ALGAE PHOTOBIOREACTOR - A POTENTIAL CARBON DIOXIDE CAPTURING TECHNOLOGY

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Abstract: The world is facing declining liquid fuel reserves at a time when energy demand is exploding. Continued use of petroleum sourced fuels is now widely recognized as unsustainable because of depleting supplies and the contribution of these fuels to the accumulation of carbon dioxide in the environment. In order to achieve a secure and stable energy supply that does not cause environmental damage, renewable energy sources must be explored and promising technologies should be developed. Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels. Unfortunately, biodiesel from oil crops, waste cooking oil and animal fat cannot realistically satisfy even a small fraction of the existing demand for transport fuels. Biodiesel derived from green algae biomass has the potential for high volume, cost effective production. It can be carbon neutral and produced intensively on relatively small areas of marginal land. The quality of the fuel product is comparable to petroleum diesel and can be incorporated with minimal change into the existing fuel infrastructure. This paper aims to analyze and promote integration approaches for sustainable microalgal biofuel production to meet the energy and environmental needs of the society.

Key-words: photobioreactor, biodiesel, carbon dioxide, mitigation technology

INTRODUCTION

The world is entering a period of declining non-renewable energy resources, popularly known as 'Peak Oil', while energy demand is increasing. Energy is essential for living and vital for development. India meets nearly 30% of its total energy requirements through imports. India's transportation fuel requirements are unique in the world. According to an estimate, automobiles alone contribute to 70% of the total diesel consumptions. Indian people consume almost six to seven times more diesel fuel than gasoline, whereas in the rest of the world, almost all the other countries use more gasoline than diesel fuel. Therefore, diesel is India's main liquid fuel; it burns roughly 64 MT (million tonnes), or 450 million barrels, of the stuff a year, as opposed to about 84 million barrels of gasoline. Thus, our search for alternatives in India has to have a different emphasis. This is where biodiesel is comparatively much more important for us than for others.

At present, the consumption of petroleum products in India has been increasing at an annual growth rate of 5%–6% and in the year 2005/06, it was about 112 MT/year. According to

MoPNG's (Ministry of Petroleum and Natural Gas) annual report (2006/07), India has imported about 99 MT of crude oil during the year 2005/06, causing a heavy burden of Rs 1,71,702 crore on foreign exchange as shown in table 1.

As India being an agricultural country, requirement for diesel is more and it is necessary to see the better alternative of diesel. Unfortunately, bio-diesel from oil crops, waste cooking oil, and animal fat cannot realistically satisfy even a small fraction of the existing demand for fuels. Although, Indian vegetable oil economy is world's fourth largest after USA, China, and Brazil. India needs about 200 billion gallons of bio-diesel per annum to replace all the transportation fuels used.

Table 1 Import and production of crude oil in India

Year	*Production* (MT)	*Import* (MT)	*Money paid for importing crude oil* (crore rupees)	*Total* (MT)
1970/71	6.8	11.7	-	18.7
1980/81	10.5	16.2	-	26.7
1990/91	33.0	20.7	-	53.7
2000/01	32.4	74.0	65,932	106.4
2001/02	32.0	78.7	60,397	110.7
2002/03	33.0	82	76,195	115.0
2003/04	33.3	90.4	83,528	123.7
2004/05	33.9	95.8	1,17,003	129.7
2005/06	32.1	99.4	1,71,702	131.5

MT - million tonne

To fulfill the above said bio-diesel demand we required 952 million acres (384 million hectare) of land for jatropha cultivation which is a big constraint. While only 13 million acres (5.4 million hectare) area of algae ponds required replacing all petroleum transportation fuels. So, for a country like us, which already depends on the imports of crude oil, it is important to see another viable a novel alternative for bio-diesel production. This scenario changes dramatically if microalgae are used to produce bio-diesel. Algal biomass contains three main components: carbohydrate, protein, and natural oils. Therefore, it is capable of producing a number of potential fuels, such as production of methane gas via biological or thermal gasification, production of ethanol via fermentation, production of bio-diesel, and the direct combustion of the algal biomass for production steam or electricity.

Recent research initiatives have proven that microalgae biomass appear to be the one of the promising source of renewable bio-diesel capable of meeting the global demand for transport fuels. Microalgae commonly double their biomass within 24 hours. Microalgae with high oil productivities are desired for producing bio-diesel. Using microalgae to produce biodiesel will not compromise production of food, fodder, and other products derived from crops.

As shown in Table 2, microalgae appear to be the only source of biodiesel that have the potential to completely displace fossil diesel. Unlike other oil crops, microalgae grow extremely rapidly and many are exceedingly rich in oil. Oil productivity, that is the mass of oil produced per unit volume of the microalgal broth per day, depends on the algal growth rate and the oil content of the biomass. Photobioreactors have been successfully used for producing large quantities of microalgal biomass.

Table 2 Comparison of some sources of biofuel

Gallon of oil per acre per year	
Algae	500-20000
Palm Oil	635
Coconut	287
Jatropha	207
Rapeseed/Canola	127
Peanut	113
Sunflower	102
Soyabeans	48
Hemp	38
Corn	18

PRODUCTION OF BIODIESEL

Biodiesel is a biofuel consisting of monoalkyl esters that are derived from organic oils, plant or animal, through the process of tranesterification (Demirbas, 2007). The biodiesel transesterification reaction is very simple: Adopting biodiesel has a number of advantages. Firstly, because the fuel is derived from biomass, it does not contribute to atmospheric CO_2 emissions. Second, biodiesel emissions are, on the whole, lower than petroleum diesel. Substituting biodiesel for petroleum diesel results in substantial reductions of soot, sulphur, unburned hydrocarbon, and polycyclic aromatic hydrocarbon emissions (Rakopoulos et al., 2006; Aresta et al., 2005; Demirbas, 2007). Third, the infrastructure needed for biodiesel already exists. Biodiesel can be used in existing diesel engines blended with petroleum diesel, or can be run unblended in engines with minor modifications (Crookes, 2006; Rakopoulos et al., 2006; Bowman et al. 2006). Because biodiesel has twice the viscosity of petroleum diesel, its lubricatio n properties can actually improve engine life (Bowman et al. 2006). Fourth, biodiesel has low toxicity and is biodegradable (Aresta et al., 2005; Demirbas, 2007). Fifth, like petroleum diesel, biodiesel has a more complete combustion than gasoline, giving a cleaner burn (Bowman et al., 2006).

Biodiesel is not without problems. First, it does produce increased NOx emissions, relative to petroleum diesel, owing to the higher compression ratios typically used in biodiesel engines (Crookes, 2006; Pradeep and Sharma, 2007). Second, using biodiesel does reduce the power output of a diesel engine compared to using petroleum diesel; although this is only around 2%

overall (Schneider, 2006). Third, the production of biodiesel results in glycerine by-products and wash wastewater. Fourth, the price of biodiesel is typically higher than petroleum diesel. Fifth, and most importantly, the biomass feed stocks for making biodiesel are diverted from other important uses, typically food production.

Biodiesel can be made from virtually any source of organic oil. Typical sources include restaurant waste oil, animal fats, and seed oils. The supply of waste oil is very limited; however, it is a popular source for small scale, independent producers. Large commercial producers often use seed oils, such as soybean, rapeseed, palm, and corn oils. Unfortunately, biodiesel derived from seed oil diverts from the food supply and the increasing competition for seed causes the oil, and resulting biodiesel, to become increasingly expensive. It has been estimated that 0.53 billion m^3 of biodiesel would be needed to replace current US transportation consumption of all petroleum fuels (Christi, 2007). Neither waste oil nor seed oil can come close to meeting the requirement for that much fuel; therefore, if biodiesel is to become a true replacement for petroleum, a more productive source of oil is needed (Scott and Bryner, 2006; Christi, 2007).

APPLICATION OF ALGAE FOR GREENHOUSE GAS MITIGATION

CO_2 is recognized as the atmospheric pollutants that contribute to the 'greenhouse effect', a term coined by the French mathematician Fourier in the mid-1800s to describe the trapping of heat in the earth's atmosphere by gases capable of absorbing radiation. The burning of fossil fuels is the major source (about 95%) of the current build up of atmospheric CO_2.

Bio-fixation of CO_2 using microalgae has emerged as a potential option. On a worldwide basis, coal is the largest fossil energy resource available. In India, at current rates of consumption, coal reserves could last for over 200 years. Inevitably, the demand for electricity will have to be met by coal. Coal will remain the mainstay of world baseline electricity generation, accounting for half of electricity generation by the year 2015. Flue gases from power plant are responsible for more than 7% of the total world CO_2 emissions. India has an installed base of about 1,24,287 MW of electricity as of the year 2006, which includes about 66% thermal energy (85% of which is coal based). In India, electricity demand, growing at 9% annually during the present decade and it is estimated that CO_2 emission may be expected to increase at an annual rate of 3% between 2005 and 2030. The long-term demand for coal brings with it a demand for technologies that can mitigate the environmental problems associated with coal. Coal is the most carbon-intensive of the fossil fuels. In other words, for every unit of energy liberated by combustion, coal emits more CO_2 than either petroleum or natural gas. A typical coal-fired power plant emits flue gas from their stacks containing up to 15% CO_2. As pressure to reduce carbon emissions grows, this will become an increasingly acute problem for the world (Akshay Urja, 2008).

Carbon Dioxide is essential for successful growth of algae. Because of this, cultivating algae for oil could also lead to a reduction of CO_2 emissions. Coupling a coal-fired power plant with an algae farm could potentially use the CO_2 emitted from the power plant to produce fuel (Sheehan, 1998). This concept could also be applied to other high CO_2 emission sources.

The simple, direct method of greenhouse gas mitigation is the removal of CO_2 from stack gases, followed by long-term sequestration of CO_2 by tubular photobioreactor. It could be located adjacent to power plants. The bubbling of flue gas from a power plant into these reactors provides a system for recycling of waste CO_2 from the burning of fossil fuels. According to one estimate, 1,000 tonnes of CO_2 can be sequestered by algae/acre / year. The concept of coupling a coal-fired power plant with a photobioreactor provides an elegant approach to GHG mitigation of the CO_2 from coal combustion into a useable liquid fuel.

Microalgal-based carbon sequestration technologies can, in principle, not only cover the cost of carbon capture and sequestration but also produce environment-friendly biodiesel. In the present scenario, algal biomass is a key link between energy, local environment and climate change and further research are necessary to unlock full potential of algae.

The algae that are used in biodiesel production are usually aquatic unicellular green algae. This type of algae is a photosynthetic eukaryote characterized by high growth rates and high population densities. Under good conditions, green algae can double its biomass in less than 24 hours (Christi, 2007; Schneider, 2006). As shown in table -1, green algae can have huge lipid contents, frequently over 50% (Christi, 2007; Schneider, 2006).

Oil content is the important criterion for selecting the species for cultivation along with growth rate, density, and survivorship must also be considered. (Data from Christi, 2007)

<u>Table 3 Comparison of the oil content found in green algae</u>

Species	**Oil Content (% based on dry weight)**
Chlorella sp.	28-32
Nitzschia sp.	45-47
Nannochiropsis sp.	31-68
Schizochytrium sp.	50-77

Algae have a number of unique benefits. As an aquatic species, they do not require arable land for cultivation. This means that algae cultivation does not need to compete with agricultural commodities for growing space. In fact, algae cultivation facilities can be built on marginal land that has few other uses. The water used in algae cultivation can be fresh water or saline, and salt concentrations up to twice that of seawater can be used effectively (Brown and Zeiler, 1993; Aresta et al., 2005). This means that algae need not compete with other users for fresh water. Algae also have a greater capacity to absorb CO_2 than land plants, and are also not prone to photosynthetic inhibition under conditions of intense sunlight (Brown and Zeiler, 1993). After oil extraction from algae, the remaining biomass fraction can be used as a high protein feed for livestock (Schneider, 2006; Haag, 2007). This gives further value to the process and reduces waste.

Algae cultivation is typically performed in two ways; open ponds and bioreactors. Open race-way based ponds are the preferred method of large scale algae cultivation, and they have been used since the 1950's to produce food supplements and pharmaceuticals (Christi, 2007). A paddlewheel circulates the material down a raceway while providing aeration, mixing, and preventing the material from settling on the bottom. This is a relatively simple system that uses the sun as the primary energy source. Unfortunately, race-way system suffers from relatively low algae densities, environmental variability, water evaporation, and a high land foot print (Christi, 2007; Haag, 2007). Because the ponds are open to the environment, maintaining specific species of algae, to the exclusion of others, can be difficult (Haag, 2007).

Bioreactors as shown in figure 1 are the preferred method for scientific researchers, and recently for some newer, innovative production designs**.** These systems are more expensive to build and operate; however, they allow for a very controlled environment .This means that gas levels, temperature, pH, mixing, media concentration, and light can be optimized for maximum production (Christi, 2007). Unlike open ponds, bioreactors can ensure a single alga species is grown without interference or competition.

Biodiesel production from biomass sources has a number of problems. First, most biomass sources, such as waste oil, animal fat, and vegetable oil have a limited supply (Ma and Hanna, 1999). Second, many of these sources have competitive uses, such as food or cosmetic production. Third, the resources that were used to create the biomass have competition with other uses, and this includes arable land. Third, because of the limited supply and competition, many sources of biomass have become increasing expensive (Haag, 2006). Algae cultivation has the potential to address all of these issues. First, algae biomass can be produced at extremely high volumes and this biomass can yield a much higher percentage of oil than other sources. Second algae oil has limited market competition. Third, algae can be cultivated on marginal land, fresh water, or sea water. Fourth, innovations to algae production allow it to become more productive while consuming resources that would otherwise be considered waste.

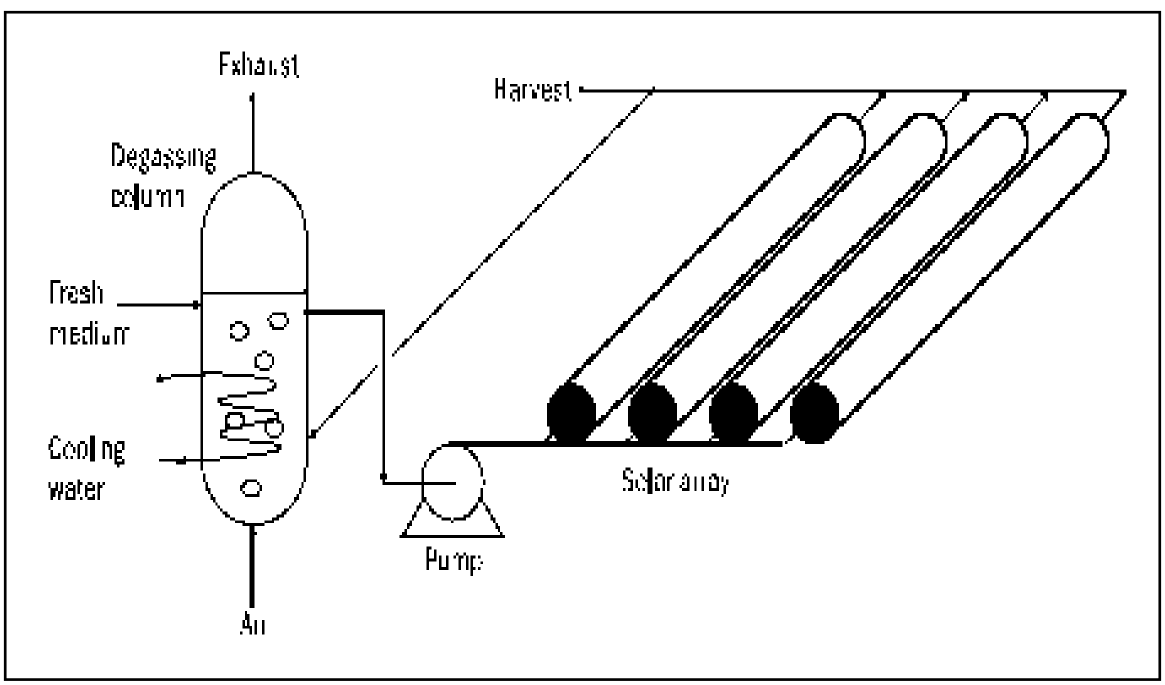

Fig.1 Conventional Photobioreactor

NOVEL APPROACHES TO ALGAE CULTIVATION

Algae cultivation has four basic, and equally important, requirements: carbon, water, light, and space. By maximizing the quality and quantity of these requirements, it is possible to maximize the quantity of oil-rich biomass and the return on investment.

Carbon, from carbon dioxide (CO_2), is the first requirement. In order to maximize algal growth, CO_2 needs to be provided at very high levels, much higher than can be attained under natural conditions. Rather than becoming an expense, this need for CO_2 fertilization creates a unique opportunity to offset costs by consuming air pollution. The flue gases from industrial processes, and in particular from power plants, are rich in CO_2 that would normally be released directly into the atmosphere and thereby contribute to global warming. By diverting the CO2 fraction of the flue gas through an alga cultivation facility, the CO_2 can be diverted back into the energy stream and the rate of algal production can be greatly increased (Pulz, 2007).

Water, containing the essential salts and minerals for growth, is the second requirement. Fresh water is a valuable resource as are the salts and minerals needed; however, algae cultivation can be coupled to another type of environmental remediation that will enhance productivity while mitigating pollution. High nutrient wastewater from domestic or industrial sources, which may already contain nitrogen and phosphate salts, can be added to the algal growth media directly (Schneider, 2006). This allows for algae production to be improved cheaply, while simultaneously treating wastewater. Alternately, salt water can be used, either from saline aquifer or sea water. This means that competition for water will be low.

Abundant light, which is necessary for photosynthesis, is the third requirement. This is often accomplished by situating the facility in a geographic location with abundant, uninterrupted sunshine. (Brown and Zeiler, 1993). This is a favored approach when cultivating in open ponds. When working with bioreactors, sunlight quantity and quality can be further enhanced through the use of solar collectors, solar concentrators, and fibre optics in a system called photo-bioreactors (Scott and Bryner, 2006; Christi, 2007). These technologies allow optimal sunlight to reach the algal cells either by allowing them to float in arrays of thin, horizontal tubes or by directing light, through a fiber optic matrix, through the bioreactor chamber itself.

Space is the fourth requirement. Other biomass sources require terrestrial cultivation on valuable arable land. This causes a diversion of agricultural produce from the food supply to the energy supply and increases cost of production. Algae cultivation is unique in that it does not require arable land; algae can be cultivated in ponds, in fresh or salt water bodies, or in bioreactors. This versatility means that an algae production facility can theoretically be located any where there is cheap, available land. Bioreactor facilities have a comparatively low footprint (Christi, 2007). Through a combination of these light, water, and carbon fertilization techniques, the production of high density algae is starting to be achieved.

CONCLUSION

Biodiesel has great potential; however, the high cost and limited supply of organic oils prevent it from becoming a serious competitor for petroleum fuels. As petroleum fuel costs rise and supplies dwindle, alternative fuels will become more attractive to both investors and consumers. For biodiesel to become the alternative fuel of choice, it requires an enormous quantity of cheap biomass. Using new and innovative techniques for cultivation, algae may allow biodiesel production to achieve the price and scale of production needed to compete with, or even replace, petroleum. Economics of producing microalgal biodiesel need to improve substantially to make it competitive with petrodiesel, but the level of improvement necessary appears to be attainable. Producing low-cost microalgal biodiesel requires primarily improvements to algal biology through genetic and metabolic engineering. Use of the biorefinery concept and advances in photobioreactor engineering will further lower the cost of production.

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