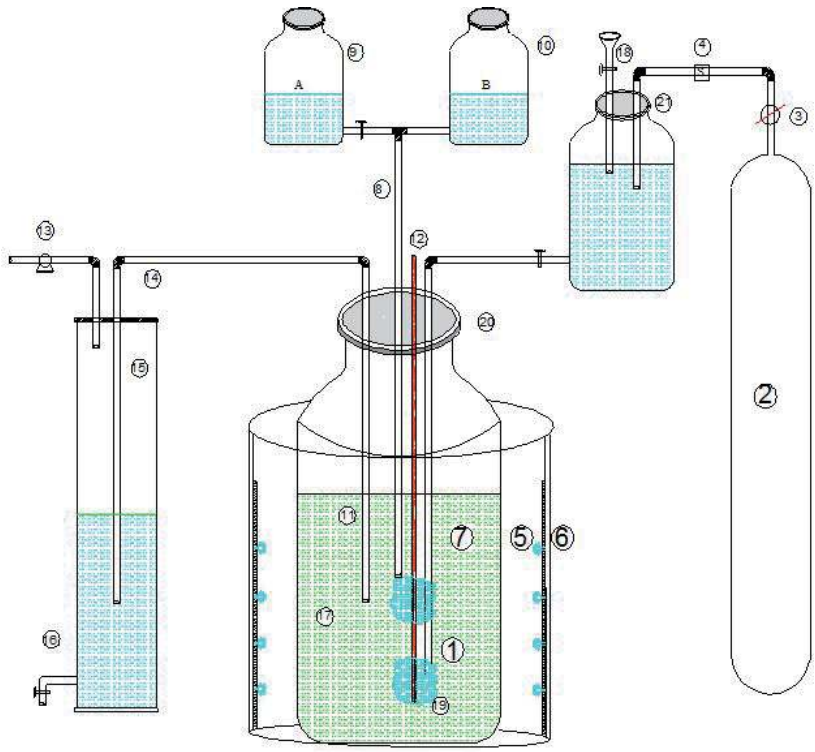

Figure 3.
CO_2 capture and algal fuel production from lab to pilot scale: Facilities at CSIR-CIMFR.

Pigment estimation, protein content, and fatty acid determination were carried out at 5 days interval to determine the growth and subsequently to compare the tolerance of the algal species. The experiment was carried out in flat panel photo-bioreactor (**Figure 3**), which contained 15 l of algal media. Injection of CO_2 rich gas was carried out at a rate of 500 ml/30 min continuously for 48 h. Determination of pH was undertaken at 3 h interval and pigment estimation was carried out at 24, 36, and 48 h intervals.

3. Results and discussion

Oscillatoria is a filamentous blue-green algae with uniserially arranged cells that are not constricted at the cross walls (**Figure 1**). The straight, unbranched, filaments are dark blue-green, covered with a thin hyaline sheath and is not attenuated or capitated at the end. This unbranched filamentous alga occurs singly or in tangled mats. Terminal cells are hemispherical with a slightly thickened membrane on the outer cell envelope (**Figure 4**, Geitler [5]). *Oscillatoria* is common in freshwater environments, including hot springs. It has more than 100 species.

The growth pattern showed that the lag phase of *Oscillatoria* was from 0 to 24 h, exponential phase from 24 to 36 h, the stationary phase from 36 to 60 h and then the decline phase (**Figure 5**).

Growth of algae, in general, depends upon the availability of nitrogen and phosphate (**Table 3**). The increased nutrients result in higher growth and higher biomass of cyanobacteria. Phosphorus was reported to be an essential element for pigment development. Algae are known to assimilate phosphorus in excess of their requirements. The algae (*Oscillatoria*) could not survive in water to which urea was added. Sodium and potassium containing salts along with orthophosphate

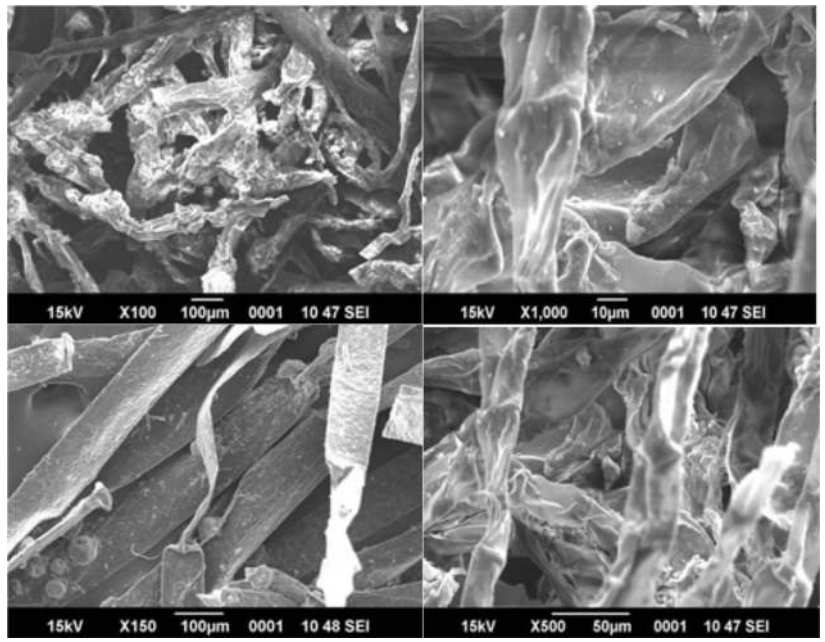

Figure 4.
CO_2 capture system using filamentous cyanobacteria: 1—gas absorbed media inlet, 2—gaseous source for feed, 3—gas outlet valve, 4—gas regulator, 5—illumination source, 6—photo-reactor outer wall, 7—growth media, 8—pH control inlet tube, 9—acid source - pH control, 10—alkali source - pH control, 12—media outlet tube, 13—spent media container, 14—spent media exhaust, 15—media inlet tube, 16—media container, 17—media inlet valve, 18—photo-bioreactor vessel, 19—media exhaust tube, 20—fibrous matrix attachment, 21—photo-bioreactor lid, and 22—gas absorption container lid.

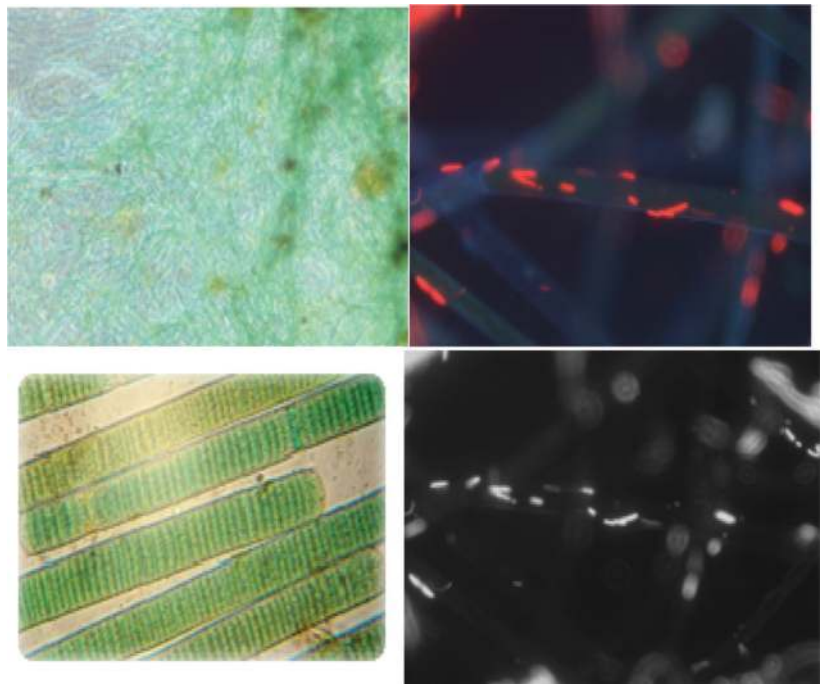

Figure 5.
Growth curve of Oscillatoria.

proved to be a good nutrient for the growth of *Oscillatoria*. Luxuriant growth of *Oscillatoria* was observed in KNO_3 + sodium orthophosphate and $NaNO_3$ + sodium orthophosphate.

Nutrient	Day 0	Day 10	Day 20	Day 30
Control	+	+	+	+
KNO_3 + $NaHPO_4$	+	+++	+++	+++
$NaNO_3$ + $NaHPO_4$	+	+++	+++	+++
Urea	+	+	+	+
Glucose	+	++	++	++

+++: luxuriant growth; ++: moderate growth; +: mild growth.

Table 3.
Effect of nutrients on growth of Oscillatoria.

Metal ion	Days						
	0	5	10	15	20	25	30
Control	+	+	+	+	+	+	+
Ba^{+}	+	-	+	+	+	+	++
Ca^{++}	+	+	++	++	++	++	++
Co^{++}	+	-	+	+	+	+	++
Cr^{+++}	+	+	+	+	+	+	++
Cu^{++}	+	+	+	+	+	+	++
Fe^{+++}	+	+	++	++	++	++	++
Fe^{++}	+	-	-	+	+	+	++
Mn^{++}	+	-	-	+	+	++	+++
Mg^{++}	+	+++	+++	+	+++	+++	+++
Ni^{++}	+	+	+	+	+	+	++
K^{+}	+	++	++	+++	+++	+++	+++
Na^{+}	+	++	++	+++	+++	+++	+++
Sn^{++}	+	+	+	++	++	++	++
Zn^{++}	+	+	+	+	+	+	++
Ag^{+}	+	-	-	-	-	-	-
Hg^{+}	+	-	-	+	+	+	+

+++: luxuriant growth; ++: moderate growth; +: mild growth; -: no growth.

Table 4.
Effect of metal ions on growth of Oscillatoria.

3.1 Effect of metal ions on growth of *Oscillatoria*

Maximum growth was observed in salts containing Na^{+}, Mg^{++}, Ni^{++}, Co^{++}. A drastic increase in chlorophyll content was observed in salt containing Mg^{++}, Mn^{+2} ions. Growth was observed in 15 metal salts out of 16. The algae (*Oscillatoria*) died in salt containing Ag^{+}. Since, nearly all algae possess chlorophyll and all are expected to carry out molecular phosphate transfers, magnesium is without doubt needed universally by algal species. Net synthesis of RNA may stop immediately following magnesium withdrawal. Potassium is a major cell electrolyte, used for balancing the ionic charge. Sodium plays a key role in maintaining turgor pressure within the organism (**Table 4**).

Vitamin	Day 0	Day 5	Day 10	Day 15
Control	+	+	+	+
Vitamin B12	+	+++	++	+
Vitamin B1	+	+++	+++	+++
Vitamin C	+	+++	+	+

+++: luxuriant growth; ++: moderate growth; +: mild growth.

Table 5.
Growth of Oscillatoria in different vitamins.

Hormones	Day 0	Day 10	Day 20	Day 30
Control	+	+	+	+
IAA*	+	+	++	++
GA**	+	+	++	++

*++: moderate growth; +: mild growth. *IAA: Indole-3-acetic acid; **GA: Gibberellic acid.*

Table 6.
Growth of Oscillatoria in different hormones.

Surfactants	Day 0	Day 5	Day 10	Day 15
Control	+	+	+	+
Triton X	+	+++	+++	+++
Tween 20	+	+++	+++	+++
Tween 80	+	+++	+++	+++
SDS	+	+++	++	+

+++: luxuriant growth; ++: moderate growth; +: mild growth.

Table 7.
Growth of Oscillatoria in different surfactants.

3.2 Effect of vitamins, growth hormones and surfactants on growth of *Oscillatoria*

Growth was observed in all the three vitamins (B_1, B_{12}, and C). An increase in the chlorophyll content was observed in all the three vitamins till the fifth day. Afterward, luxuriant growth was observed in Vitamin B_1, good growth was observed in Vitamin B_{12}, and moderate in Vitamin C. Vitamin B_{12} acts as a growth factor for all algae as well as higher plants. A good growth was observed in Gibberellic acid as well as Indole-3-acetic acid. Gibberellic acid is a plant growth hormone that influences various developmental processes; while, cyanobacteria respond to IAA in a manner analogous to higher plants. Luxuriant growth was observed in all the four surfactants with increase in the pigment content of *Oscillatoria*. Almost equal growth was observed (visually) up to 7 days. At the tenth day, moderate growth was observed in SDS while luxuriant growth was observed in Triton-X, Tween-20, and Tween-80 (**Tables 5–7**).

3.3 CO_2 capture by *Oscillatoria* in photo-bioreactor

Photo-bioreactors act as closed pond system that are used for microalgae cultivation, as they can reduce contamination risk from unwanted algae, mold, and bacteria; control temperature; minimize water evaporation; and reduce carbon

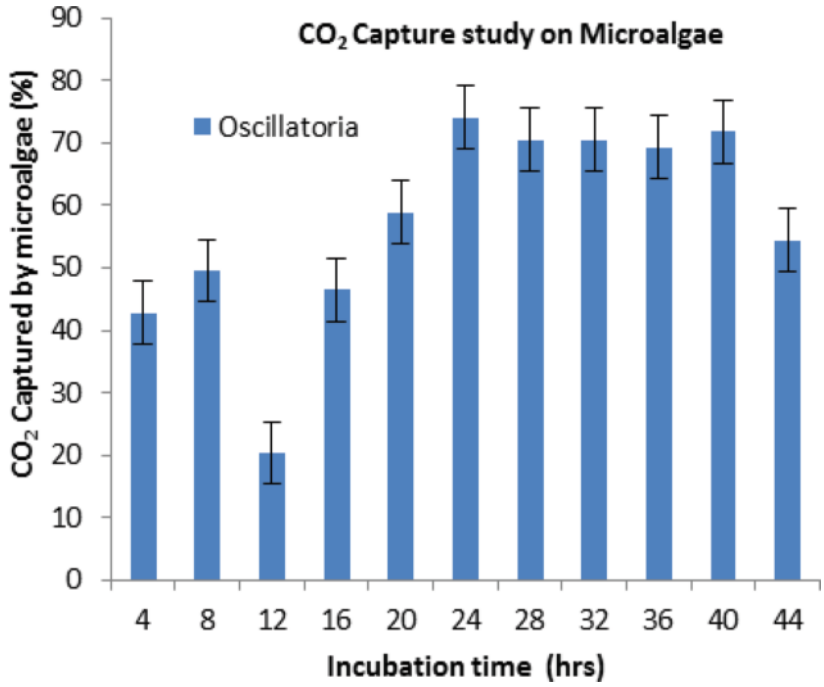

Figure 6.
CO_2 capture by Oscillatoria.

dioxide losses. Photo-bioreactor FMT 150 used in the present study consists of an algal-cultivation vessel with a sealable lid and a base box containing electronics circuitry, LED light panel, and other components essential for the optimal operation of the photo-bioreactor (**Figure 3**). The cultivation vessel is rectangular in shape and flat with a working volume capacity of 400 ml. Its front and back windows are made of glass plates. The bottom of the cultivation vessel is made of stainless steel and contains a thermal bridge that helps heat transfer between a Peltier cell in the instrument base and the culture suspension.

The culture vessel is fixed with the array of high-power light emitting diodes (LEDs). These LEDs produce a highly uniform light with the irradiance flux that can be controlled in the range of 0–3000 μmol (photons)/m^{-}/s^{1} PAR. The irradiance of the LEDs can be dynamically modulated by the instrument control unit through external computer with software. The photo-bioreactor is equipped with semiconductor light sensor for measuring fluorescence emission and suspension optical density by attenuation of light that was emitting from the LEDs. The solenoid valves are used to switch off the gas supply to the culture (bubbling) during optical measurements. For the supply of fresh medium or buffer, the Peristaltic pumps are used in turbidostat and chemostat mode.

Higher CO_2 capture capacity observed in *Oscillatoria* from 16 to 32 h (**Figure 6**). Higher CO_2 capture efficiency, algal biomass productivity was observed in the selected strains of algae at optimum pH of 7–9 and temperature 25–30°C. The results indicate that the selected blue-green algae *Oscillatoria* can be used for CO_2 capture and biomass production, freshwater algae are ideal candidates for CO_2 capture, when treated with CO_2-rich gas.

4. Conclusion

Developed process for the CO_2 capture will lead to environment-friendly alternatives to chemical CO_2 capture process. The study exclusively relates to integrated

methods and systems for utilizing 99.9% CO_2 as a nutrient carbon source along with modified growth media derived from coal mine water for filamentous cyanobacteria culture. The modified algal media was enriched with the addition of Fe, Mg, vitamins, and surfactants for higher photosynthetic efficiency of algae.

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