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Global Warming Mitigation through Algal Biomass- Way Forward Towards Green Technology

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Abstract

Microalgae-based sequestration systems is more versatile and high energy efficient method for CO_2 sequestration with respect to economic perspective and time consuming. Microalgae are more photosynthetically efficient and are able to mitigate CO_2 from 10 to 50 times higher than terrestrial plants. They can utilise CO_2 emissions from power plants and other industrial sources for their growth in a CO_2 biosequestration process. Typically, 1 kg of microalgal biomass synthesis requires about 1.8 kg of CO_2. Microbial carbon capture cells (MCCs) used in the production of algae were proved to be an effective technology for CO_2 emission reduction with simultaneous voltage output without aeration. This article focuses on different techniques for culturing of microalgae, carbon reserve capacity of microalgae and recent advancement in production of algae for CO_2 sequestration.

Introduction

Rise in temperature and acidification led to drastic changes, like melting ice bergs, rising sea level, volcanic eruptions and disruption of ecosystem. Since pre-industrial period, the release of greenhouse gases (GHGs) from anthropogenic activities has resulted in an increase in atmospheric carbon dioxide (CO_2) concentrations from approximately 280 parts per million (ppm) in 1750 to 390 ppm in 2010, with as much as 50 % of the increase occurring in the last three decades, leading to global warming. Carbon dioxide (CO_2) is contributing maximum in the warming potential of all greenhouse gases (GHG), due to the over usage of world economies on fossil fuels. While CO_2 levels and global temperatures were higher in the geological past, it is the current rate of change that will pose a problem for biota. Keeling curve from Mauna Lao observatory clearly showed that average concentrations of atmospheric CO_2 have risen from about 316 ppm in 1959 to approximately 370 ppm in 2000 and 390 ppm in 2010. The biggest concern is that after 1970, the curve showed increase by roughly 2 ppm per year with global CO_2 emission already reached 48 Gigatons (Gt) in 2010. It is high time to reduce the global CO_2 emission to 44 Gt if we have to limit global warming to 2 °C. This concern led to United Nations Framework Convention on Climate Change Kyoto Protocol (UNFCCC Kyoto Protocol) promotion with the objective of reducing GHGs by 5.2 % based on the emissions in 1990. Several methods have been proposed to reduce the load of atmospheric CO_2 concentration, such as oceanic sequestration through oceanic injection, terrestrial sequestration, establishing fast growing vegetation and chemical methods such as cryogenic fractionation, absorption, adsorption, and membrane separation but they are less energy efficient with respect to economic perspective, time consuming and laborious. Of the several methods proposed for the carbon sequestration, micro algal carbon sequestration is believed to be more versatile.

Microalgae

Algae are the large and diverse group of simple phototrophic unicellular to multicellular organisms that utilize CO_2 during photosynthesis using green coloured chlorophyll pigment to produce carbohydrates, proteins, lipids, vitamins, and several by-products. Algae have been broadly classified in to two types based on their size into micro algae (less than 2 mm in diameter) and macro algae (are macroscopic). All the algae differ with each other with respect to colour, pigmentation, biochemical composition, nature of by-products, photosynthetic efficiency, preferential growth medium, temperature, pH and light intensity etc. Different algal species so far been isolated from marine and fresh water viz., Anabaena cylindrical, *Ankistrodesmus sp., Chaetoceros muelleri, Chaetoceros calcitrans, Chlamydomonas rheinhardii., Spirulina spp., Tetraselmis spp.* etc are known to sequester carbon from the environment.

Culturing the Microalgae

Naturally microalgae grow in the places such as open ponds, pools, ditches, reservoirs, lakes, lagoons, moist and damp walls and soil etc. It grows by sequestering carbon dioxide but believed to be less productive than photo-bioreactor, due to limitations with respect flexibility of temperature, light, nutrients, pH etc. Microalgae also grows abundantly in the flooded water after the rainfall, flowing domestic water drainage channels and results in the green coloration of water. There are two methods which are most commonly used for the carbon dioxide sequestration using micro algae, 1) Open pond system and 2) Closed photo bioreactor. Other improved algal culture systems that provides large scale algal biomass includes, 1) High rate ponds and 2) Continuously stirred tank reactors.

Open Pond System

Open pond system is traditional method of the cultivation of algae (Schenk *et al.,* 2008). The most commonly used system includes shallow big ponds, tanks, circular ponds and raceway ponds. Among the Open ponds, Raceway ponds are easy to construct and operate and has been used commonly for the mass culture of algae. However, major constraints include poor light utilization by the cells, high evaporation rate, diffusion of carbon dioxide to the atmosphere, requirement of large land areas and prone to contamination which result in low biomass productivity.

Closed System

To overawed the limitations of open culture systems, development of closed culture system has gain attention. Different types of closed system have been developed such as flat – plate photobioreactor, tubular, vertical column etc. The main advantage of closed system includes higher productivity and less contamination rate as compared to open system. Most photobioreactors are characterized by largely exposed illumination surfaces.

Harvesting of Algae

Though there is no particular method for harvesting algae, the most commonly used harvesting method is flocculation, micro screening and centrifugation. Harvesting process also depends on the type of strain that is cultivated. For example, Spirulina sp. is easily harvested by microscreening method. Flocculation methods are mainly used for the harvesting of algae in raceway ponds.

Importance of Microalgae as Carbon Sequester

Microalgae uses sunlight and carbon dioxide to form biofuel, food, feed and several high-value bioactive compounds. Microalgae can utilise CO_2 emissions from power plants and other industrial sources for their growth in a CO_2 biosequestration process. Typically, 1 kg of microalgal biomass synthesis requires about 1.8 kg of CO_2. Microalgae can convert more solar energy (at about 4–7.5%) during cellular metabolism compared to 0.5% for land-based crops. It has a great potential for biosequestration of CO_2 released from power plants and industrial processes which would otherwise go into the atmosphere. Microalgae also acts a pool of several by-products, such as methane produced by anaerobic decomposition of algae, biodiesel and several other products of an industrial importance, biodiesel is derived from microalgal cells and photobiologically produced biohydrogen and as a source of fuel. Production of fuel using micro algae has now gained much momentum due to increased fossils fuel prices and effect of global warming and climate change. Several researchers reported that macroalgae could sequester about 173 TgC yr^{-1} (with a range of 61–268 TgC yr^{-1}) globally.

Carbon Reserve Capacity of Algae

Cyanobacteria and algae are first organisms on earth and these photosynthetic organisms sucked the atmospheric CO_2 and started releasing extra oxygen. Due to this, the levels of CO_2 started reducing to such an extent that leads to evolution of life on earth. Most

Table 1: Growth characteristics of microalgal candidates for biofixation of carbon dioxide

Microalgae	CO_2 %	NOx ppm	SOx ppm	Growth rate in linear phase g L^{-1} day^{-1}
Chlorococcum littorale	70	50	30	0.47
Chlorella HA-1	20	100	50	0.51
Synechocystis sp.	100	600*	100*	-
Cyanidium caldarium	15	-	-	-
Chlorella KR-1	30	100	100	0.78

Lee and Lee, 2003; *NOx and SOx concentration in aqueous phase

anthropogenic emissions of CO_2 resulted from fossil fuels combustion as two sectors, electricity and heat generation and transport, produced nearly two-thirds of these global emissions at present. It is well known that algae are more photosynthetically efficient and have higher productivity rates than terrestrial plants and as a consequence alga have greater capacity to generate and are more efficient CO_2 fixers. For example, microalgae are able to mitigate CO_2 from 10 to 50 times higher than terrestrial plants. Producing 1 t of algal biomass fixes 1.6–2.0 t of CO_2 because approximately half of the dry weight of algal biomass is carbon. Thus, algae have a huge potential to considerably contribute to GHG emission reductions right at the very first stage of the feedstock production. Microalgae present one of the few technologies for the capture and utilization of atmospheric carbon dioxide through the process of photosynthesis. The biomass produced contributes in reducing the carbon dioxide concentration in the atmosphere, and also provides a feedstock for biofuel production.

Advantages of Microalgae-Based Sequestration Systems

The main advantages of microalgae-based sequestration systems are as follows:

• Microalgae do not require traditional agricultural resources for cultivation, as they can be cultivated with or without land and in seawater or freshwater. Further, it requires e lesser volumes of water for cultivation compared to terrestrial crops.

• Algal culture does not require high purity CO_2 and flue gas containing a mixture of CO_2 and NO_2 can be fed directly to the algal ponds.

• The combustion products in flue gas such as NO_x and SO_x can be utilized as nutrients for microalgal culture which could reduce the cost of production of algae.

• These systems have minimal negative impacts on environment, and are eco-friendlier as compared to chemical and physical sequestration.

• These systems have higher growth rate within a short duration of time compared to land-based crops and are sustainable, and environment friendly biofuel that can meet the global energy demand.

• Transition to low carbon economy, namely from hydrocarbon to carbohydrate, protein and lipid resources.

• Huge and superior feedstock to displace terrestrial biomass for producing bioenergy.

• Enormous greenhouse gas uptake and especially superior CO_2 capture and sequestration with extra oxygen release while growing.

Recent Advancement in Production of Algae for CO_2 Mitigation

In recent times, CO_2 mitigating effect of a liquid fuel production process from microalgae using thermochemical liquefaction were studied. Thermochemical liquefaction has the advantage of treating wet materials compared with direct combustion, gasification and pyrolysis, as it does not require a drying process. Successful studies on thermochemical liquefaction of *Botryococcus braunii* and *D. tertiolecta* was conducted achieving 64% and 42% yield of bio oil at 300 ˚C with a higher heating value (HHV) of 45.8% MJ kg^{-1} and 34.9 MJ kg^{-1}. Gasification converts organic or fossil based carbonaceous materials into clean fuel gases or synthetic gases. This is achieved by reacting materials at high temperature (800–1000˚C) without combustion in partial oxidation of air, oxygen or steam. Biomass pyrolysis occurs at 200–750 ˚C in anaerobic condition to produce bio oil and gases. Further, due to integration of anodic off gas into an alga grown cathode (*Chlorella vulgaris*), microbial carbon capture cells (MCCs) were proved to be an effective technology for CO_2 emission reduction with simultaneous voltage output without aeration (610 ± 50 mV, 1000 Ω). The mitigation of CO_2 can be augmented by combining other processes such as wastewater treatment as a medium for microalgae cultivation (Singh *et al.,* 2011).

Conclusion

Micro algae are the diverse group of microscopic chlorophyllous creatures with the wide range of physiological and biochemical diversity capable of growing at a wide range of aquatic environment, accumulating carbohydrates in them by fixing CO_2 present in the atmosphere, growth medium and industrial exhaust flue gas. These micro algae are capable of producing large biomass in short time and yields several economically, ecologically and industrially important by-products compared to terrestrial vegetation. Thus, Microalgae gain an immense potential in alleviating socio-economic status of individual, society and country in a sustainable way by CO_2 sequestration.

The biomass production of algae can facilitate a dual benefit situation where atmospheric carbon dioxide sequestration and value-added products such as biofuels can be obtained by down-stream processing of the biomass. Though, currently projected costs of algal biomass production appear to be on higher side, however, the overall cost of production can be reduced by utilizing the waste resources and industrial emissions such as flue gases, hence a strategic significance to an environmentally sustainable society.

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