Green Solutions for CO_2 Mitigation: Exploring Microalgae-Based Carbon Capture and Utilization Technologies

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ABSTRACT

Background: Rising carbon dioxide concentrations in the Earth's atmosphere drive greenhouse gas accumulation and climate change. Addressing this critical concern mandates inventive solutions, among which the Microbial Carbon Capture Cell (MCC) system stands out. Central to MCC technology is microalgae, encompassing diverse species with exceptional carbon dioxide absorption capabilities. Microalgae convert carbon dioxide into biomass through photosynthesis, effectively sequestering it and mitigating environmental impact. Beyond carbon sequestration, MCC technology extends to wastewater treatment and flue gas purification, providing a dual advantage by combating pollutants while capturing carbon dioxide. This holistic approach contributes to cleaner air and water, promoting sustainable development. MCC technology harbors transformative potential in energy. Microalgae-derived biomass can yield biofuels, a renewable energy source, substantially reducing greenhouse gas emissions. This shift from fossil fuels to biofuels is pivotal for reducing our carbon footprint and advancing sustainability..
Objective: This study has multiple objectives, including emphasizing the role of microalgae in efficiently sequestering carbon dioxide, the parameters that affect microalgae growth and performance, and improving their carbon sequestration capabilities**. Discussion:** The study also highlights the power generation of MCC technology and its contribution to clean energy production and grid sustainability. The study also addresses the production of biodiesel from microalgae as a renewable and environmentally friendly fuel source, reducing carbon emissions, reducing dependence on depleting fossil fuels, and enhancing energy security**. Conclusion**: Microbial carbon capture cell technology holds promise in combating climate change by efficiently capturing carbon, reducing pollution, and transitioning to cleaner, sustainable energy sources.

Keywords: CO_2 sequestration, microalgae, power generation, Microbial carbon capture.
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INTRODUCTION

Atmospheric carbon dioxide holds a pivotal role as a primary pollutant, actively contributing to the escalation of greenhouse gas concentrations (1). Therefore, CO_2 transformation into fuels and products with value-added would substantially contribute to efforts to mitigate climate change (2)**.** Addressing the worldwide concern regarding CO_2 emissions necessitates enhancing diverse CO_2 fixation systems. These systems contribute to the sequestration of CO_2 from the atmosphere through biological mechanisms that not only offer efficient energy recovery but also ensure sustainable and extended operational capabilities (3)**.** In the past few years, the notion of carbon capture and use has piqued the curiosity of many in the chemical industry. This notion proposes a technical way to fight carbon dioxide emissions by transforming them into compounds of higher value (4)**.** To address the environmental consequences of CO_2 emissions from fossil fuel burning and other sources, the Capture and storage of CO_2 will probably form a fundamental element of a comprehensive solution (5)**.** Microorganisms, such as microalgae and cyanobacteria, can flourish by fixing and consuming CO_2. In particular, cyanobacteria and microalgae have shown a remarkable ability to convert CO_2 into oxygen and biomass. The efficacy of Microalgae in reducing CO_2 is contingent on a multitude of variables, including their specific algal species, cultivation methodology employed, nutrient ratios, light intensity, temperature, pH levels, rate of CO_2 gas flow, and the concentration of CO_2 present (6). In contrast to the traditional method of underground CO_2 sequestration, modern initiatives by companies involve using organic chemistry to harness CO_2 as a chemical precursor. This shift has resulted in the development of CO_2 utilization processes that tap into the captured CO_2 from power plants. This approach has gained global recognition for its dual benefits: it mitigates atmospheric CO_2 emissions and yields commercial products. A prime illustration of this is the utilization of CO_2 to enhance the growth of microalgae, a subject that has been extensively investigated due to its extraordinary capacity to convert CO_2 into biofuel feedstock (7). The process of bio-fixing CO_2 is commonly achieved through photosynthesis, which involves a variety of terrestrial plants and ubiquitous microorganisms. These organisms can convert CO_2 into O_2 and organic compounds by utilizing photon energy. As a result, technologies centered on bioelectrochemical systems (BESs) are on the rise (8). Bioelectrochemical systems are emerging as highly promising technologies that leverage the synergy between electrochemistry, microbiology, and biotechnology. Their inherent versatility enables various applications, including but not limited to wastewater treatment, power production, resource recovery, and CO_2 conversion into valuable and beneficial items (9). Nonetheless, current recovery rates and electricity generation efficiencies are inadequate to yield top-tier effluents with a high potential for re-utilization and self-sustaining electricity production. Recent advances have been made in bioelectrochemical systems (BESs), particularly in the form of Plant-microbial fuel cells (PMFCs) and microbial carbon capture cells (MCCs). In recent years, microbial fuel cell (MFC) innovation has been a sustainable technology development. MFCs achieve direct conversion of organic matter to energy via biocatalytic processes aided by microorganisms (10). Combining the advantages of microalgal and MFC technologies into a single system known as microbial carbon capture (MCC) cells gives an appealing method for addressing the treatment of wastewater, carbon capture, and bioelectricity generation all at the same time (11). This review delves into the utilization of microalgae within a bioelectrochemical system, specifically the microbial carbon fuel cell, to effectively sequester carbon dioxide. The system not only facilitates carbon capture but also demonstrates the potential for power generation, the creation of enhanced products, and the treatment of wastewater.

CARBON DIOXIDE SEQUESTRATION

The utilization of carbon sequestration and storage offers a solution to the escalating global energy demand. This approach involves converting collected CO_2 into fuels or using it to improve oil recovery, substantially reducing CO_2 emissions (12). To address CO_2 mitigation, a range of physicochemical and biological approaches have been used, with biological sequestration employing cyanobacteria emerging as one of the most potent solutions for efficiently moderating CO_2 levels (13). The physical technique of CO_2 sequestration involves an injection of CO_2 into deep oceans or geological formations for temporary confinement. The chemical approach employs adsorption materials or introduces alkaline neutralization reagents, such as carbonate or bicarbonate, to capture CO_2 directly. The photosynthesis of green plants is used in the biological fixation process to convert CO_2 into organic matter, serving as an energy source while maintaining the carbon-oxygen balance in the atmosphere. Among the various strategies, biological approaches have emerged as the most pragmatic because of their favorable cost-effectiveness, environmental compatibility, and sustainability. Plants and microalgae play essential roles in biological carbon sequestration (14). Based on previous research findings detailed examination of the potential optimization and process impacts of microalgae CO_2 fixation technology is presented in Figure (1). This review encompasses multiple aspects: first, examining the CO_2 fixation mechanisms within microalgae, followed by analyzing the principal factors that influence both carbon sequestration and growth (15).

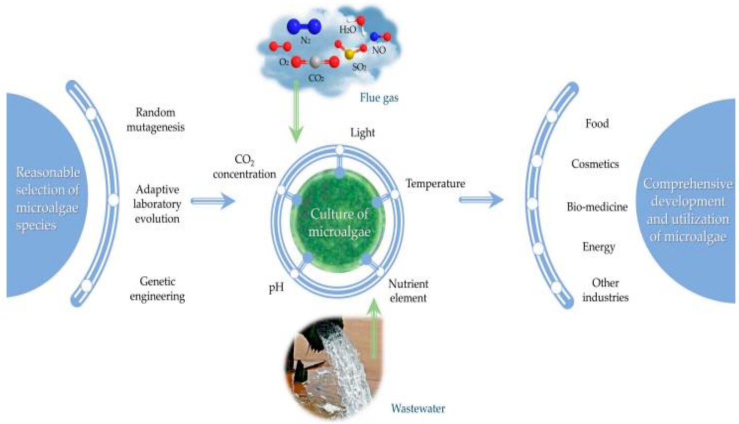

Figure (1): Microalgal carbon sequestration flow diagram (15).

The use of microalgae for biological carbon sequestration has gained traction more recently as a strategy to counter anthropogenic CO_2 emissions. This approach harnesses photosynthesis and produces valuable products. The process of CO_2 sequestration within microalgae unfolds in two main steps. First, a carbon-concentrating mechanism occurs, followed by the photosynthesis process. This progression is illustrated in Figure (2) (16)**.**

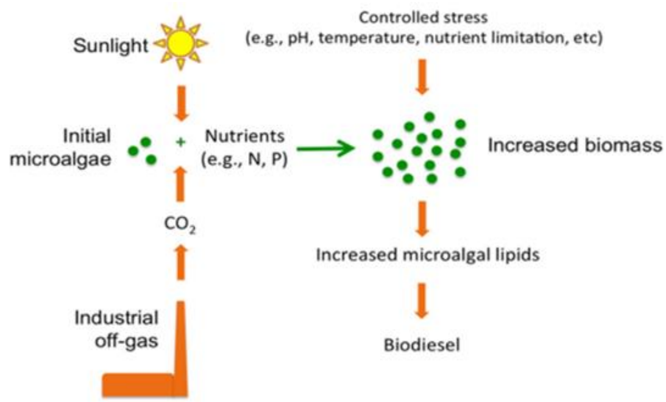

Figure (2): Diagram illustrating the biological carbon dioxide mitigation process and subsequent biodiesel production (16).

Microalgae

Microalgae thrive in watery conditions, where they use light and carbon dioxide to grow biomass. These microorganisms include lipids and fatty acids that function as vital constituents in membranes, storage compounds, metabolites, and energy reserves. The potential role of algae as an alternative biofuel source has undergone extensive examination. Notably, lipids derived from microalgae have significant potential as substitute lipid reservoirs for biodiesel production (17). In addition to biodiesel produced from microalgal oil, microalgae provide a variety of additional renewable biofuels Figure (3). These include methane produced by the anaerobic digestion (AD) of algae biomass and microalgae bio-oils produced by methods such as pyrolysis or gasification (18)**.**

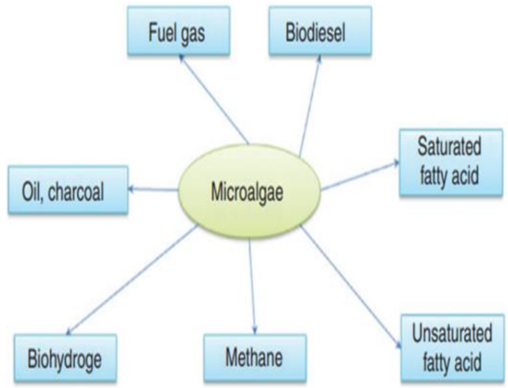

Figure (3): Processes for converting microalgae energy (17).

Within algae, lipids are the biomass components with the most significant industrial significance. These lipids serve as sources of biofuels and lubricants, which are examples of secondary products. Consequently, the careful selection of strains that yield high lipid quantities, coupled with the optimization of cultural circumstances such as light exposure, temperature, and pH, becomes crucial. These measures enhance lipid production, thereby maximizing the potential benefits of algal carbon capture and utilization (19)**.**

1. Environmental Factors Influencing Microalgae Growth

The relationship between different environmental parameters and the growth rate of microalgae is depicted in Figure (4) (15). Various pivotal ecological factors have a substantial influence on the development of microalgae. These contain critical characteristics including light availability, temperature, pH levels, salinity, and qualitative and quantitative data. Composition of nutrients, levels of dissolved oxygen (DO), and the presence of potentially detrimental elements or substances such as heavy metals and synthetic organics. Biological variables, including predation, viral infections, competition, and epiphyte growth, can further constrain microalgal growth rates (20). The development of microalgae within a reactor depends on the prevailing operational conditions. These include factors such as the hydraulic residence time, frequency of harvesting, efficacy of gas exchange, and nature of the mixing equipment employed. These conditions wield their influence by directly affecting crucial variables, such as the accessibility of CO_2, the levels of shear stress experienced, and the degree of illumination exposure that collectively govern the growth process.

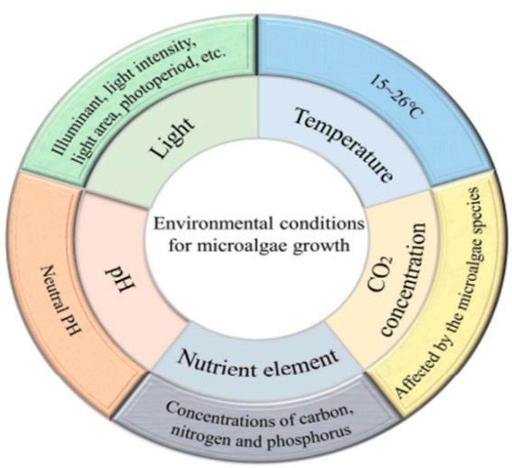

Figure (4): Various environmental factors influence the growth rate of microalgae (15).

1-1. Light

Light is a foundational energy source that intricately shapes the photosynthetic dynamics of microalgae. This, in turn, exerts a considerable influence on cellular growth and metabolic processes. Modifying factors such as the light source, intensity, temporal exposure intervals, and spatial coverage collectively govern microalgal development and metabolic activities (21). The provision of light can manifest as either uninterrupted or periodic photoperiods. Specifically, dark-light cycles, such as 12:12 or 18:6, have been documented to be effective in fostering substantial carbon dioxide fixation (22). Furthermore, specific investigations have highlighted the notable impact of photoperiod on microalgal growth. For instance, examining the influence of photoperiod on *Dunaliella salina* CCAP 19/30 yielded compelling results. Extended photoperiods were correlated with heightened microalgal growth, resulting in elevated cell densities (23). Demonstrated that under constant illumination, *Aphanothece microscopica Nägeli* microalgae attained a fantastic 99.69% efficiency in CO_2 fixation, nearly eliminating the presence of CO_2. Additionally, it is worth noting that the interplay between light and dark cycles is not the sole determinant of algal growth and CO_2 fixation.

1-2. Temperature

Temperature is a primary regulator that controls microalgae's cellular, morphological, and physiological reactions. Its influence extends to the domain of photosynthesis, inducing alterations that subsequently affect the efficiency of carbon sequestration within microalgae (15). Findings (19) unveiled a temperature range of utmost suitability for the growth of prevalent microalgae. This range spans from 15 to 26°C, signifying the temperature band within which these microorganisms thrive most effectively. The solubility of carbon dioxide is contingent upon temperature, with a recognized correlation wherein elevated temperatures (above 20°C) lead to a decrease in carbon dioxide solubility (24). The impact of temperature on various microalgae species was examined thoroughly, with a specific focus on metabolic ramifications and aptitude for adaptation to increased temperatures. Microalgae typically develop at temperatures ranging from 15 to 30°C, with ideal circumstances occurring between 20 and 25 25°C.

1-3. pH

The pH is thought to be a fundamental factor influencing cellular metabolism and biomass production in microalgae. (25). Although most microalgal species survive in a neutral pH environment, particular species, such as *Spirulina platensis*, can withstand increased pH values (26). Elevated CO_2 concentrations can potentially enhance biomass productivity; however, they can also trigger a reduction in pH, negatively affecting microalgal physiology. Conversely, in open ponds, microalgae have been observed to elevate pH levels to the range of 10–11 because of their uptake of CO_2 (24). Algae have been identified as capable of thriving under a broad spectrum of conditions, encompassing alkaline and acidic surroundings (27).

1-4. Carbon Dioxide Concentration

Microalgae exhibit varying capacities to withstand CO_2 concentrations, highlighting differences among species. Although certain microalgae show high levels of CO_2 tolerance and can flourish within a broad spectrum of CO_2 concentrations, researchers have identified specific optimal growth concentrations for these organisms (15). A variety of microalgae thrive under low CO_2 concentrations, whereas some exhibit optimal growth rates only in the presence of high CO_2 levels. With a rise in CO_2 content from 3% to 7%, *Chlorella vulgaris* demonstrated remarkable improvements in CO_2 fixation rate and maximum biomass output, showing a significant increase of 56% and 57%, respectively (28). Conducted an extensive review examining the effect of varied amounts of CO_2 on several microalgal species such as *Scenedesmus*, *Botryococcus*, *Chlorella vulgaris*, and *Nannochloropsis*. According to their findings, *S. aquatilis*, *B. braunii*, *C. vulgaris*, and *synchronous* species displayed the most significant carbon dioxide fixation capabilities among the studied microalgae (29). Flue gas was utilized as a direct source of CO_2 for several species. Both *Botryococcus braunii* and *Scenedesmus* were demonstrated to use flue gas as a carbon source to support their growth (53). Most microalgae flourish in low CO_2 environments, and CO_2 concentrations of more than 5% (v/v) restrict their ability to grow. While many microalgae may flourish in flue gas with CO_2 concentrations of 10% to 15%, this typically leads to a decline in carbon fixation and biomass production rates.

1-5. Nutrient Component

The presence of vital nutrient sources is an extra factor that influences both CO_2 reduction and the production of biomass, varying according to the specific requirements of microalgal species. While nitrogen and phosphorus stand out as pivotal nutrients for microalgal growth, trace elements like magnesium, calcium, manganese, zinc, copper, and molybdenum, as well as vitamins like B1, B12, and H, are commonly supplemented to ensure successful cultivation, reflecting their significance in the process (16). Microalgae species that grow quickly tend to favor ammonium as their primary nitrogen source over nitrate. To ensure sufficient phosphorus supply, providing forms like phosphate, H_2PO_4, and HPO_4-2 dihydrogen phosphates is vital. However, certain phosphorus forms may become unavailable to algae due to precipitation when they interact with metal ions or other phosphorus compounds (20,19,30). Microalgae growth is hindered by exceedingly low nitrogen (N) and phosphorus (P) concentrations, while elevated levels can impede or even halt their growth.

2. The Potential of Microalgae

Algae can uniquely convert solar power into diverse biochemical forms of energy. This phenomenon constitutes a significant portion, exceeding fifty percent, of the Earth's primary photosynthetic output (31,32). Microalgae are garnering increasing attention worldwide because of their extraordinary growth and CO_2 fixation rates, which have the potential to reach an impressive 6.24 kg day/m^3. This trend highlights the significant opportunities that lie within the realm of harnessing solar energy through photosynthetic microorganisms (33,34). The intricate process of photosynthesis can be conceptualized as a multifaceted biological redox reaction carried out by both algae and plants. In this process, these organisms utilize solar energy to synthesize carbohydrates and release oxygen through a sequence of complex redox reactions (35,34).

3. Microalgae-derived biodiesel production

The focal point of biodiesel research involving microalgae predominantly revolves around the production process. This process is primarily categorized into two essential phases: The upstream process consists of microalgae cultivation, including growth and lipid buildup. In contrast, the downstream process consists of harvesting and lipid extraction. Figure (5) provides a visual representation of this process flow (36).

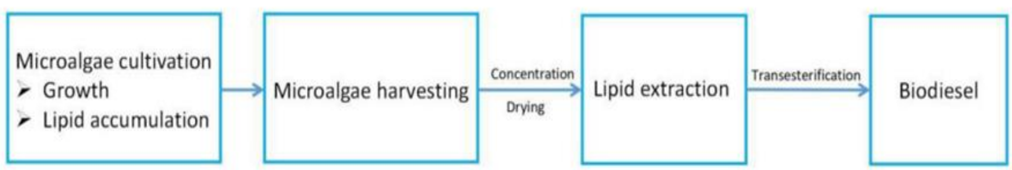

Figure (5): Microalgal biodiesel manufacturing method (36).

The carbohydrate, lipid, and protein content of microalgal cells vary depending on parameters such as culture circumstances, species, and development stage. It's worth noting that there are documented cases where certain strains of microalgae, when exposed to specific conditions, have demonstrated the capability to achieve lipid contents of up to 90% of their dry weight (16).

Microbial carbon fuel cell (MCCs) technology

Microbial Carbon fuel cell systems harness the inherent capabilities of algae situated within the cathodic chamber to accomplish carbon sequestration. Within this bio-electrochemical configuration, the carbon dioxide produced as off-gas in the anodic compartment is channeled into the cathodic compartment. Here, algae adeptly capture and sequester the carbon dioxide. The process is visually illustrated in Figure (6) (37). Additionally, the process serves to minimize CO_2 emissions through the activity of bacteria in the anode compartment and microalgae in the cathode compartment (38). The scalability of MCCs can be achieved by expanding the system through methods such as augmenting the cathode surface area and adjusting the spacing between electrodes (39,40).

Furthermore, MCCs demonstrate elevated power densities compared to Microbial Fuel Cells (MFCs), primarily due to their generous cathode-specific surface area and the optimized electrode spacing, which collectively contribute to a reduction in solution resistance (40,41,42). Within the framework of MCCs, the carbon dioxide generated during the anaerobic electrogenic degradation of an organic compound in the anodic chamber can be utilized by Photosynthetic microorganisms situated in the cathodic chamber. This symbiotic utilization results in electricity generation, the reduction of CO_2, and the synthesis of biomass or other valuable products (43). Equations (1) through (4) provide a comprehensive representation of the entire physicochemical reactions that transpire within the anodic and cathodic chambers of Microbial Carbon Capture Cells (MCCs), as depicted in Figure (6). In the anode chamber:

$$\mathbf{CH_3COO^- + 2H_2O \rightarrow 2CO_2 + 7H^+ + 8e^-} \quad \textbf{(1)}$$

Two types of reactions occur in the cathodic chamber of an MCC: light-dependent and light-independent reactions. Equations (2), (3), and (4) show examples of them. The light-dependent reaction in the cathodic compartment, in particular, involves:

$$\mathbf{nCO_2 + nH_2O \rightarrow (CH_2O)_n + nO_2} \quad \textbf{(2)}$$

$$\mathbf{2O_2 + 8e^- + 8H^+ \rightarrow 4H_2O} \quad \textbf{(3)}$$

Reaction that is not affected by light, in the cathodic compartment:

$$\mathbf{C_2H_4O_2 + 2O_2 \rightarrow 2CO_2 + 2H_2O} \quad \textbf{(4)}$$

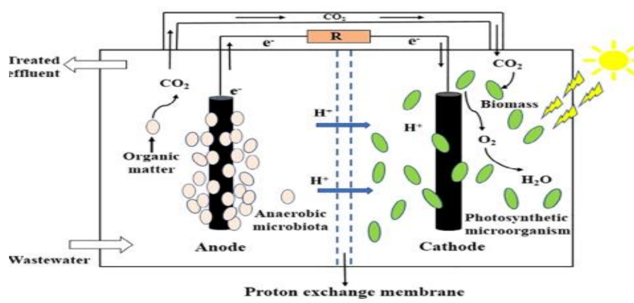

Figure.(6): A diagram depicting the operation of a microbial carbon fuel cell (37).

1. Utilizing MCC for Microbial Carbon Dioxide Sequestration

Numerous microorganisms, notably cyanobacteria and algae, possess the capability to capture atmospheric carbon dioxide. The process of photosynthesis plays a pivotal role in this regard, transforming sunlight into biomass and other valuable compounds. In photosynthetic bacteria, CO_2 sequestration occurs through both the Calvin-Benson cycle and the tricarboxylic acid reductive cycle. On the contrary, algal cells exclusively engage in the Calvin-Benson cycle as part of their photosynthetic process (44). The following are the benefits of employing microbes for CO_2 sequestration: Fast Microbial Biomass Production: Microorganisms possess the ability to rapidly generate biomass, making them efficient agents for CO_2 sequestration and utilization. High Photosynthetic Conversion Efficiency: Microorganisms, particularly photosynthetic ones like cyanobacteria and algae, exhibit a high degree of efficiency in converting sunlight and CO_2 into biomass and other useful chemicals. Diverse Value-Added Product Generation: Microorganisms can be harnessed to provide a diverse range of value-added items, such as biofuels, biochemicals, and biomaterials, thereby making the process economically viable Table (1).

Table (1): MCC performance evaluation utilizing several photosynthetic bacteria (37).

Photosynthetic Organisms	System Configuration	Power density	References
Microcystis aeruginosa	Single Chamber	58.4	(46)
Desmodesmus Sp	Double compartment MFC	64.2	(47)
Cyanobacteria	Double Compartment	100	(45)
Phototrophic Sludge	Double-compartment MFC	750	(48)
Chlorella vulgaris	Double-compartment MFC	2.7 W/m^3	(49)
Chlorella pyrenoidosa	Double chamber MCC	6.4 W/m^3	(50)
Chlorella sorokiniana	Dual-compartment MCC	3.2 W/m^3	(51)

2. Elements influencing the efficacy of Microbial Carbon Capture Cells (MCCs)

Numerous physiological adjustments that promote bacterial growth in the anode chamber, such as the materials used for electrodes and anolyte pH in the, as well as cathodic conditions, including Microbial photosynthetic activity and carbon dioxide content, collectively impact the electricity generation in Microbial Carbon Capture systems (MCCs), as illustrated in Table (2). In the cathodic chamber of MCC, microalgae are commonly chosen for cultivation due to their elevated photosynthesis rates, which enable efficient CO_2 uptake, and their rich profile of unsaturated and saturated fatty acids. These fatty acids can be subsequently collected for biofuel production from microalgae (52). A range of biological parameters, encompassing variables such as the carbon source, intensity of light exposure, and more, impact biomass output and other important products obtained from the microbes. These parameters also have an impact on the development of the microbes themselves. Among these factors, two crucial growth determinants that exert a considerable impact on the performance of Microbial Carbon Capture systems are carbon and nitrogen availability (3).

Table (2): Environmental factors influence MCC performance and the recovery of valuable products (3).

Environmental Condition	Condition of Culture	Results	References
Carbon source	The specific growth rate was recorded at a range of glucose concentrations between 5 and 20 g/l.	The greatest measured specific growth rate was 0.031 per hour when the glucose concentration was maintained at 20 g/l.	(53)
Nitrogen source	The amount of nitrates was raised from 0.5 to 2.0 g/l.	As the nitrate concentration was elevated, there was a corresponding increase in power generation.	(52)
Light	The range of light intensity tested spanned from 2.4 to 11.4 W/m2.	The peak power density achieved was 972.5 mW/m^3, which corresponded to the optimal light intensity of 8.9 W/m2.	(54)
Inoculum condition	Sodium alginate was employed to immobilize Chlorella vulgaris.	The maximum power density of 2.48 W/m3	(55)

3. Microbial carbon fuel cell applications

3-1. Production of electricity

The primary objective, concentrating on the realization of environmental sustainability, is a wastewater treatment approach characterized by both carbon and energy neutrality, accomplished with minimal energy utilization. However, physical adsorption, cryogenic, chemical absorption, and membrane separation approaches just reduce CO_2 emissions rather than exploiting wastewater as an energy recovery resource. Jadhav *et al*. demonstrated power densities of 4.29 W/m^3 and 6.36 W/m^3 by utilizing *Anabaena ambigua* and *C. pyrenoidosa*, respectively, within the cathodic chamber of a Microbial Carbon Capture system (50).

3-2. MCC's scope of beneficial by-product recovery

Biomass from microalgae, in particular, contains a high concentration of protein, fats, and carbs that can be exploited as a possible antibiotic feedstock, Biofuels (for example, biodiesel, bioethanol, biobutanol, and biohydrogen), as well as other products for animal feed (instances encompass elements like pigments, polyunsaturated fatty acids, and antioxidants) (56). Brown algae like *Fucus vesiculosus* and *Turbinaria conoides* produce a wide range of polysaccharides such as laminarin, fucoidan, and alginates. These polysaccharides include antioxidant components that are utilized in anti-aging creams to treat skin diseases (57). MCC was created for microalgae biorefinery applications to provide feedstock for bioethanol production while simultaneously producing bioelectricity utilizing an Anodic chamber substrate: fermented beer yeast (58).

3-3. Treatment of Wastewater

Utilizing electrogenic microorganisms as biocatalysts, the anodic chamber of a Microbial Carbon Capture system becomes effective for the treatment of organic contaminants present in wastewater. This treatment involves the anaerobic decomposition of the organic matter already present. Various types of wastewater, including those from septic tanks, waste-activated sludge, municipal sources, residential areas, agriculture, food-processing industries, pharmaceuticals, and lignocellulosic materials, among others, can be successfully treated within an MCC. This treatment is carried out in tandem and includes the simultaneous generation of bioelectricity and the recovery of value-added products from harvested biomass (1). Photosynthetic microbes were introduced into the cathodic chamber of a Microbial Carbon Capture system (MCC). The results indicated a remarkable recovery of 80–93% of CO_2, coupled with nearly 100% removal of COD (chemical oxygen demand) from synthetic wastewater artificial wastewater (59).

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الحلول الخضراء لتخفيف ثاني أكسيد الكربون: استكشاف تقنيات احتجاز الكربون واستخدامه القائمة على الطحالب الدقيقة

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الخلاصة

الخلفية: يؤدي ارتفاع تركيزات ثاني أكسيد الكربون في الغلاف الجوي للأرض إلى تراكم غازات الاحتباس الحراري وتغير المناخ. تتطلب معالجة هذا الشاغل الحرج حلولًا مبتكرة، من بينها نظام خلايا احتجاز الكربون الميكروبية (MCC). تعتبر الطحالب الدقيقة لها دور رئيسي في تقنية MCC، حيث تشمل أنواعًا متنوعة ذات قدرات امتصاص استثنائية لثاني أكسيد الكربون. تقوم الطحالب الدقيقة بتحويل ثاني أكسيد الكربون إلى كتلة حيوية من خلال التمثيل الضوئي، وعزله بشكل فعال والتخفيف من التأثير البيئي. إلى جانب عزل الكربون، تمتد تقنية MCC إلى معالجة مياه الصرف الصحي وتنقية غاز المداخن، مما يوفر ميزة مزدوجة من خلال مكافحة الملوثات أثناء التقاط ثاني أكسيد الكربون. ويسهم هذا النهج الشامل في تنظيف الهواء والماء وتعزيز التنمية المستدامة. تحتوي تقنية MCC على إمكانات تحويلية في الطاقة. يمكن للكتلة الحيوية المشتقة من الطحالب الدقيقة إنتاج الوقود الحيوي، وهو مصدر للطاقة المتجددة يقلل بشكل كبير من انبعاثات غازات الاحتباس الحراري. يعد هذا التحول من الوقود الأحفوري إلى الوقود الحيوي أمرًا محوريًا لتقليل اوكسد الكاربون والاستدامة. **الهدف:** لهذه الدراسة أهداف متعددة، بما في ذلك التأكيد على دور الطحالب الدقيقة في عزل ثاني أكسيد الكربون بكفاءة، والمعايير التي تؤثر على نمو الطحالب الدقيقة وأدائها، وتحسين قدراتها على عزل الكربون. **المناقشة:** بالإضافة إلى ذلك، تسلط الدراسة الضوء على توليد الطاقة لتكنولوجيا MCC ومساهمتها في إنتاج الطاقة النظيفة واستدامة الشبكة. تتناول الدراسة أيضًا إنتاج الديزل الحيوي من الطحالب الدقيقة كمصدر وقود متجدد وصديق للبيئة، وتقليل انبعاثات الكربون، وتقليل الاعتماد على استنفاد الوقود الأحفوري، وتعزيز أمن الطاقة. **الاستنتاج:** إن تكنولوجيا خلايا احتجاز الكربون الميكروبية تبشر بالخير في مكافحة تغير المناخ من خلال التقاط الكربون بكفاءة، وتقليل التلوث، والانتقال إلى مصادر طاقة أنظف ومستدامة.

الكلمات المفتاحية: عزل ثاني أكسيد الكربون ، الطحالب الدقيقة ، توليد الطاقة ، احتجاز الكربون الميكروبي.