Using algae for carbon dioxide capture and bio-fuel production to combat climate change

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ABSTRACT

The global carbon cycle has altered significantly due to extensive use of fossil fuels, coal etc. This lead to increase in the emission of Green House Gases such as CO_2, CH_4, NO_2 and Fluorocarbon. In order to achieve environmental and economic sustainability, a renewable, carbon neutral fuels are required that are also capable of sequestering atmospheric carbon dioxide. In this both micro and macroalgae appear to be a major source that can sequester high level of CO_2 and can replace fossil fuels. Algae use CO_2 as well as water and convert them into carbohydrates and other useful products. Algae are used as food, feed, fodder, fertilizers and pharmaceuticals. Microalgae can be extensively used to capture CO_2 from power plants, steel, cement, oil, automobiles and many other industries and the resulting algal biomass can be not only used for biofuel production but also for various industrial products. Macroalgae has a huge potential for the production of bioethanol. Besides giving environmental and economic benefit, large scale algae cultivation can create a large number of jobs at different levels in the society.

Keywords: Algae, Biofuel, CO_2 sequestration, Fossil fuel, Global warming,

INTRODUCTION

Over the past 200 years, human activities have altered the global carbon cycle significantly. Understanding the consequences of these activities in the coming decades is critical for formulating economic, energy, technology, trade and security policies that will affect the global environment and economy. The altered carbon cycle is mainly caused by increased CO_2 emission in the atmosphere due to extensive burning of fossil fuels. Dresselhaus and Thomas (2001) reported that the fossil fuel currently supply most of the world's energy needs. The use of fossil fuels results in the emission of Greenhouse Gases such as Carbon dioxide (76%), Methane (13%), Nitrous oxide (6%) and Fluorocarbons (5%). Out of these gases carbon dioxide is the major culprit to cause climate change. The level of carbon dioxide in the atmosphere has increased by 31% since 1750 (Fig. 1). More than 50% of the total annual anthropogenic carbon dioxide production is actually accumulated in the atmosphere, the remainder is found in various terrestrial and oceanic sinks (Ritschard 1992). Such an enormous increase in carbon dioxide in the atmosphere will have disastrous environmental consequences such as rise in the earth's temperature, rise in the sea level, acidification of ocean, melting of glaciers, extreme weather conditions, change in ecosystems, coral reef bleaching etc (IPCC, 2007; Hill and Ralph 2008). Until and unless major changes are made in the way fossil fuels are used to provide energy, CO_2 level in the atmosphere will rise (Hoffert *et al,* ., 1998 and Berndes *et al,* ., 2003). Therefore, the use of fossil fuel is now widely accepted as unsustainable due to depleting resources and the accumulation of Greenhouse gases in the environment. Since the days of industrial revolution, the developed countries have emitted most of the anthropogenic greenhouse gases into the atmosphere. On the other hand the developing countries are the most vulnerable to climate change impacts because they have fewer resources to adapt socially, technologically and financially (UNFCCC 2007).

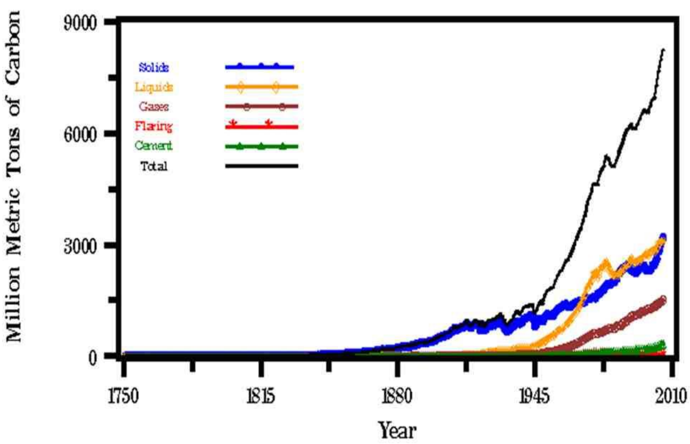

Fig. 1. Graph showing increase level of CO_2 since 1750. (Courtesy Boden et al 2010).

Therefore, in order to achieve environmental and economic sustainability, the future fuel production processes need to be not only renewable but also capable of sequestering atmospheric carbon dioxide (Schenk *et al,* ., 2008). So, a shift from fossil fuels to low carbon fuels becomes the highest priority. The most effective ways to reduce CO_2 emission is to improve the energy efficiency of each economic sector and to reduce the cutting of tropical and temperate forest around the world. These methods however may not be able to control CO_2 emissions due to various political and socio-economic barriers, so other more innovative and less well defined CO_2 mitigation measures are required. The most practical of these innovations is to increase CO_2 sinks through photosynthesis including increased carbon storage in standing tree biomass, substitution of fossil fuels with biofuels, increase in soil carbon sequestration and increase in soil primary productivity (Ritschard 1992).Microalgae can be extensively used to capture CO_2 from power plants, steel, cement, oil, automobiles and many other industries and the resulting algal biomass can be not only used for biofuel production but also for various industrial products. Besides giving environmental and economic benefit, large scale algae cultivation can create millions of jobs at different levels of the society.

CARBON DIOXIDE CAPTURE BY MICROALGAE

Amongst various CO_2 sequestration technologies, the biological methods particularly the ones using microalgae, have several merits. These include, direct CO_2 capture and fixation from flue gases by suitable microalgal strains and their biomass conversion into useful products. The last advantage is quite important because the separation of CO_2 from flue gases takes a major portion over 70% of the total sequestration cost (Lee and Lee , 2003).In addition to these advantages, carbon fixed by microalgae is incorporated into carbohydrates and lipids, so that energy, chemicals or food can be produced from algal biomass (Sawayama *et al,* ., 1999; Lee *et al,* , 2001; Becker 1994; Metzger and Largeau 1999 and Olaizola 2003). Due to these advantages microalgae can be extensively used to capture CO_2 from power, steel and cement plants as well as transport vehicles exhaust. Much work has been done in capturing CO_2 from power plants (Table1). Various microalgal species including *Chlorella kessleri*, *Chlorella* sp. T-1, *Chlorella* KR-1, *Chlorella emersonii*, *Chlorella* HA-1, *Chlorella* ZY-1, *Chlorococcum littorale*, *Synechococcus* PCC7942, *Stichococcus bacillaris* , *Thermosynechococcus* sp. CL-1, *Nannochloropsis oculata*, *Galdieria partita*, *Chlorogleopsis* sp., *Spirulina platensis* etc. (Kurano *et al,* 1995; Maeda *et al,* 1995; Yanagi *et al,* 1995; Kajiwara *et al,* 1997; Iwasaki *et al,* 1998; Sung *et al,* 1999; Yue and Chen 2005; Morais and Costa 2007a; Morais and Costa 2007b; Ono and Cuello 2007; Hsueh *et al,* 2009; Douskova *et al,* 2009; Ramanan *et al,* 2010 and Borkenstein 2011) can be used to capture carbon dioxide from power plants. Various algal strains treated with different concentration of carbon dioxide were also tested (Fig. 2A-B) (Elangbam and Sahoo 2009).

Table1. Growth characteristics of microalgal candidates for biofixation of carbon dioxide (courtesy Lee and Lee 2003)

Microalgae	CO_2 %	NO_x ppm	SO_x 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	50	-	-
Chlorella KR-1	30	100	100	0.78

*** NO_x and SO_x concentration in aqueous phase**

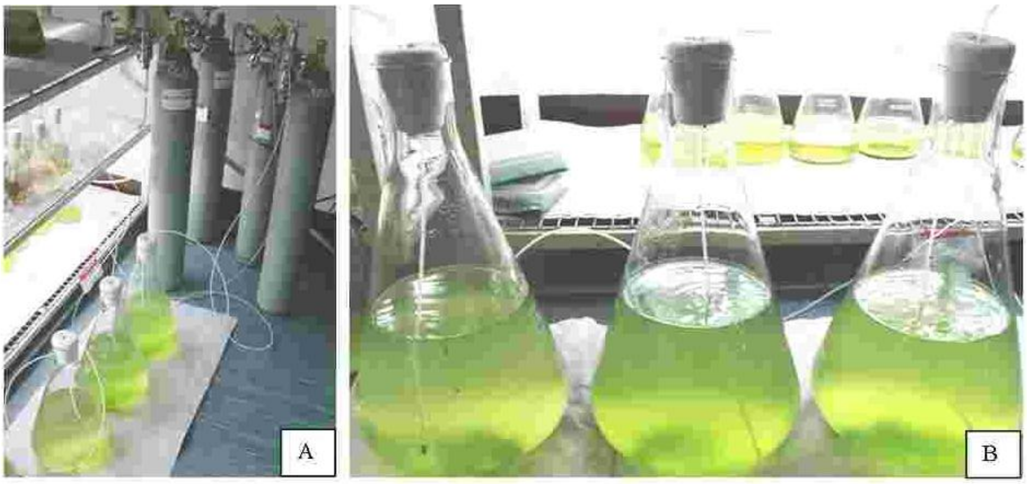

Fig. 2(A-B) Different concentration of carbon dioxide treatment in laboratory scale at Delhi University; (C-D) Microalgae cultivation in the laboratory at Delhi University, India

CARBON DIOXIDE CAPTURE BY MACROALGAE

Macro marine algae popularly known as seaweeds have emerged as a major group for CO_2 sequestration from the ocean. According to Beardall and Raven (2004) marine photosynthesis contributes 54–59 Pg C year−1 of the total primary productivity of planet and out of this ~ 1 Pg C year^{-1} is contributed by seaweeds and seagrasses. Marine macroalgae such as *Macrocystis*, *Laminaria, Sargassum*, *Ascophyllum*, *Fucus*, *Porphyra*, *Palmaria*, *Ulva* and *Enteromorpha* also achieve high rates of CO_2 assimilation per gram fresh weight (Jackson 1987; Gao and McKinley 1994; Muraoka 2004 and Chung *et al,* 2011). Macroalgae can incorporate an average of 0.26 x 10^6 tonnes C into the harvested algae annually (Chung *et al,* 2011) thus, seaweeds also have a good potential in capturing carbon.

ALTERNATIVE FUEL

The escalating price of petroleum and most significantly the emerging concern about global warming which is associated with the burning of fossil fuels has led scientists all over the world to look for an alternative eco-friendly source of fuel. Thus, biofuel has become more attractive because of its environmental benefits as it is made from renewable biological resources. It is biodegradable, non toxic and has low emission profiles, therefore beneficial to the environment.

One hundred years ago, Rudolf Diesel tested vegetable oil as fuel for his car engine. In 1930s and 1940s vegetable oils were used as biodiesel only in emergency situations. Recently increase in crude oil prices coupled with environmental concerns, has resulted renewed interests in production of biofuel. Continued and increasing use of petroleum will intensify local air pollution and magnify the global warming problems caused by carbon dioxide (Shay 1993 and Ma and Hanna 1999). Thus, biofuel has the potential to reduce the level of pollutants and the level of probable carcinogens (Krawezyl 1996 and Ma and Hanna 1999).

Considerable amount of food crops and their products which include maize, sugarcane, wheat, palm oil, soybean, sunflower oil, rapeseed oil etc are being used for production of first generation biofuels. Unfortunately biofuel derived from food crops, edible oil, waste cooking oil and other vegetable oils cannot realistically satisfy even a small fraction of the existing demand for transport fuels (Chisti 2007).

Moreover, biofuels from food crops also contribute to land clearing if they are produced on existing cropland or on newly cleared lands (Buchanan *et al,* ., 2008; Curran *et al,* ., 2004; Fargione at al., 2008; Nepstad *et al*, ., 2008). FAO, 2008 reports concluded that rapid expansion in liquid biofuel production offers both risks and opportunities for the global food and agriculture system primarily through its impact on commodity prices. The immediate risk is that higher prices hurt poor consumers in the developing world, who often spend more than half of their total household income on food (FAO 2008 and Raney 2009). Therefore, it is necessary to minimize environmental risks associated with the first generation biofuels and maximize the potential opportunities for agricultural development that would require a shift away from current policies that subsidize the production of first generation liquid biofuels, towards a more balanced package of policies that consider environmental, food security, energy and agricultural needs in a more integrated way (Raney 2009).

Algae for biofuel production

Microalgae can use water and carbondioxide to produce biofuels, food, feeds and high value bioactive compounds. Algae have several advantages over other crops including *Jatropha* (Sahoo 2010). It was already reported that Microalgae produce 15 – 300 times more oil than the other first generation oil crops (Chisti 2007 and Schenk *et al,* 2008). Microalgae oil differs from most vegetable oils in being quite rich in polyunsaturated fatty acids with four or more double bonds (Belarbi *et al,* 2000 and Chisti 2007). The advantage of microalgae over land plants as a source of transportation biofuels are as follows:

- Oil yield per area of microalgae cultures could greatly exceed the yield of the best oilseed crops.
- Microalgae grow in an aquatic medium, but need less water than terrestrial crops.
- Microalgae can be cultivated in sea water or brackish water on non arable land and do not compete for resources with conventional agriculture.
- Microalgae biomass production may be combined with direct biofixation of waste carbon dioxide.
- Algae cultivation does not need herbicides or pesticides
- The residual algal biomass after oil extraction may be used as feed, fertilizer or fermented to process ethanol or methane.
- The biochemical composition of the algal biomass can be modulated by varying growth conditions and the oil content can be highly enhanced.

Microalgae for biodiesel production

Microalgae contribute a major role as alternative fuels in order to combat global warming due to their high lipid content. One of the most advantages of microalgae is that, their chemical composition can be manipulated by altering the growth environment of the algae of interest. Moreover their chemical composition is influenced by the growth phase and by various environmental factors such as temperature, light etc. thus the key challenges for biodiesel production from microalgae lies in screening and isolation of microalgal strains with high growth rate and high oil content. Screening and isolation using techniques such as filtration, differential centrifugation, micropipetting, serial dilution and agar streaking are the main steps in culture methods for microalgae. Various works were done on screening and isolation of potential microalgae for biodiesel production (Devi 2008 and Devi *et al,* 2009). Microalgae when grown under nitrogen deficient culture medium and heterotrophic culture medium show a great increase in oil quantity.

CULTIVATION AND HARVESTING

Microalgae can be grown either in open culture systems or closed systems (photobioreactors). Earlier microalgae were grown mainly in open ponds especially for food and feed supplements, waste water treatments, pharmaceuticals, biosorption of heavy metals etc. Closed system of algae cultivation has attracted much interest because they allow a better control of cultivation condition than open systems. In closed photobioreactors higher biomass productivities are obtained and contamination can be easily prevented (Ugwa *et al,* 2008).

Open Ponds

Open ponds were extensively used in the past for the cultivation of algae (Ugwa *et al,* 2008; Hase *et al,* 2000; Boussiba *et al,* 1988 and Tredici and Materassi 1992). Open ponds can be categorized into natural waters (lakes, lagoons, ponds) and artificial ponds. The most commonly used system includes shallow big ponds, tanks, circular ponds and raceway ponds. Among the types of open ponds, raceway ponds are very common and they have been used for the mass culture of algae since 1950s. The advantage of open ponds is that they are easier to construct and operate, easy to clean after cultivation. However, major limitation in open ponds include poor light utilization by the cells, high evaporation rate, diffusion of carbondioxide to the atmosphere, requirement of large land areas and prone to contamination which result in low biomass productivity.

Closed System

In order to overcome the limitations of open culture systems, attention is now given on the development of closed culture system. Till now various types of closed system has been developed such as flat – plate photobioreactor, tubular, vertical column etc. In closed system biomass productivities are high and contamination rate are very less compared to open system. Most photobioreactors are characterized by largely exposed illumination surfaces. Closed photobioreactors are good for the immobilization of algae and biomass productivities are very high compared to the open system of cultivation. Closed culture microalgae were also done in the laboratory of Department of Delhi, University of Delhi (Fig.2C-D).

Fig. 2(C-D) Microalgae cultivation in the laboratory at Delhi University, India

Harvesting of Algae

There is not a particular method for the harvest of algae. The most common 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. In laboratory filtration is also used but they cannot be applied in large scale cultivation. Flocculation methods are mainly used for the harvesting of algae in raceway ponds (Schenk *et al,* 2008).

SEAWEEDS FOR BIOETHANOL PRODUCTION

Brown Seaweed contains two main sugars, mannitol and laminarin. Both are easy to extract and are by-products of the alginate industry. Through conversion and fermentation Seaweeds polysaccharides are converted into alcohol. Seaweed doesn't need soil and fresh water as other agricultural biofuel producer crops desperately do. Many criticize that the cultivation of massive agricultural crops to produce bio fuel requires very large acres of land, that makes it inefficient and potentially harm the environment. Food price will rise as the effect of more land is taken away to produce biofuel. Algae / Seaweed grow 10 times faster than sugar cane. According to researchers at the Center for Biorefining of the University of Minnesota and Chisti (2007) reported that Algae / Seaweed produce 5000 gallons (approx 18927 Liters) of bio fuel per acre as compared to the corn which yields 18 gallons (approx 68 Liters), soybeans produce 48 gallons (approx 181 Liters).

CONCLUSION

Most of the World's energy supply comes from fossil fuel as a result there is rise in the atmospheric CO_2 leading to Global Warming. Thus, it is very important to develop new methods for CO_2 sequestration. At the same time, to develop an alternative clean energy sources which do not depend on fossil fuel and which have a tolerable environmental impact. Therefore carbon sequestration and biofuel production from micro and macro algae becomes one of the alternative to combat climate change as higher plants have various limitations to be used as a model system for carbon sequestration and biofuel production. Numerous work have been done on carbon sequestration and biofuel production by algae but still it needs much research in order to meet the increasing demand for energy. We hope that in future it will replace the fossil fuel to larger extent and reduce the atmospheric CO_2 to combat Global warming.

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