IJCR
International Journal of Chemical Research
ISSN: 0975-3699 & E-ISSN: 0975–9131, Vol. 3, Issue 3, 2011, pp-110-117
Available online at http://www.bioinfo.in/contents.php?id=23

AN OVERVIEW OF CO_2 MITIGATION USING ALGAE CULTIVATION TECHNOLOGY

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Received: August 08, 2011; Accepted: October 07, 2011

Abstract- From the industrial revolution to the present, energy consumption has lead to a substantial rise in atmospheric greenhouse gases. The burning of fossil fuels accounts for about 80% of the rise of atmospheric carbon-dioxide (CO_2), since the pre-industrial era, to its current level of 390 ppm. The increase in CO_2 is already causing changes in the climate such as global warming. The "micro-algae based technology" (Biological carbon sequestration) is a new, might be the most promising, environmentally friendly and cost-effective means of reducing CO_2 emissions in the energy sector. The most common micro-algae species are *Spirulina sp., Chlorella sp*[a]*., Haematococcus sp*[a]*.* and *Dunaliella sp*[a]., etc. This technology, have more important characteristics apart from carbon sequestration such as high biomass yield per unit of light and area. In this context, paper has focused the underlying issues in CO_2 sequestration from algae based on geography, photosynthetic light, productivity and application of algal biomass. for conditions prevailing in India.
Key words -Micro-algae, biomass, biofuel, CO_2 sequestration, bioreactors

Introduction

The increase of world energy demand and greenhouse gas (GHG) emission has been concerning all sectors since last decades. An economic growth combined with a rising population has led to a steady increase in global energy demands. If the governments around the world stick to current policies, the world will need almost more percent of energy than energy in 2030 than today. Of this 45% will be accounted by China and India together [1-2]. On a worldwide basis, coal is by far, the largest fossil energy resource available. Coal will remain the mainstay of world baseline electricity generation by the year 2015 [1]. The combined use of fossil fuels is not sustainable, as they are finite resources [2] and their combustion will lead to increased energy-related emission of GHG, CO_2, sulfur dioxide (SO_2) and nitrogen oxides (NOx). Since the onset of the industrial revolution about 150 years ago, human activities such as the burning of fossil fuels and deforestation have accelerated, and both have contributed to a long-term rise in atmospheric burning fossil fuel (oil, natural gas and coal) releases carbon into the atmosphere far more rapidly than it is being removed, and this imbalance causes increase carbon dioxide (CO_2) concentrations in the atmosphere. Power generation, transport, industry and domestic uses are also contributing for increasing CO_2. However; CO_2 produced by combustion of fossil fuels is a major source of GHG emission, because CO_2 increases the atmosphere's ability to hold heat, approximately atmosphere is loaded with around 90 MT (million tonnes) of heat trapping substances every day that slowly wrap the earth with an artificial GHG screen. The climates change due to CO_2 level should not be allowed to get much higher than 550 ppm as per 'Keeling curve'. CO_2 emissions are expected to increase at an annual rate of 3%. The potential effects of global warming on India vary from the submergence of low lying islands and coastal lands to the melting of glaciers in the Indian Himalayas, threatening the volumetric flow rate of many of important rivers of India and South Asia.

It is the increased demand for energy, particularly in the developing world, which underlies the projected increase in CO_2 emissions. In addition, by clearing forests, we reduce the ability of photosynthesis to remove CO_2 from the atmosphere, also resulting in a net increase of CO_2 and atmospheric CO_2 concentrations are higher today than they have been over the last half-million years or longer (~390 ppm of CO_2 concentration in the atmosphere on 2010) which was estimated by 'Keeling curve' [3]. In terms of emission volumes, CO_2 is the major GHG, with nearly 80% of world emissions and 70-75% of the emission of industrialised countries, its increase the atmospheric (CO_2 or carbonic gas) by 30% between 1745 and 1998 [4]. Energy-induced CO_2 emission stood at 25 billion tonnes in 2003. The US, responsible for 27% of world emission. Russia after a 24% fall its emissions between 1990 and 2003. China is emitting practically as much CO_2 as the European Union of 25, with 15% of world emission. India emits three times less than China. In France is emitting 2.2 times fewer tonnes of CO_2 than Germany and 1.4 times less the UK [4].

Many attribute the observed 0.6 ^{o}C increase in global average temperature over the past century mainly due to increases in atmospheric CO_2. The best scientific

[a] *text with details given in algae-planet.com, ncbi.nlm.nih.gov, genome.jgi-psf.org*

estimate is that global mean temperature will increase between 1.4 and 5.8 °C over the next century as a result of increases in atmospheric CO_2 and other GHG. This type of phenomena cause the increase in global temperature would cause significant rise in average sea-level (0.09-0.88m)[b]. Without substantive changes in global patterns of fossil fuel consumption and deforestation, warming trends are likely to continue for environmental safe aspects.

Countries like China and India will likely be the greatest emitters in the 21st century and will probably use their expansive coal reserves to continue developing their economies [5]. Since climate change is a global problem, a recovered ton of CO_2 is equivalent in any location. India has committed itself orally in January 2010 to reduce its GHG emissions by 20% in the 2008-2012 period compared to 1990 levels. However, in order to stabilize GHG concentrations in the atmosphere at acceptable levels, much deeper cuts in emissions (by more than 50% globally over the next 50 years) will be necessary. The various options to limit CO_2 emissions, in the energy and transport sectors, which includes reducing energy consumption, increasing energy efficiency, low-carbon fuels application and renewable sources. Traditionally India has dependent on high carbon intensive energy production methods specifically coal-based electrical generation flue gases from power plant are responsible for more than 7% of the total world CO_2 emission. A typical coal-fired power plant emits flue gas from their stacks containing upto 15% CO_2[b]. In India, it is estimated that CO_2 emission may be expected to increase at an annual rate of 3% between 2005 and 2030[b]. The long term demand for coal brings with it a demand for technologies that can mitigate the environmental problems associated with coal. While control technologies will be used to reduce air pollutants, no technologies exist today, which address the problem of GHG emissions. A sustainable approach to the capture and removal of CO_2 and retain CO_2 from the atmosphere in a self sustaining manner is the need of the hour. In addition, it is necessary to enhance the carbon sink capacity of the biosphere (e.g. forests). Meeting the energy demand without huge increases in CO_2 emissions requires more than merely increasing the efficiency of energy production. Since coal is much more plentiful than oil or gas, reducing coal emissions is absolutely essential to avoid dangerous effect of climate change.

The future reduction in the ecological footprint of energy generation will reside in a multi-faceted approach that includes nuclear, solar hydrogen, wind and fossil fuels (from which carbon is sequestered) and biofuels [2, 6-9]. Mitigation of GHG emission would result from the conversion of the algal biomass to renewable biofuels (methane, ethanol, biodiesel and hydrogen) and fossil fuel sparing products (fertilizers, biopolymers and lubricants). Carbon sequestration–capturing and storing carbon emitted from the global energy system – could be a major tool for reducing atmospheric CO_2 emissions. Carbon sequestration technologies could be incorporated and best applied in connection with large-scale energy conversion plants such as coal power plants and oil refineries. Carbon sequestration offers the possibility for new industrial applications such as the production of hydrogen, together with electricity, from fossil fuels. The CO_2 produced as a by-product could be captured, recycled and converted into usable form. CO_2 Sequestration technology can be readily installed on developing countries' power plants. The field of algal cultivation for CO_2 fixation and/or its conversion to biofuels is not new, having been suggested as early as 1955 [10-11] and the earliest internal combustion engines were run on biologically derived molecules (plant oils for diesel engines and bioethanol for spark-ignition engines) until plentiful petroleum- derived fuel stook over due to their lower price. There are many reports on the potential and bio-economics of algal biomass to generate fuels and most of these are based on the premise that one would utilise the CO_2 emitted from fossil-fuelled power stations or other industrial sources of CO_2 such as cement processing [12-13]. There are comparatively few, but valuable, studies in the literature exploring algal capture of either simulated or actual flue gas CO_2. Micro-algae ponds are also used for municipal wastewater treatment and a plant in California is using the methane obtained from the harvested algal biomass, produced from some 180 ha of oxidation ponds, to generate electricity. Engineering cost analyses project that for larger systems (>100 ha) and assuming higher biomass productivities (> 100 metric tons/ha/year) and low-cost harvesting [12,14-16].

The microalgae are veritable miniature biochemical factories and appear more photosynthetically efficient than terrestrial plants [2, 17] and are efficient CO_2 fixers [18]. A number of features of algae make them attractive when compared to terrestrial feedstock crops [19], Although their growth requirements are simple (nutrients, nitrogen and phosphate source, trace metals, water, CO_2 and sunlight) and are similar to terrestrial plants, they use these resources very efficiently [19] and therefore have high productivity with comparatively low water use [18-19].

Rudolph diesel (biofuel) first demonstrated the use of biodiesel from a variety of crops in nineteenth century. However, the widespread availability of inexpensive petroleum during the twenth century determined otherwise. The biofuels are getting from petroleum and other sources, renewable biomass contributes to the development of sustainable industrial society and effective management of GHG [2, 20-21]. A major drawback often levelled against biomass, particurly ineffective in the large-scale fuel production, is that it will consume vast space of farmland and native habitats, drive up food prices [2]. They are petroleum replacement for internal combustion engines, and derived from food crops (sugarcane, sugarbeet, maize, sorghum and wheat and other forms of biomass) [22] and non-food feedstock which are extracted from microalgae and other microbial sources, lingo-cellulsic biomass, rice straw and bio-ethers. Microalgae, use a photosynthetic process similar to higher plants and can complete an entire growing cycle every few day. Infact, the biomass doubling time for microalgae during exponential growth can be as short as

[b] *text with details given in seaweb.org, unstats.un.org, indianenvironmentportal.org*

3.5h [2,23]. Some mciroalgae grow hetrotrophically on organic carbon source. However, heterotrophic production is not efficient as using photosynthetic microalgae [2, 23]. Chisti [22] clearly reviewed and demonstrated the important of microalgal biofuels. Many algae are exceedingly rich in oil, which can be converted to biofuel. The oil content of some microalgae exceeds 80% of dry weight of algae biomass [23]. The growth of algae requires CO_2 as one of the main nutrients needed. There is an opportunity to sequester CO_2 by using flue gas emissions from industrial sources as the CO_2 feed for algae cultivation and produce the biofuel from the algae biomass. Very few literatures are available for potential technology and applications of microalgae for carbon sequestration and biofuel production [2, 11, 23-36]. The present study is focussed to assess the potential of micro-algae sequestration technology, issues, challenges involved and develop a techno-economic analysis of a process for sequestering CO_2 from flue gas into growing algae which produce biodiesel.

Micro-algae is a source: carbon sequestration in Indian scenario

Energy from the biomass for CO_2 sequestration using micro-algae is one of the most important components to mitigate GHG emissions [6]. The simple, direct method of GHG mitigation is the removal of CO_2 from stack gases followed by long-term sequestration of CO_2 by microalgae ponds [37]. Microalgae are attractive is that CO_2 (of about half of the of dry algae weight) is needed for growth [28]. CO_2 is a common industrial pollutant, thus microalgae can contribute to reducing atmospheric CO_2 by consuming CO_2 wastes from industrial sources such as power plants. There are nine major groups of algae which are cyanobacteria (*Cyanophyceae*), green algae (*Chlorophyceae*), diatoms (*Bacillariophyceae*), yellow-green algae (*Xantophyceae*), golden algae (*Chrysophyceae*), red algae (*Rhodophyceae*), brown algae (*Phaeophyceae*), dinoflagellates (*Dinophyceae*) and 'pico-plankton' (*Prasinophyceae* and *Eustigmatophyceae*) [38]. Of these nine groups, the green algae are the largest taxonomic group [23]. *Chlorella sp.* has been grown at different condition of CO_2 (around 15% in concentration), NOx and SOx showing resistance to harsh ambiances [10]. Algae are the most common and fastest growing plants in this world. Algae are a very promising solution to diminishing oil reserves, escalating oil prices and climate change caused by greenhouse gas emissions Algae by means of Photosynthesis has the capacity too sequester anthropogenic CO_2. Aquatic microalgae have been identified as fast growing species whose carbon fixing rates are higher than those of land-based plants by one order of magnitude. It does not require agricultural land. Fresh water is not essential and nutrients can be supplied by wastewater and CO_2 by combustion gas. Thus algae have a clear potential to be used as a source for the production of renewable energy. Most of areas in India have climates suitable for algae cultivation [39]. In order to utilize algae for this purpose, the most common systems (open pond and photo bioreactor) are described.

The operating conditions, needed for algae cultivation are examined and analysed. "Biological" sinks involve the use of CO_2 from the power generation process. Biological Sequestration is a concept based on capturing the total (process+combustion) CO_2 emitting from a thermal power plant via growing micro algae which is used to produce bio-fuel, and its residue can be burned as solid biomass, as well. However, contrary to what is often stated, CO_2 capture by algal cultures is not a CO_2 sequestration or GHG abatement process. That can only come from converting the algal biomass to biofuels and their use in replacing fossil fuels. As a mitigation strategy, biological sinks (micro-algae) offers the advantage of allowing the continued use of the well-established fossil fuel infrastructure.

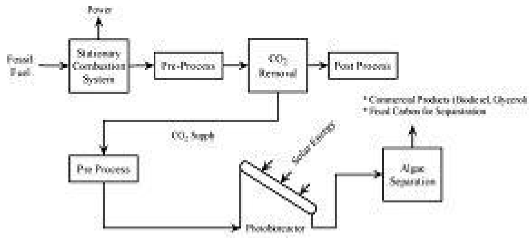


Figure 1: Recovery and sequestration of CO_2 from stationary combustion systems by photosynthesis of microalgae [23]

Photosynthetic microorganisms are capable of fixing the CO_2 sequestration and renewable energy production as shown in (Figure 1). Some of the main characteristics which set algae apart from other biomass sources are that algae have a high biomass yield per unit of light and area [23]. Algae have high oil or starch content. Microalgae have been known to survive under a wide range of conditions. Under optimal conditions, microalgae have lipid content between 5 and 20% dry weight while under unfavorable conditions lipid content increases between 20 and 50% [38]. Hence, it is ideal to cultivate microalgae under optimal conditions and later expose them to unfavorable conditions in order to increase lipid content.

Various parameters and conditions for potential of biological sequestration in India

India is a country near the equator, which means that given its geographical location, it is subject to a large amount of solar radiation throughout the year. It is both densely populated and has high solar insolation, providing an ideal combination for micro algal carbon sequestration.

Favorable Climate: High insolation and warm temperature is required for high algal productivity and therefore, latitudes within a certain distance of the equator are best for locating algae farms.

Availability of land: Land requirement is an extremely pertinent criterion for assessing the ethical implications behind developing algae farming for Carbon Sequestration and subsequent processing to displace fossil fuels for transportation. The land required for energy production should not be arable land as competition between agriculture for food and fuel will ensure exacerbating increases in food prices further. Theoretically, algae farms should use about half of the land to produce the same yield of bio fuel compared to the next highest yielding agricultural biofuel crop, that of palm which grows well only in certain parts of the world. In fact, algae farming in 2% of Indian land area could possibly completely displace fossil fuel use for transportation in India.

Availability of Sunlight: The annual global radiation varies from 1600 to 2200 kWh/m^2. This is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy/year. The India Meteorological Department maintains a nationwide network of radiation stations which measure solar radiation and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250 to 300 days a year.

***Availability of power plants CO_2 Source*:** Table 1 shows that the CO_2 emissions per day from Indian thermal power plants. Tropical climate, plenty of degraded land (>60 M ha)[c] and enough man power make India an ideal location for microalgae for carbon sequestration. Micro algae require optimum conditions like light, CO_2, water, and inorganic salts to grow. Temperature also has a major effect in the production of algal fatty acids. The optimum temperature for growth averages between 18-24 ^oC. Table 1 shows that most cultured microalgae tolerate temperature between 16-27 ^oC [40].

Table 1: Optimum and tolerance ranges of algal growth conditions [40].

Conditions	Tolerable range	Optimum range
Temperature (^oC)	16-27	18-24
Salinity (g/l)	12-40	20-24
Light intensity	1000-10000	2500-5000
Photoperiod (light: dark, h)	24:0 (max.)	16:8 (min.)
pH	7-9	8.2-8.7

***Emissions from coal fired thermal power plants in India*:** CO_2 emissions are estimated based on the carbon content in the coal and the excess air used at the power plants. Most of thermal power plants in India use E and F grade coals. Computed data indicate that CO_2 emissions per unit of electricity from most power plants range between 0.8 and 1.8 kg/Kwh. Thermal power plant flue gas contains nearly 15% CO_2. This relatively high content of CO_2 in flue gas can be used to increase the growth rate of algae as shown in the (Table 8).

Table 8: Composition of flue gas and ranges of CO_2 emission per day in a typical Indian Thermal Power plant

Flue gas Composition	
CO_2	12.33%
O_2	7.47%
N_2	80.2%
CO_2 (Thousand ton)	Coal used per day (million tons)
10-50	0.08-0.43

Capture and injection of CO_2 to microalgae culture: CO_2 from various industrial sources (power plants, cement, steel and chemical industries etc) can be converted to biomass using algae mass culture pond systems. Flue gases can be sent directly to microalgae culture or CO_2 can first separated from flue gases before being injected. In the first case, microalgae culture can have problems with high temperature and high concentration of CO_2. NO_x , and SO_x, but that will depend on microalgae species. As an example, *Chlorella .sp*. has been grown at different condition of CO_2 (around 15% in concentration), NO_x, and SO_x showing resistance to harsh ambiances [10]. In power plants a solvent like MEA is usually used in order to separate CO_2 from flue gases. The separated contains a high % of CO_2, Nitrogen, CO, H_2 and small quantities of methane and hydrogen sulfide. According to several authors, it is possible to inject flue gases directly into the system [37]. Flue gases or pure CO_2 are usually injected into photo bioreactors or ponds in form of bubbles. Authors affirm that fixation of CO_2 will improve in the system if it is injected in the liquid phase and not spread directly into the microalgae culture. Several studies establish that around 80-90% of CO_2 can be removed from flue gases [39].

There is potential to effectively reduce the amount of CO_2 and NOx released into the atmosphere from many stationary emitters by feeding the carbon-rich flue gas to the algae. Algae are therefore able to fix approximately 1.8 kg of CO_2 fixed for every 1 kg of algae biomass produced [23].

A practical example of a current microalgae production process is *Spirulina* microalgae already produced commercially in open ponds in many countries around the world. In these production systems, the algae are cultivated in large (typically 0.2-0.4 ha), raceway-type open ponds mixed by paddle wheels. Nutrients most importantly CO_2 are added to the ponds and these filamentous algae are then harvested by fine mesh screens, spray dried and sold as specialty human foods and animal feeds. The main limitations are with technology and economics. The main technical obstacles to increasing algal productivities are light saturation and respiration (both night-time dark respiration and day time photorespiration). Light saturation is the largest single factor limiting the productivity of algal mass cultures. The major economic obstacles are land required and capital cost for the scale which can meet the required amount of power plant CO_2 reduction.

Characteristics of Micro-algae: Algae are more efficient at utilizing sunlight than terrestrial plants, consume harmful pollutants, and have minimal resource requirements and do not compete with food or agriculture for precious resources. Algae have higher growth rates than terrestrial plants, allowing a large quantity of biomass to be produced in a shorter amount of time in a smaller area. Algae growth rates of 10 to 50 g/m^2 /d (grams of algal mass per square meter per day) have been published in the literature. Compared to terrestrial plants such as corn and soy, algae have shorter harvest times because they can double their mass every 24 hours.

These short harvest times allow for much more efficient and rapid production of algae compared to corn or soy crops. Yields of different oil producing crops can be examined, as shown in Table 3.

Table 2: Typical yield and land data [41]

Crop	Oil yield (gal/acre-yr)	Land area needed (million acre)
Corn	18	2222
Cotton	35	1143
Soyabean	48	833
Canola	127	315
Jatropha	202	198
Oil palm	635	63
Micro algae (15% oil)	1200	33
Micro algae (50% oil)	10000	4

Oil Content and composition of algae: Algae can be oil-rich organisms. Compared to terrestrial crops such as corn, soy or even palm plants, algae are far more oil-rich and offer a higher yield of oil per unit of land in a year. The main components of algae are carbohydrates, proteins, and lipids. Oil content, the percentage of oil per weight of dry biomass, typically ranges from 20 to 50% depending on the species. This oil is composed of many different types of lipids that can be processed easily into biodiesel, jet fuel or other chemicals. Of particular interest are the lipids, which can be processed into valuable fuel products such as biodiesel (through transesterification), jet fuel, and even traditional gasoline and diesel depending on the species. Algae species and their typical oil contents are shown in Table 3. The general method of algal based CO_2 Sequestration and fuel production begins with the cultivation of algae, which can be done in fresh or salt water, to significant yields, followed by harvesting and dewatering processes which result in a thick algal slurry. Extraction of the oil has typically been done by various methods available in the literature. Few methods are Direct Transesterification of Lipids into FAMES Using Organic Solvent Systems, Mechanical Disruption (i.e., Cell Rupture), Subcritical Water Extraction, Accelerated Solvent Extraction, Supercritical Methanol or CO_2, Milking. Depending on the desired end product, the oil can be used directly after extraction or it can be refined into a different form. Numerous techniques have evolved for the cellular fractionation and extraction of oil, however, these techniques have not made it out of the laboratory yet.

Table 3: Algae species and typical oil content [23].

Micro algae	Oil content (% dry weight)
Botryococcus braunii	25-75
Chlorella sp	28-32
Crpthecodinium cohnii	20
Cylindrotheca sp	16-37
Dunalielia primolecta	23
Isochryais sp	25-33
Monallanthus salina	>20
Nannochloris sp	20-35
Nannochloropsis sp	31-68
Neochloris oleoabundans	35-54
Nitzschina sp	45-47
Schiochytrium sp	50-77
Tetraseknus sueica	15-23

Micro algae species selection for CO_2 fixation: Algae come in multiple forms from multi cellular organisms like kelp, to microscopic, single celled organisms. Very much like plants, algae have chloroplast and chlorophyll, but various accessory pigments are present in some algae such as phyverdin in green algae and phycoerythrin in red algae, resulting in a wide variety of colours. A selection of microalgae with high accumulation of oils and tolerance to flue gases are suitable for biodiesel production. Strain selection is dictated by high productivity ready harvest ability , and desirable co-product .beside lipid content ,selection of algal strain can also determined by its ability to be mass –cultured, hardiness in extreme environments ,relative growth rate (versus potential contaminants), and competitions in dense mass culture [42]. In the study of micro algae cultivated with CO_2 bio-mitigation [46], it was found that *Chlorella species* and *Botryococcus brauni* as ideal candidates for biodiesel production.

Technical aspects of photosynthetic CO_2 sequestration technology

After the fossil fuel has been burnt to produce power, the CO_2 is separated from the flue gas stream or captured. Flue gases can be passed directly to microalgae pond is practically known as "Photobioreator" before CO_2 can be removed from the flue gases. Various type of microalgae are available for the CO_2 sequestration in the recent literature [23]. The various conditions provides growth of microalgae like temperature and concentration of CO_2, NOx and SOx etc and also depends on the different species of microalgae.

In power plants a solvent like Methylethylamine (MEA) is usually used in order to separate CO_2 from flue gases. The separated gas contains a high % of CO_2, Nitrogen, CO, H_2 and small quantities of methane and hydrogen sulphide. According to several authors, it is possible to inject flue gases directly into the system [37]. Flue gases or pure CO_2 are usually injected into photobioreactors or ponds in form of bubbles. Authors affirm that fixation of CO_2 will improve in the system if it is injected in the liquid phase and not spread directly into the microalgae culture.

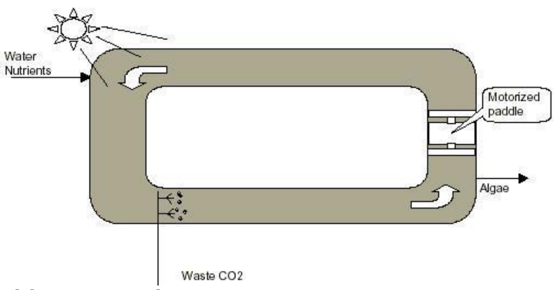
The method behind bio-fixation is Capturing the CO_2 and NO_x from power plant smoke stacks and feeding the CO_2 to a algae system where up to 50% of harmful emissions from the smoke stack will be devoured. At present there are two common methods for algae based carbon sequestration: open ponds and closed photo bioreactors. Open ponds are simple expanses of water recessed into the ground with some mechanism to deliver CO_2 and nutrients with paddle wheels to circulate the algae broth.

A large-scale photo bioreactor would be similar to a large display of solar panels, except instead of producing electricity, the solar energy would serve through photosynthesis by microalgae to convert CO_2 from fossil fuel combustion to stable carbon compounds for sequestration. Closed photobioreactors allow more precise control over growth conditions and resource management. Each system has benefits and drawbacks are shown in Table 4.

Table 4: Advantage and disadvantages of open and closed algae growth systems [25, 44].

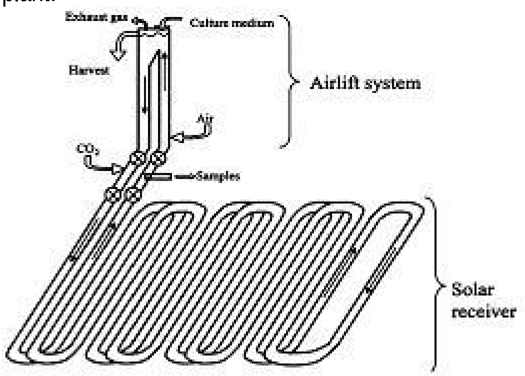
Parameter	Open pond	Closed photobioreactor
Construction	Simple	More complicated-varies by design
Cost	Cheaper to construction and operation cost is cheaper	More expensive construction, operation
Water losses	High	Low
Typical biomass concentration	Low, 0.1-0.2 g/l	High: 2-8 g/l
Temperature control	Difficult	Easily controlled
Species control	Difficult	Simple
Contamination	High risk	Low risk
Light utilization	Poor	Very high
CO_2 losses to atmosphere	High	Almost none
Typical Growth rate(g/m^2/day)	Low:10-25	Variable:1-500
Area requirement	Large	Small
Depth/diameter of water	0.3m	0.1m
Surface: volume ratio	~6	60-400

Figure 2a shows that open ponds are simple expanses of water recessed into the ground with some mechanism to deliver CO_2 and nutrients with paddle wheels to circulate the algae broth. Algae and nutrients are fed into the beginning of the raceway while paddlewheels help stir the broth and flow around the pond. Large scale open pond is preferred as there is plenty of sunlight to grow lots of cultures open ponds are the most common production facilities are shown in figure. In large open pond systems there are so many respiratory losses at night, contamination problems with grazers, dead animals and so on. Actual open ponds range in size of up to 1 ha and volumes ranging from 100 l to over 10 billions liters.



2(a) Open Pond System

Figure 2b shows that different types of photobioreactor. Closed photo bioreactors are enclosed systems usually in the form of tubes or plates that contain the algae broth. Photo bioreactors can enclose systems usually in the form of tubes or plates that contain the algae broth. Photo bioreactors can get increased productivity per area by increasing light, nutrients and control system etc. It also has better absorption input CO_2 reduce space need and increase production exponentially more than raceway pond. Contamination of other algae species is minimized or prevented, allowing for the cultivation of monoculture. Evaporation of water is prevented and permits higher cell concentration then raceway pond. Regardless of the type of photo bioreactors (tubular, thin film, bag, tank, etc.). There are limiting factor such as: fouling caused by the collecting on the surface will inhibit light absorption and reduce production. Pumping is a major concern and too much shear will damage more delicate algae species. Low flow rate will bleach algae from too much light and dissolved oxygen will build up; both of which greatly inhibit cell reproduction. Light transmission into growing media only reaches to certain depth before photosynthesis ceases. (Table 4) shows that a short comparison of open pond system and closed photobioreactors. Photobioreactors require 10 times capital investment than open pond systems. So the ideal system is not necessarily the most controllable or the most productive, but the perhaps the most scalable at the amount of CO_2 emitted from power plant-industrial sources, the amount of area used even with an optimal photo bioreactor will also be massive. Ultimately photo bioreactor are not effective for large scale CO_2 utilization when the goal is to utilize as much as CO_2 as possible from a thermal power plant.



2(b) Closed photo bioreactor

Figure 2: Algae Cultivation Methods. a. Open pond, b. photo-bioreactor [45]

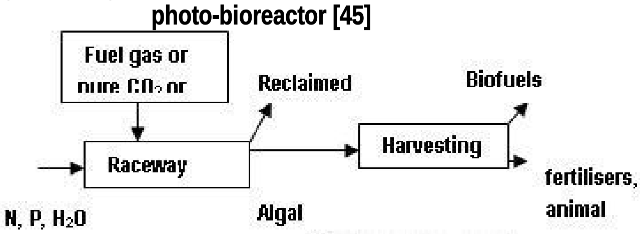


Figure 3: Photosynthetic Algae System for CO_2 Sequestration from power plant

A figure (2 and 3) shows that Algae cultivation methods and photosynthetic algae system for CO_2 Sequestration from power plant. An ideal methodology for photosynthetic sequestration of anthropogenic carbon dioxide has the following characteristics: (1) a high rate of CO_2 uptake and mineralization of CO_2, (2) resulting in permanently sequestered carbon, (3) produce revenue from sale of high value products, and (4) use of concentrated, anthropogenic CO_2 before it enters the atmosphere.

Micro-algae as a source of bio diesel in Indian scenario

Algae (of the aquatic species) require less land for growth than biodiesel feedstock from terrestrial plants because they are capable of producing more oil per hectare [17]. Table 3 shows that the potential gallons of oil per acre per year from different crops. Furthermore, the oil content in algae (per dry weight) can reach as high as 80% [28]. It is worth noting that the oil from microalgae can be extracted with yields up to 80–90% [19,26-27]. Laboratory experiments utilizing green algae, diatoms, and oleaginous species from other eukaryotic family show that the microalgae have oil content of 26, 23, and 27% dry weight, respectively, under optimal conditions and 46, 38, and 45% dry weight, respectively under stress conditions [38]. Depending on the species of microalgae, oil content can be further increased by limiting certain nutrients such as nitrogen, phosphorus or sulfur. For example, limiting sulfur content can increase lipid content in *Chlorella sp.* [24]. With the growing interest in growing algae for energy applications, different opinions have been expressed. The opinions range from concerns to skepticism about the energy efficiency, scaleup, and economic feasibility of micro-algal use for transportation fuels and other energy needs to positive assessment of its efficiency and future industrial applications in producing biodiesel meeting ASTM standards [23, 28]. Figure 4 shows that the how biomass generation is dramatically stimulated by the presence of additional low levels of CO_2. The algae absorb the extra CO_2 present, capturing it as biomass through increased growth. In relation to their potential for capture of CO_2 from fossil power plants.

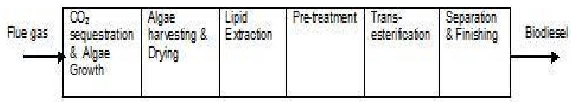


Figure 4: Key elements of the biodiesel production system [19].

The application of CO_2 directly to terrestrial crops via enclosures is likely to be prohibitively expensive though indirect stimulation of land species by flue gases is an alternative approach, which may be cost-effective espite being very much less direct and less efficient. For these reasons many believe that microalgae are the only economic route to biodiesel [23, 29], though there is robust discussion about it [15].The Royal Society of New Zealand Energy Panel's report makes a case for bioethanol deployment in New Zealand to replace petrol by 2020 [46]. This is based on the fact that the technologies for large-scale conversion of lingo-cellulosic biomass to bioethanol one would utilise the CO_2 emitted from fossil-fuelled power stations or other industrial sources of CO_2 such as cement processing [12-15]. There are comparatively few, but valuable, studies in the literature exploring algal capture of either simulated or actual flue gas CO_2.

Algae pond design and sizing: Based on the previous experimental work [47-48] for every 1 g of algae biomass produced, 1.8 g of CO_2 was utilized (this is on the assumption that algae biomass consists of ~50% carbon). it is possible to see (Figure 5) that a typical mass balance of an algae open pond system.

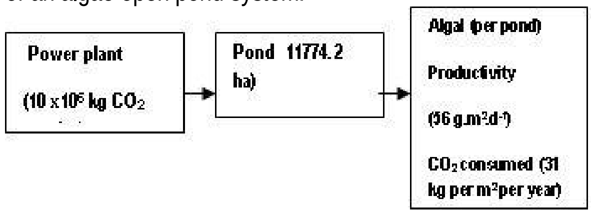


Figure 5: Mass balance of culture system

For a 500 MW coal-fired power plant which produces (considering minimum quantity emission) 9 x 10^6 kg CO_2/day. Therefore: For 180 kg biomass to be produced per day, 322 kg CO_2 can be utilized per day assuming the algal growth rate for *Spirulina* as 30 g/m^{2}day. Total amount of CO_2 used per day per pond (roughly 6000m^2 single algal pond): 322 kg/day (0.0036% of total CO_2). Total amount of CO_2 used per day for 12 ponds (600 m^2 x12 =72000 m^2): 3866.4 kg/day (0.043% of total CO_2). These values depend on the growth rate of the microalgae that are used in the pond system. The growth rate is dependent on the temperature and the season (high growth rate in the summer and low growth rate in the winter) [49]. It must be concluded that although the amount of CO_2 utilized is very low, a very valuable product is obtained in high yields which can produce high-value pharmaceuticals, fine chemicals, and commodities. According to the results of a model study based on the outdoor facility - which has been operated by NREL in Roswell, New Mexico for three years, 1000 m^2 pond consumes 54 kg CO_2 /day for micro algae growth with 90 % efficiency and 2650 kWh/year electric energy for farming operations including paddle wheel, pumping and centrifuge, and nearly 2.000 m^2 land is needed for the whole functions of the pond. CO_2 fixation rate of algae is roughly 20 times higher than that of a temperate climate forest (where the fixation rate is 5g-CO_2/m^2/day).According to very recent investigations, 90 % of CO_2 can be captured by micro algae [26].To evaluate the importance of such a process, lets assume that typical Indian thermal power plants of 500 MW are combined with algae pond systems. Based on the previous experimental work for every 1 g of algae biomass produced, 1.8 g of CO_2 was utilized (this is on the assumption that algae biomass consists of ~50% carbon), since carbon is 27.3% of the weight of CO_2, it requires approximately 1.8 times the weight of produced biomass in CO_2. Thus for every 1 ton of biomass produced, 1.8 tons of CO_2 are consumed.

A practical case of model calculation of 500 MW Indian Thermal Power plant:

CO_2 emission from the power plant= 10 x 10^6 kg CO_2/day

Availability factor= 85%.

Estimated annual average productivity= 56 gm/m^2-day (for assumed practical conditions)

Overall system productivity= 56 x 0.85 x 365 = 17.37 kg/ m^2/ year

Amount of CO_2 Consumed = 17.37 x 1.8 = 31 kg of CO_2 per square meter growing area per year.

Total hectares of land required= 11774.19 ha
Standard Algae farm size: 100 ha (247 acres)
No of algae Pond required: 118
The algae farms can be built in multiple units of the 100-hectare standard near thermal power plants where more CO_2 is available. Here, it will be interesting to compare the CO_2 assimilation capacities of micro algae pools and forests considering that 54200 km^2 forest is needed to assimilate 1,62,60,000 ton CO_2/year while only 10,000 km^2 land is necessary for capturing 12,0000000 ton CO_2/year via micro-algae.

Potential benefits of micro-algal carbon sequestration

Algae production requires a site with favourable climate, available water (which can be saline, brackish or wastewater), a ready and essentially free source of CO_2, nearly flat land, and with a clay soil or liner, as plastic liners would be too expensive. The critical issue, after technical feasibility, that is the actual ability to reliably cultivate algal strains that can produce biomass at reasonably high productivities, is the overall capital and operating cost of these production systems. Even assuming that high biomass productivities are possible and stable cultivation achievable, the major problem is likely the irreducible minimal costs of large-scale cultivation systems, including the needed infrastructure, processing, waste treatment, water supply and other support systems required.

India has 60 million ha of degraded land[c]. In 2007-08 India imported 121.67 million tons crude oil. In order to produce this much of fuel 365.01 million tons biomass required annually. As per assumed practical biomass productivity the land area required is 2.1 million hectares. The nation has the potential to meet the complete requirement of fuels by its own production. In addition to the many environmental benefits, biomass offers many economic and energy security benefits.

Assuming 20-25 % emission reduction by Micro algae CO_2 Sequestration in India, the potential in amount earned by selling carbon credits is around 6000 US$
Annual CO_2 emission in India = above 1500 million tons.
20 % reduction = 300 million tons.
Current trading rate of carbon credit = US $ 20 per ton. So, income from carbon credit sale by micro algal CO_2 Sequestration is 6000 US$ annually. CO_2 sequestration and algal energy production at power plants helps to reduce CO_2 emissions, reduce the need to import oil, earns carbon credits and generates employment. Initial investments may be high, however in the long run these investments would pay off economically and environmentally.

Conclusion

According to the evaluations already presented, we may conclude that algae may be a possible solution for reduction in CO_2 emissions. In spite of its limitations, biological carbon Sequestration technology is beneficial due to the following facts and figures: Only few km^2 land is sufficient to recover all CO_2 produced by India (1,500 million tonnes of CO_2). The technology can be implemented at any power plants in the country. CO_2 Sequestration using micro-algae will provide a global opportunity to reduce CO_2 emissions. Algal sequestration may act to slow impacts of global warming and will not contribute to additional CO_2 emissions. Theoretically, there is enough land to grow algae for carbon sequestration in India but land is unlikely to be available near the power plants. The algal based technology is very much competitive with more advanced and emerging renewable technologies such as wind, solar, geothermal, and other forms of biomass in reducing GHG emissions. Both carbon sequestration and bio-diesel production from micro algae are popular R&D subjects with some successful pilot scale applications. They are carbon neutral and producing and using them has little or no impact on the environment. By assessing the viability of algae from a true technical perspective, it is clearly apparent that micro-algae will be the only solution to mitigate global warming. Research on biological based sequestration is still in the beginning stages in India, and any large-scale use of algae for carbon sequestration and energy production would require massive investments in production facilities. However, developing and commercialization of these technologies requires a focused, comprehensive, and novel cutting-edge-research.

Acknowledgement

Authors are deeply acknowledges the financial support provided by MHRD, India.

Nomenclature

T: Temperature [K]

Abbreviation

IEA: International energy agency; Ha: hectares; H : hour; DOE: Department of Energy; Max: Maximum; Min.: Minimum; MEA: methy ethyl amine; l: lites
ASTM: American standard testing manual

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