ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



Algae's Promise to Sequester Carbon Sheds New Insight on Changing Climate

Akanksha Pal¹, Ishika Srivastava², Sweety Sahu³, Kirti Raje Singh⁴

^{1,2,3,4} Department of Botany, CMP Degree College, University of Allahabad, Prayagraj-211002, Uttar Pradesh, India

ABSTRACT: The addition of more greenhouse gases (GHG) to the earth's atmosphere, which accounts for more than half of the planet's warming potential, has resulted in changes in long-term average weather conditions, or climate change. In order to counter the increased concentration of carbon dioxide in the atmosphere, carbon sequestration is a newly developed strategy. Contrary to carbon emission reduction measures, carbon sequestration has a strong potential to lower carbon dioxide levels or mask carbon dioxide emission if the gas is trapped from several stationary sources and used effectively to produce chemical and energy. The implementation of carbon regulations has spread widely.

The cost of air pollution is credited with a monetary value. Due to this, investments in the growth of microalgae for carbon sequestration have received attention from all around the world. With these systems, existing carbon mitigation strategies are shown to be a viable and promising alternative. In general, the microorganism groups that make up microalgae are extremely diverse and quick-growing, and they are very skilled in photoautotrophic, heterotrophic, and mixotrophic settings. With a unit carbon dioxide fixation capacity 10–50 times greater than terrestrial plants, these microalgae can be grown on non-fertile land. Describe in detail the most recent advancement in the effective use of microalgae for carbon dioxide in this article review.

KEYWORDS: Biological characteristics, Carbon sequestration, Climate change, Microalgae.

INTRODUCTION

 CO_2 sequestration is the process of capturing and storing CO_2 that results from burning fossil fuels to produce electricity or from preparing fossil fuels to use in the processing of natural gas. In addition, it can be utilized in numerous industrial processes that make biomass-based fuels, as well as the production of hydrogen, ammonia, iron and steel, cement and other products. CO_2 cannot be captured unless it is removed from many other gases. Afterward, the CO_2 needs to be moved to a storage location facility for long-term storage away from the atmosphere [1]. Storage reservoirs would need to be sizable in comparison to annual emissions if they were to significantly affect CO_2 concentrations in the atmosphere.

Three essential advancements-pre-combustion, post-combustion and oxyfuel burning routes—are utilized by the carbon capture, retention and utilization method are crucial. By contrast, oxy-reforming technology accounted for just 3.4% of all publications, while the first two pathways accounted for 96.6% of all literature efforts up until 2018 [2]. Chemical, physical and biological sequestration of carbon dioxide are three effective methods. Every method has merits and drawbacks, but the earlier ones that depend on chemical methods for carbon dioxide sequestration, such as utilizing amine-coated activated charcoal, cleaning with alkaline conditions or immobilising carbon dioxide with multi-walled nanostructures, adsorption substances or both are a few possibilities. Examples of physical approaches include releasing pollutants into the earth, into the ocean, depleted oil and gas wells and aquifers. Photosynthetic bacteria, algae, and plants all participate in the biological fixation of carbon dioxide [3]. Large-scale carbon dioxide sequestrations are feasible by utilizing physical techniques including direct injection. However geomorphological and geological systems, extraction equipment and carbon dioxide gathering and contraction processes must all be available for this to happen. Uncertainty and an increased probability of long-term leakage result from this. The utilization of chemical neutralization techniques is constrained by the expensive cost of the neutralization reagents, despite the fact that they are safer and offer long-term carbon dioxide fixation. It is difficult to collect carbon dioxide from diffused or nonpoint sources at low quantities using physical or chemical methods **[4]**. In recent decades, all industries have been concerned about the rising global energy demand and greenhouse gas (GHG) emissions. In 2030, the globe will require almost a higher percentage of energy than it does today if governments

2904 *Corresponding Author: Kirti Raje Singh

ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



throughout the world maintain their current policies. China and India combined will account for 45% of this [5]. CO_2 levels are also rising due to the production of power, transportation, industry and home usage. The atmosphere is pumped full of about 90 MT (million tons) of heat-trapping substances every day, slowly encircling the earth with an artificial GHG screen. However, CO_2 produced by the combustion of fossil fuels is a major source of GHG emissions because CO_2 increases the atmosphere's capacity to hold heat. According to the "Keeling curve," it is recommended that the CO_2 level in the atmosphere not rise above 550 ppm [6].



Figure 1: Measured annual atmospheric CO_2 concentrations. The straight line is a fit to the CO_2 concentrations at the South Pole. The keeling curve is the accepted expression for the increase in atmospheric CO_2 concentrations since the 1950s [7].

The manufacture of cement, the production of power from the burning of fossil fuels [8] and other anthropogenic activities all contribute to global CO_2 emissions. Effects of global warming include more deserts in the subtropics, altered rainfall patterns, and rising sea levels. Extreme weather phenomena such as heavy rains, heavy snowfall [9], heat waves, ocean acidification [10], droughts and major animal extinctions owing to sudden changes in the environment are predicted to result from global warming more over the land than the oceans. Threats to food security result from these harsh weather events that harm agriculture [11]. The most sustainable and environmentally benign method of sequestering CO_2 is through photosynthesis [8]. Algae and plants both engage in photosynthesis. By enhancing natural sinks like forestry, ocean fertilization and microalgae farming, biological CO_2 capture is made possible [12].

The Current Global Focus on the Carbon Cycle and Carbon Credits

The development of green and clean biofuels to replace conventional fossil fuels has become a focus of international study in recent years due to the depletion of fossil fuels, the global energy crisis, and the escalating severity of environmental pollution **[13-15]**. Energy efficiency is one of the major obstacles to transforming existing power plants in the United States to use carbon capture, as the National Energy Technology Laboratory (NETL) noted in its report in 2011. The Global CCS Technology Research Center reported in 2016 that the annual capacity of carbon capture demonstration projects worldwide had exceeded 700,000 tonnes and that carbon capture's energy consumption is still a significant issue **[16]**. One of the most significant and efficient carbon sequestration technologies in the world is the carbon dioxide fixation technology used by microalgae. Long-term carbon dioxide fixation technology is practical from an economic, environmental, and sustainability standpoint **[10]**.

Following are some special features of microalgae as an effective type of micro-cell factory for fixing carbon dioxide:

- When compared to physical and chemical approaches, solar energy can be directly used to save a significant amount of energy.
 A significantly higher rate of photosynthetic activity. Microalgae are 10–50 times more effective at fixing carbon dioxide using
- sun energy than other terrestrial plants [17].

ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



(3) There is rapid growth. Microalgae can multiply significantly more quickly than bigger plants in a matter of hours [17-22].

The Kyoto Protocol is the first global agreement to reduce GHG emissions. due to the difficult ratification procedure (target of least 55 countries emitting 55% GHG). The following six greenhouse gases (GHGs) are recognized under the Kyoto Protocol: HFCs, PFCs, N₂O, SF₆, CH₄, and CO₂. The treaty mandated a 5.2% reduction in six GHG emissions among 41 nations and the European Union. The Kyoto Protocol, which was signed by 169 countries, set enforceable emission targets for developing nations. Members of this agreement have pledged to reduce their GHG emissions within the country-specific target ranges in a set amount of time. The Kyoto Protocol, which went into force in February 2005, stipulates that 55 countries must either adopt new techniques for CO₂ scrubbing and sequestration through tree planting and algae farming.

CARBON CREDIT

A carbon credit is a certificate or permission that may be traded that certifies that a certain amount of carbon dioxide or another greenhouse gas can be emitted. An aspect of national and worldwide efforts to reduce the rise in greenhouse gas concentrations is the use of carbon credits and carbon markets (GHGs). One tonne of carbon dioxide, or in certain markets, carbon dioxide equivalent gases, equates to one carbon credit. An implementation of the emissions trading strategy is carbon trading. After setting a cap on greenhouse gas emissions, the emissions are distributed among the group of controlled sources using markets. The objective is to enable market mechanisms to steer industrial and commercial processes toward low emissions or less carbon-intensive ways than those utilized when there is no cost associated with generating carbon dioxide and other GHGs into the atmosphere. This strategy can be used to fund carbon reduction programs among international trading partners because GHG mitigation initiatives earn credits seeking issue statements and priority areas from the country's business community as India moves toward decarbonizing its industrial sector and fulfilling its contribution obligations. There are two common ways to use carbon credit:

- (1) Reforestation and afforestation operations can absorb CO₂: Afforestation and reforestation activities can be used to further this dual function for forest ecosystems. On the other hand, reforestation is the practice of replanting trees on previously deforested land. On the other hand, afforestation describes the establishment of woods where none previously existed or where none had existed for a significant amount of time (50 years, according to UNFCCC) (i.e. converting recently non-forested land in the forest). It might be possible to find "win-win" policy solutions if these two approaches are considered complementary. Both methods could be contentious, though, as they could result in the extinction of the original non-forest ecosystems if they are not maintained sustainably (e.g. natural grassland). Between 1994 and 2015, two million hectares of trees were planted on agricultural land with the help of EU afforestation programs. Although afforestation is currently thought of as a CO₂ sequestration mitigation option, the level of afforestation has dropped over the past few decades. According to the current budgetary allotment in the EU Rural Development programs (2014–2020), an additional 510 thousand hectares will be planted [23].
- (2) CO₂ reduction initiatives, such as the utilisation of renewable energy sources : CO_2 that has been gathered from industrial sources can be mixed with hydrogen that has been extracted from water using extra renewable energy to create methanol. Additionally, the resultant fuel can be used in vehicles or ships, lowering both the consumption of fossil fuels and greenhouse gas emissions. The MefCO₂ project demonstrated how industry may aid in the preservation of renewable energy as it is created and assist in absorbing some of the variations inherent in the generation of sustainable energy. In order to illustrate the procedure, the study utilized carbon capture technology at a coal-fired power station in Germany, storing some of the emissions as methanol [24].

Global Carbon Cycle

It is determined that carbon, which offers a unique cycle of capture and buildup, is a crucial element needed to sustain ecological stability. This balance has been dramatically altered by human interference. The instability brought on by growing industrialization has had devastating effects on the ecosystem [2]. Additionally, this adverse effect is a result of the unrestrained use of natural resources [25]. Global ecosystems are at risk as a result of increased atmospheric carbon dioxide and long-term viability brought on by the post-industrial age. With 68% of all greenhouse gas emissions being carbon dioxide, it contributes to global warming. According to the UNFCCC Kyoto Protocol, some helpful measures should be taken to lower the earth's temperature, such as

ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



geoengineering and the widespread use of environmental engineering to fend off harmful changes in atmospheric chemistry, particularly to lower concentrations of greenhouse gases like carbon dioxide [26, 27]. In 2009, Folger emphasized that while the total amount of vegetation only uses around 2.8 GtC (Gigatonne carbon)per year [28], approximately 7.2 GtC of CO₂ is released into the atmosphere annually through the combustion of fossil fuels. As a result, the CO₂ level in the atmosphere rises. The Kyoto Protocol (UNFCCC) has defined a maximum increase in global warming of 2° C above the range of pre-industrial temperature levels as the upper limit. With a budget for a maximum of 250 Gt of emissions between 2000 and 2049, the likelihood of exceeding this limit is limited to less than 20%, yet by 2005, more than 30% of that had already been consumed. According to estimates on current CO₂ emissions, the budget will expire in 2024 [29, 30].

Microalgae Capacity to Sequester Carbon Dioxide and its Process

By raising the temperature of the atmosphere, the increase in carbon dioxide in the atmosphere exacerbated the hazards associated with climate change [**31**]. Algae-based carbon dioxide mitigation is one of the potential methods for reducing greenhouse gas emissions and might be easily replaced by currently available technology [**4**]. The bio-sequestration of CO₂ utilizing microalgae cell factories would be a cost-effective and environmentally sustainable solution to the pressing problem of growing carbon dioxide emissions [**32**, **33**]. Microalgae contribute significantly (about 50%) to photosynthesis on earth by generating a large portion of the atmospheric oxygen and ingesting carbon dioxide [**34**].

The photosynthetic efficiency of microalgae typically ranges from 11 to 20 percent, which is higher than that of terrestrial plants (1-2 percent). Microalgae are more capable of fixing CO_2 than C_4 plants. When some algae species experienced exponential growth, their biomass might quadruple in as little as three and a half hours [**35**]. Additionally because of their benefits of improved carbon dioxide tolerance, these microorganisms are a great choice for organisms (flue gas), low light intensity needs, environmental sustainability, and co-production of important products [**36**, **37**].

Microalgae can thrive in any severe climate, including high temperatures, saline-alkaline soil, land and water. This makes them far easier to cultivate than standard forestry, agricultural and aquatic plants. On the toxic effluent, they can even thrive [38].

For one kilogram of biomass 1.3 kilos carbon dioxide can be held in reserve by microalgal species. Nicotinamide adenine dinucleotide phosphate (NADP), adenosine triphosphate (ATP), adenosine diphosphate (ADP) are all produced by microalgal species as a consequence of photon absorption. Following that, this energy is directed toward the dark cycle, which uses the Calvin-Benson cycle to transform carbon dioxide into functional organic molecules [**39**]. Different kinds of microalgae start a system where inorganic carbon is actively transformed in their cells to vary in response to variations in the amount of inorganic carbon in water. This is known as a carbon dioxide concentration mechanism, which is important for microalgae because it is the only way for them to use carbon dioxide during their photosynthetic process [**40**]. Different microalgae. In order to survive in situations with low carbon dioxide concentrations, microalgae at carboxylated sites have developed processes similar to concentration mechanisms. Microalgal cells are immobilized by an increase in carbon dioxide concentration, which prevents photosynthesis and algal development [**4**].

These phases make up the cycle, which is broken down into three categories: fixation, reduction, and regeneration.

Carboxylation stage: Ribose-1, 5-diphosphate carboxylase catalyses the reaction between carbon dioxide and ribose-1, 5-diphosphate to create 3-phosphoglyceric acid.

Reduction stage: In order to make 3-phosphoglyceric acids more acidic, adenosine triphosphate is utilized. The 3-phosphoglyceric acid kinase subsequently converts this acid into 1, 3-diphosphate glyceric acid. Once NADPH and phosphoglyceraldehyde dehydrogenase is involved, this is converted into glyceraldehyde-3-phosphoric acid.

Regeneration stage: Ribose 1, 5-diphosphate is regenerated as part of it. After that, ribonuclease 1, 5-diphosphate, an enzyme and adenosine triphosphate, acidify the glyceraldehyde-3-phosphate molecule. Ribose 1, 5-diphosphate is produced as a result of carbon dioxide fixation. Carbon dioxide was recycled through biological mechanisms and used for photosynthetic activity **[40]**.

Positive Aspects of Microalgae Based Carbon Sequestration

Compared to terrestrial plant systems, the cultivation of photosynthetic microalgae can offer a long-term solution for carbon sequestration. Microalgae are a viable option due to their straightforward harvesting, quick development, minimal requirements,

ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



higher tolerance to environmental stress, increased carbon dioxide improved biomass production levels, robust photosynthetic capacity, and adaptability. The ability of microalgae to withstand higher carbon dioxide concentrations, which increases their maximum production by even more effectively fixing carbon dioxide than plant species, efficiently converts solar energy into biomass [41]. Growing photosynthetic microalgae is one of the innovative methods for reducing environmental carbon emissions and it can easily meet all the criteria for carbon sequestration [42]. Microalgae are more effective at reducing carbon dioxide than other terrestrial plant systems because of their quick and easy harvesting processes, low light intensity needs, high CO_2 tolerance, higher photosynthetic capabilities, and increased biomass production rate [43]. Carbon can come from soluble carbonates, industrial exhaust gases, and atmospheric CO_2 (e.g. sodium bicarbonate and sodium carbonate). The most practical and cost-effective way to reduce CO_2 emissions from the environment by cutting cooling costs is to use different thermopile microalgae. Wastewater from industrial, agricultural and municipal sources can encourage the development of microalgae because it contains a variety of trace elements and heavy metals that are essential for their survival. Therefore, this microalgae utility can be applied to bioremediation, especially the elimination of toxic metals from aquatic bodies and wastewater reuse [44--46]. Algae can develop in conditions that are autotrophic, heterotrophic, or mixotrophic [47]. Algae have significantly improved mechanisms for CO_2 concentration, a greater rate of CO_2 fixation [48] and a faster rate of growth [49].

Algal Strains for Sequestering Carbon Dioxide

The recommended range for the ideal CO₂ level for microalgae cultivation is 0.038 to 10%. Algae's growth efficiency was significantly impacted at CO₂ concentrations greater than 5% (v/v) [**50**] and research has revealed that biomass production peaks around 2.5% [**51**]. At 6% CO₂, *Scenedesmus obliquus* was found to be the most productive [**52**]. Furthermore, compared to lower CO₂ concentrations, certain microalgae species cannot thrive at higher CO₂ concentrations (10–15% CO₂) due to reduced growth rates, carbon fixation, and productivity. Some specific strains of *Chlorella* sp. ZY-1 and *Chlorella* sp. KR-1 has evolved to withstand exceptionally high CO₂ concentrations of 70%. Additionally some species, such as *Chlorella* sp. T-1[**53**, **54**] can withstand 100% CO₂. If a stepwise adaption strategy is used, *Chlorococcum littorale* is shown to be tolerant to 60% CO₂ and might develop.

Microalgae that are thermophilic may grow between 42 and 100 °C, which lower cooling expenses. For instance, the thermophilic microalga *Cyanidium caldarium* can withstand 100% CO₂ [55]. Cyanobacterial species *Synechococcus* elongates can withstand temperatures of 60 °C and 60% CO₂ [55].



ISSN: 2581-8341 Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789 IJCSRR @ 2023



The Principal Obstacles to Microalgae's Ability to Efficiently Sequester Carbon during Photosynthesis

Microalgae's ability to photosynthesis allows for the production of biofuels and other goods with a high added value. This is in accord with how the carbon cycle works in nature. Its effective metamorphosis has drawn increasing attention. The technology for sequestering carbon using microalgae still has several issues, which limits its industrial use [56].

Problem 1 The method of growing microalgae for biological carbon sequestration outdoors involves a lot of hazardous variables. The entire interaction of engineering technicians and theoretical researchers is required to maintain and regulate specific illumination conditions and ensure the stability of culture temperature [56].

Problem 2: Theoretical investigation on the CO_2 absorption process is lacking. The majority of absorption is based on a selection process or empirical operation. The paucity of thermodynamic and kinetic research on the CO_2 absorption mechanism has no scientific justification. It is therefore difficult to implement the quantitative control of the industrial process since experimental results cannot give design data for the industrial production process [56].

Problem 3: Algae farming requires a lot of land area, which is challenging to achieve in industrial zones even if microalgae have a high photosynthetic efficiency. System engineering is needed to solve this issue, as well as the interdisciplinary use of fields including chemical engineering, biotechnology, materials science, manufacturing, and engineering [56].

Problem 4: Microalgae products should be used in food and medicine in order to maximize the added value of the products and the process economy. Analysis and verification are required of the algal products produced by industrial waste gas [56, 57].

Updated Strategies Increasing Microalgae's Capacity to Sequestering Carbon Dioxide (Future Prospects)

The concrete ways to improve carbon sequestration efficiency of microalgae are as follows:

1) Select and grow algae species that are easy to grow outdoors, can fix carbon effectively, and can withstand pollution.

Effective carbon sequestration, anti-pollution, and simple large-scale outdoor cultivation should be taken as the objective and basis of algae species optimization throughout the research of screening and cultivating algae species. This is essential for advancing this technology from the lab to industry **[58]**.

2) To design and develop a new photobiological reaction system with high efficiency, three dimensions, and a reasonable cost in order to realize the commercialization of microalgae carbon sequestration technique. This requires for sound theoretical investigation, material and engineering assistance, as well as the knowledge and system integration of design developers.

In order to apply microalgae carbon sequestration technique, the relationship between algal culture and industrial sources of CO_2 emissions must first be understood [57, 59, 60, 61].

3) Conduct study on the microalgae growing process using quantitative and scientific methods. Realizing the quantitative control of the process with scientific research methods and engineering control mechanisms is a prerequisite for industrialization. Measurements of the CO_2 absorption rate, solubility, and associated pH values under various settings can be used to quantitatively control the best pH culture conditions for various algae species (e.g. CO_2 concentration, temperature, medium).

4) The economics is a key component in technological industrialization. The commercialization of microalgae sequestering carbon technology will be substantially aided by accelerating the development of microalgae energy technology and the development of high value-added product extraction and production technology.

CONCLUSION

Microalgae productivity is limited, which restricts the large-scale development of photoautotrophic microalgae carbon sequestration. This technical issue can be resolved by further researching its energy-to-mass conversion method. Different strains of microalgae have been shown in numerous works of literature to be effective at assimilating inorganic and organic carbons from a variety of significant sources. Therefore, to encourage its development on a larger scale, effective studies should be conducted in the areas of biological features, reaction characteristics, and efficiency characteristics. The investigation of photosynthetic reaction can provide quantitative solutions to the bottleneck of low yield in the industrialization process and can also correlate various scales and subject contents. It can also disclose the rules of energy conversion and energy quality transition in microalgal carbon sequestration. The majority of microalgae farming operations are suited for carbon mitigation applications. However, the feasibility and cost-effectiveness of microalgae-based carbon sequestration systems for large-scale use have not yet been determined.

ISSN: 2581-8341

Volume 06 Issue 05 May 2023

DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789



IJCSRR @ 2023

REFERENCES

- Perry, A. (2003). Book Review: Climate change 2001: synthesis report. Third assessment report of the Intergovernmental Panel on Climate Change (IPCC); Climate change 2001: the scientific basis; Climate change 2001: impacts, adaptation, and vulnerability; Climate change 2001: mitigation. *The Holocene*, 13(5), 794-794. https://doi.org/10.1177/095968360301300516
- Osman, A. I., Hefny, M., Abdel Maksoud, M. I. A., Elgarahy, A. M., & Rooney, D. W. (2021). Recent advances in carbon capture storage and utilization technologies: a review. *Environmental Chemistry Letters*, 19(2), 797-849. https:// doi. org/ 10. 1007/ s10311- 020- 01133-3
- Shukla, S. P., Gita, S., Bharti, V. S., Bhuvaneswari, G. R., & Wikramasinghe, W. A. A. D. L. (2017). Atmospheric carbon sequestration through microalgae: status, prospects, and challenges. *Agro-Environmental Sustainability*, 219-235. https:// doi. org/ 10. 1007/ 978-3- 319- 49724-2_ 10
- Zhou, W., Wang, J., Chen, P., Ji, C., Kang, Q., Lu, B. & Ruan, R. (2017). Bio-mitigation of carbon dioxide using microalgal systems: Advances and perspectives. *Renewable and Sustainable Energy Reviews*, 76, 1163-1175.https:// doi. org/ 10. 1016/j. rser. 2017. 03. 065
- 5. Nakicenovic, N. (2007). World energy outlook 2007: China and India insights .https://doi.org/10.1787/weo-2007-en
- 6. Srivastava, A., & Prasad, R. (2000). Triglycerides-based diesel fuels. *Renewable and sustainable energy reviews*, 4(2), 111-133. <u>https://doi.org/10.1016/s1364-0321(99)00013-1</u>
- Quirk, T. The secrets of the keeling curve Kumar, A., Ergas, S., Yuan, X., Sahu, A., Zhang, Q., Dewulf, J., & Van Langenhove, H. (2010). Enhanced CO2 fixation and biofuel production via microalgae: recent developments and future directions. *Trends in biotechnology*, 28(7), 371-380. <u>https://doi.org/10.1016/j.tibtech.2010.04.004</u>
- Schneider, S. H., Semenov, S., Patwardhan, A., Burton, I., Magadza, C. H. D., Oppenheimer, M., & Yamin, F. (2007). Assessing key vulnerabilities and the risk from climate change. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate change. Ml parry, of canziani, JP palutik of, pj van der linden, and ce hanson, eds.
- 9. Battisti, D. S., & Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science*, *323*(5911), 240-244. <u>https://doi.org/10.1126/science.1164363</u>
- 10. Singh, S. K., Dixit, K., & Sundaram, S. (2014). Algal-based CO2 sequestration technology and global scenario of carbon credit market: a review. *Am J Eng Res*, *3*(4), 35-37.
- Wang, L., Min, M., Li, Y., Chen, P., Chen, Y., Liu, Y., Wang, Y., & Ruan, R. (2009). Cultivation of Green Algae Chlorella sp. in Different Wastewaters from Municipal Wastewater Treatment Plant. *Applied Biochemistry and Biotechnology*, 162(4), 1174-1186. <u>https://doi.org/10.1007/s12010-009-8866-7</u>
- Dębowski, M., Zieliński, M., Kisielewska, M., & Krzemieniewski, M. (2016). Efficiency of methane fermentation of waste microalgae biomass (WMAB) collected in processes of reclamation of eutrophicated water reservoirs. *Environmental Earth Sciences*, 75(6), 1-12.<u>https://doi.org/10.1007/s12665-015-5168-y</u>
- Gonzalez-Fernandez, C., Sialve, B., & Molinuevo-Salces, B. (2015). Anaerobic digestion of microalgal biomass: challenges, opportunities and research needs. *Bioresource technology*, *198*, 896-906. https://doi.org/10.1016/j.biortech.2015.09.095
- Kinnunen, V., Craggs, R., & Rintala, J. (2014). Influence of temperature and pretreatments on the anaerobic digestion of wastewater grown microalgae in a laboratory-scale accumulating-volume reactor. *Water research*, 57, 247-257 <u>https://doi.org/10.1016/j.watres.2014.03.043</u>
- 15. He, J., Wang, J., Deng, S., ZHAO, R., & ZHAO, L. (2017). Research progress on energy-efficiency analysis of carbon capture: theoretical model, evaluation tool and developing trend. *Chem. Ind. Eng. Prog. (In Chinese).*
- 16. Bohutskyi, P., & Bouwer, E. (2013). Biogas production from algae and cyanobacteria through anaerobic digestion: a review, analysis, and research needs. *Advanced biofuels and bioproducts*, 873-975.

ISSN: 2581-8341

LJCSRR @ 2023

Volume 06 Issue 05 May 2023

DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789



www.ijcsrr.org

- Mendez, L., Mahdy, A., Ballesteros, M., & González-Fernández, C. (2015). Chlorella vulgaris vs. cyanobacterial biomasses: Comparison in terms of biomass productivity and biogas yield. *Energy conversion and management*, 92, 137-142.<u>https://doi.org/10.1016/j.enconman.2014.11.050</u>
- 18. Polakovičová, G., Kušnír, P., Nagyová, S., & Mikulec, J. (2012). Process integration of algae production and anaerobic digestion. In *15th international conference on process integration, modelling and* (Vol. 29).
- Caporgno, M. P., Taleb, A., Olkiewicz, M., Font, J., Pruvost, J., Legrand, J., & Bengoa, C. (2015). Microalgae cultivation in urban wastewater: Nutrient removal and biomass production for biodiesel and methane. *Algal Research*, 10, 232-239 <u>https://doi.org/10.1016/j.algal.2015.05.011</u>
- Mahdy, A., Mendez, L., Tomás-Pejó, E., del Mar Morales, M., Ballesteros, M., & González-Fernández, C. (2016). Influence of enzymatic hydrolysis on the biochemical methane potential of Chlorella vulgaris and Scenedesmus sp. *Journal* of Chemical Technology & Biotechnology, 91(5), 1299-1305.
- Schwede, S., Rehman, Z. U., Gerber, M., Thesis, C., & Span, R. (2013). Effects of thermal pretreatment on anaerobic digestion of Nannochloropsis salina biomass. *Bioresource Technology*, 143, 505-511. <u>https://doi.org/10.1016/j.biortech.2013.06.043</u>
- 22. Sagemuller, I. (2006). Forest sinks under the United Nations framework convention on climate change and the Kyoto protocol: opportunity or risk for biodiversity. *Colum. J. Envtl. L.*, *31*, 189.
- 23. Reyer, C., Guericke, M., & Ibisch, P. L. (2009). Climate change mitigation via afforestation, reforestation and deforestation avoidance: and what about adaptation to environmental change? *New Forests*, *38*(1), 15-34.
- 24. Jaiswal K K et al (2021) Photosynthetic microalgae–based carbon sequestration and generation of biomass in biorefinery approach for renewable biofuels for a cleaner environment. Biomass Convers Biorefinery. https:// doi. org/ 10. 1007/ s13399-021-01504-y
- 25. Burniaux, J. M., Château, J., Duval, R., & Jamet, S. (2008). The economics of climate change mitigation: Policies and options for the future.
- 26. Toichi, T. (2012). Balance between energy security and mitigation responses. In *Climate Change Mitigation* (pp. 63-87). Springer, London.<u>https://doi.org/10.1007/978-1-4471-4228-7_4</u>
- 27. Folger, P. (2009, June). Carbon capture and sequestration (CCS). Library of Congress Washington DC Congressional Research Service.
- Singh, U. B., & Ahluwalia, A. S. (2013). Microalgae: a promising tool for carbon sequestration. *Mitigation and Adaptation Strategies for Global Change*, 18(1), 73-95. <u>https://doi.org/10.1007/s11027-012-9393-3</u>
- 29. Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C., Frieler, K., Knutti, R., & Allen, M. R. (2009). Greenhousegas emission targets for limiting global warming to 2 C. *Nature*, 458(7242), 1158-1162. <u>https://doi.org/10.1038/nature08017</u>
- Cassia, R., Nocioni, M., Correa-Aragunde, N., & Lamattina, L. (2018). Climate change and the impact of greenhouse gasses: CO2 and NO, friends and foes of plant oxidative stress. *Frontiers in plant science*, 9, 273. <u>https://doi.org/10.3389/fpls.2018.00273</u>
- 31. Kassim, M. A., & Meng, T. K. (2017). Carbon dioxide (CO₂) biofixation by microalgae and its potential for biorefinery and biofuel production. *Science of the total environment*, *584*, 1121-1129. <u>https://doi.org/10.1016/j.scitotenv.2017.01.172</u>
- Yadav, G., & 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. *Journal of CO2 Utilization*, 17, 188-206.<u>https://doi.org/10.1016/j.jcou.2016.12.006</u>
- Cuellar-Bermudez, S. P., Garcia-Perez, J. S., Rittmann, B. E., & Parra-Saldivar, R. (2015). Photosynthetic bioenergy utilizing CO2: an approach on flue gases utilization for third generation biofuels. *Journal of Cleaner Production*, 98, 53-65. <u>https://doi.org/10.1016/j.jclepro.2014.03.034</u>
- Razzak, S. A., Hossain, M. M., Lucky, R. A., Bassi, A. S., & De Lasa, H. (2013). Integrated CO₂ capture, wastewater treatment and biofuel production by microalgae culturing—a review. *Renewable and Sustainable Energy Reviews*, 27, 622-653. <u>https://doi.org/10.1016/j.rser.2013.05.063</u>

ISSN: 2581-8341

Volume 06 Issue 05 May 2023

DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789



- IJCSRR @ 2023
 - 35. Jaiswal, K. K., Banerjee, I., Singh, D., Sajwan, P., & Chhetri, V. (2020). Ecological stress stimulus to improve microalgae biofuel generation: a review. Octa J Biosci, 8, 48-54.
 - 36. Serrano-Ruiz, J. C. (Ed.). (2015). New microbial technologies for advanced biofuels: Toward more sustainable production methods. CRC Press.
 - 37. Verma, R., & Srivastava, A. (2018). Carbon dioxide sequestration and its enhanced utilization by photoautotroph microalgae. *Environmental development*, 27, 95-106. https://doi.org/10.1016/j.envdev.2018.07.004
 - Xu X et al (2019) Progress, challenges and solutions of research on photosynthetic carbon sequestration efficiency of microalgae. Renew Sustain Energy Rev 110:65–82. https:// doi. org/ 10. 1016/j.rser. 2019. 04. 050
 - 39. Banerjee, I., Dutta, S., Pohrmen, C. B., Verma, R., & Singh, D. (2020). Microalgae-based carbon sequestration to mitigate climate change and application of nanomaterials in algal biorefinery. *Octa J. Biosci*, *8*, 129-136.
 - 40. Farrelly, D. J., Everard, C. D., Fagan, C. C., & McDonnell, K. P. (2013). Carbon sequestration and the role of biological carbon mitigation: a review. *Renewable and sustainable energy reviews*, 21, 712-727 <u>https://doi.org/10.1016/j.rser.2012.12.038</u>
 - 41. Mata, T. M., Martins, A. A., & Caetano, N. S. (2010). Microalgae for biodiesel production and other applications: a review. *Renewable and sustainable energy reviews*, *14*(1), 217-232. <u>https://doi.org/10.1016/j.rser.2009.07.020</u>
 - Show, P. L., Tang, M. S., Nagarajan, D., Ling, T. C., Ooi, C. W., & Chang, J. S. (2017). A holistic approach to managing microalgae for biofuel applications. *International journal of molecular sciences*, 18(1), 215. <u>https://doi.org/10.3390/ijms18010215</u>
 - 43. Harun, R., Singh, M., Forde, G. M., & Danquah, M. K. (2010). Bioprocess engineering of microalgae to produce a variety of consumer products. *Renewable and sustainable energy reviews*, 14(3), 1037-1047. https://doi.org/10.1016/j.rser.2009.11.004
 - 44. Jaiswal, K. K., Kumar, V., Vlaskin, M. S., & Nanda, M. (2020). Impact of glyphosate herbicide stress on metabolic growth and lipid inducement in Chlorella sorokiniana UUIND6 for biodiesel production. *Algal Research*, 51, 102071. <u>https://doi.org/10.1016/j.algal.2020.102071</u>
 - 45. Mutanda, T., Ramesh, D., Karthikeyan, S., Kumari, S., Anandraj, A., & Bux, F. (2011). Bioprospecting for hyper-lipid producing microalgal strains for sustainable biofuel production. *Bioresource technology*, *102*(1), 57-70. https://doi.org/10.1016/j.biortech.2010.06.077
 - 46. Maeda, K., Owada, M., Kimura, N., Omata, K., & Karube, I. (1995). CO 2 fixation from the flue gas on coal-fired thermal power plant by microalgae. *Energy Conversion and Management*, 6(36), 717-720. <u>https://doi.org/10.1016/0196-8904(95)00105-m</u>
 - 47. Metting, F. B. (1996). Biodiversity and application of microalgae. *Journal of industrial microbiology*, *17*(5), 477-489 .<u>https://doi.org/10.1007/bf01574779</u>
 - 48. Cheng, L., Zhang, L., Chen, H., & Gao, C. (2006). Carbon dioxide removal from air by microalgae cultured in a membranephotobioreactor. *Separation and purification technology*, *50*(3), 324-329. <u>https://doi.org/10.1016/j.seppur.2005.12.006</u>
 - 49. Chiu, S. Y., Kao, C. Y., Chen, C. H., Kuan, T. C., Ong, S. C., & Lin, C. S. (2008). Reduction of CO2 by a high-density culture of Chlorella sp. in a semicontinuous photobioreactor. *Bioresource technology*, *99*(9), 3389-3396. https://doi.org/10.1016/j.biortech.2007.08.013
 - De Morais, M. G., & Costa, J. A. V. (2007). Carbon dioxide fixation by Chlorella kessleri, C. vulgaris, Scenedesmus obliquus and Spirulina sp. cultivated in flasks and vertical tubular photobioreactors. *Biotechnology letters*, 29(9), 1349-1352. <u>https://doi.org/10.1007/s10529-007-9394-6</u>
 - 51. Kodama, M. (1993). A new species of highly CO_2 tolerant fast growing marine microalga suitable for high-density culture. *J Mar Biotechnol*, *1*, 21-25.
 - 52. Sung, K. D., Lee, J. S., Shin, C. S., Park, S. C., & Choi, M. J. (1999). CO2 fixation by Chlorella sp. KR-1 and its cultural characteristics. *Bioresource technology*, 68(3), 269-273.
 - 53. Miyairi, S. (1995). CO2 assimilation in a thermophilic cyanobacterium. *Energy conversion and management*, *36*(6-9), 763-766. <u>https://doi.org/10.1016/0196-8904(95)00116-u</u>

ISSN: 2581-8341

LJCSRR @ 2023

Volume 06 Issue 05 May 2023 DOI: 10.47191/ijcsrr/V6-i5-28, Impact Factor: 6.789



www.ijcsrr.org

- 54. Salih, F. M. (2011). Microalgae tolerance to high concentrations of carbon dioxide: a review. Journal of Environmental Protection, 2(05), 648.
- 55. Li, W., & Kang, S. (2011). Research status and development ideas of microalgae carbon se-questration technology. *Biotechn*, 6, 22-27.
- 56. WenGuang, Z. H. O. U., & RongSheng, R. U. A. N. (2014). Biological mitigation of carbon dioxide via microalgae: recent development and future direction. *Scientia Sinica Chimica*, 44(1), 63-78. <u>https://doi.org/10.1360/032013-256</u>
- 57. Browne, J. D., Allen, E., & Murphy, J. D. (2013). Evaluation of the biomethane potential from multiple waste streams for a proposed community scale anaerobic digester. *Environmental technology*, 34(13-14), 2027-2038. https://doi.org/10.1080/09593330.2013.812669
- 58. Yuan, X., Shi, X., Zhang, D., Qiu, Y., Guo, R., & Wang, L. (2011). Biogas production and microcystin biodegradation in anaerobic digestion of blue algae. *Energy & Environmental Science*, 4(4), 1511-1515. <u>https://doi.org/10.1039/c0ee00452a</u>
- Santos-Ballardo, D. U., Rossi, S., Reyes-Moreno, C., & Valdez-Ortiz, A. (2016). Microalgae potential as a biogas source: current status, restraints and future trends. *Reviews in Environmental Science and Bio/Technology*, 15(2), 243-264. <u>https://doi.org/10.1007/s11157-016-9392-z</u>
- Mendez, L., Mahdy, A., Timmers, R. A., Ballesteros, M., & González-Fernández, C. (2013). Enhancing methane production of Chlorella vulgaris via thermochemical pretreatments. *Bioresource technology*, 149, 136-141. <u>https://doi.org/10.1016/j.biortech.2013.08.136</u>

Cite this Article: Akanksha Pal, Ishika Srivastava, Sweety Sahu, Kirti Raje Singh (2023). Algae's Promise to Sequester Carbon Sheds New Insight on Changing Climates. International Journal of Current Science Research and Review, 6(5), 2904-2913