Microalgae for Carbon Sequestration vis-à-vis Bio-fuels Production

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ABSTRACT

Emission of green house gases is a critical environmental concern confronting the world community today. Unrestraint anthropogenic activities have proved to be the major cause, affecting the earth's atmosphere due to the emission of excess carbon dioxide (CO_2). Although techniques are well acquainted and applied for CO_2 sequestrations but the use of microalgae for sequestration of CO_2 is considered to be an energy efficient process. Over the years, the most productive system of recognition is growing of microalgae for generation of biomass and capture of carbon. An important aspect is that algae being autotrophic microorganisms are capable of converting CO_2 into carbohydrates and lipids in the presence of light through the phenomenon called photosynthesis. In open ponds, the CO_2– or bicarbonate- capturing efficiencies have been reported to be as high as 90%. Another interesting feature of algae is that it can be widely used to seize CO_2 from different industries like automobiles, oil, power plants, cement, and steel. Further the biomass can be utilised for production of bio-fuels, medicines, fertilizers, and both human and animal feed. Apart from economic and eco-friendly benefits, it is believed that the large scale algal cultivation would open up numerous doors at different levels in the society.

Keywords: Microalgae; CO_2 sequestration; Bio-fuels; Pilot plant operation

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INTRODUCTION

According to the latest analysis there is a continuous increase of the fossil fuels consumption, despite of steady primary energy consumption. The combustion of fossil fuels continues to emit different greenhouse gases (1). Although many empowered bodies of different countries have initiated various agenda to reduce the greenhouse gases, an alternative approach is always preferable to the existing method (2). Carbon dioxide (CO_2) gas is one of the greenhouse gases having the major share in the atmosphere. The well-known natural application of CO_2 is the autotrophic primary production during photosynthesis. In the primary production process, CO_2 is converted to biomass of organic carbon such as carbohydrates, lipids, proteins, amino acids, celluloses and other complex organic compounds. Algae are the photoautotrophic organisms. Their cellular structures enable high rate of biomass production capacity compared to the higher plants. They provide a sustainable natural tool in terms of primary production to reduce CO_2 levels in the atmosphere. The high biomass production by algae reciprocates the CO_2 sequestration in the atmosphere. The algae biomass rich of lipids can be used as a sustainable feed for the production of different bio-fuels. Worldwide, there is a strong view about accepting the fact that bio-fuels production from algae has ability to replace the entire global fossil fuel requirement. Algae have various potentials for bio-fuel products such as biodiesel, ethanol, methane, jet fuel, bio-crude and many more. Notably, huge interest has been seen for bio-fuels in the present times that not only has caught the attention of the investors, but also, at the same times have led down a basis to carry out new potential in research. Several companies and universities have come forward in this direction. It is now the peak time to increase our development of alternative fuels, taking advantage of one of the vast growing renewable resources, i.e. algae. According to a new survey, about 70 companies and 200 universities are involved in serious exploratory efforts into algal bio-fuels (3). Bio-fuels from the natural resources have the potential to provide energy with minimized emission of greenhouse gases or other air pollutants. A dual objective, i.e. CO_2 sequestration and bio-fuels production can be achieved in a single frame of work which is massive algal biomass generation.

It has been recently reported (4) a complete sequence of one of the ecologically important algae called haptophytes. She also added that this could be transformed

into a new tool for aquaculture, bio-fuel production and nutrition. Scientists from the Rice University have found an oil-rich algal species capable of nitrogen (N) and phosphorus (P) removal from wastewater (5). This adds one more objective to remove N and P from the eutrophic water by the help of algae. So algae biomass production enables another tool for restoring the aquatic ecosystem. For the generation of effective biomass, they have developed a novel, innovative and sustainable technology called hanged adjustable v-shaped pond (HAVP). Further, the algae can be used as an excellent feedstock for all kind of bio-fuels production and expected to produce 50 dollar per barrel as per the current rate of crude fossil oil. The Bio-energy Technologies Office's (BETO's) focuses on a long-term technological strategy to increase the effective production which would reduce the cost of algal bio-fuels (6). The focuses of BETO include production, logistics, and algal integrated bio-refineries. The developments of applications of algal bio-fuels have been extended to produce bio-jet fuels and bio-kerosene (7).

ALGAE

Algal species grow in the both fresh and marine water (8). They are the most promising species for sustainable sources of biomass and bio-fuels. They have evolved over billions of years and can produce energy in the form of oil. With potentially millions of species, algal diversity gives researchers many options for identifying production strains and provides sources for genetic information that can be used to improve the strains for different application. The microalgae are the fine algae species proven to be more efficient and profitable in terms of biomass and bio-fuels. Microalgae are microscopic unicellular organisms capable to convert solar energy to chemical energy via photosynthesis. They contain numerous bioactive compounds that can be harness for commercial use as an alternative. Microalgae can be use to produce a wide range of metabolites such as proteins, lipids, carbohydrates, carotenoids or vitamins for health, food and feed additives, cosmetics and for energy production. They efficiently use CO_2, and are responsible for more than 40% of the global carbon fixation, with the majority of this productivity coming from marine microalgae (9,10). Microalgae are potential feedstock for the production of bio-fuels but are very difficult for cultivating and harvesting. They contents high oil in total biomass. For example the *Botryococcus species* has high oil content (11,12). Selection of right kind of strains especially microalgae and its parameters are

responsible for getting a better yield. While do so, the cost exceeds than the estimated cost and new challenges start taking new shapes. While lots of on-going research, collaborations and ventures are going on international platforms, it is the peak time for the countries to start using the potentialities of algal strains for the production of biodiesel in a full pledge scale. Minimizing the Don't, people, scientists and activists should focus on the Do's of using "Microalgae for a Green, Clean and Safe Environment". Nonetheless, it is equally important and necessary to aware the public about the advanced bio-fuel which not only helps in cutting down the greenhouse gas emissions but also creating numerous jobs and opportunities. Moreover, it can generate millions revenues and reduces our dependency on foreign oil, the single largest components of our massive national trade discrepancy (13). Specific inputs has to be made by the government for upbringing certain rules and regulations for using an alternative renewal resources. For successfully transferring the knowledge into reality, proper collaborations should be made with the industries to carry it in a large scale. The advantages of microalgae are (i) fast growing, (ii) high bio-fuel yield, (iii) CO_2 consumer, (iv) not competitive to other aquacultures, (v) fuel, feed and food, (vi) N and P remover from wastewaters, and (vii) job creator engine (14).

BIO-FUELS

Bio-ethanol

The biomass of microalgae utilised as the feedstock for bio-ethanol production has been a promising technology. The large carbohydrates content enables an easy production of bio-ethanol. The high content of complex carbohydrates entrapped in the cell wall of the microalgae makes it essential to incorporate a pre-treatment stage to release and convert these complex carbohydrates into simple sugars prior to the fermentation process. The key features of the process involve less intake of energy and simpler compared to the biodiesel production. Besides, the undesired CO_2 released as a by-product can be recycled and cultivate additional microalgae, resulting in the reduction of greenhouse gas emissions. However, the commercial production of bio-ethanol from microalgae is still being investigated (15,16).

Bio-hydrogen

Hydrogen gas has more energy value. Its utilisation would reduce the increasing pollution caused by the fossil fuels. It holds much promise as a future fuel for the substitution of traditional fuels in the combustion engines (17). Bio-hydrogen produced from algae is not only a clean source of energy but can also be a major substitute for the continuous depleting gasoline. Third generation bio-hydrogen from algae have provided solutions to drawbacks of first and second-generation bio-fuels up to an extent. However, the major problem is associated with its production which processed through a fossil fuel route thereby causing environment pollution.

Bio-methane

Methane is an important fuel for generation of electrical power. It produces less carbon dioxide during combustion compared to other hydrocarbon fuels (18). So production of methane is a fruitful utilisation of algae biomass. The production of methane from algae biomass involves different stages such as (i) pre-treatment of the algae, capable of producing a liquid suspension of fine solid particles, said treatment being moreover capable of partially depolymerising the solid algae matter, (ii) running the suspension through a fluidized bed containing granules on which enzymes are immobilized which are capable of transforming the particles into sugar, said liquid containing acidify bacteria capable of transforming said sugars into volatile fatty acids, (iii) decantation of the suspension, so as to remove any solid particles that may remain, and to extract a decanted liquid, and (iv) running the decanted liquid across a fixed bed containing methanogenic bacteria set onto a support to cause the liquid to release a gas mixture containing mainly methane.

Bio-oil

Liquid bio-oil is efficiently produced from different biomass in the pyrolysis process. The pyrolysed gases are cooled and further condensed into a bio-oil. Also there are some non-condensable gases contain hydrogen, carbon monoxide having modest heating value. The solid residue called biochar can be utilised for bioremediation applications. The bio-oil production solves various issues related to pre- and post-utilisation of biomass. The pyrolysis conducted at high temperatures in the absence of oxygen does not produce any biomass residue which is a headache for the bio-fuel industries; however, it is an energy intensive process results a less net energy value of the process.

Bio-diesel

The biodiesel produced from microalgae biomass has highest net energy value as the production process involves a much less energy-intensive method than that for other bio-fuels. This advantage makes biodiesel production from algal biomass more favourable. It is a promising renewable energy that does not require engine modification, and reduces CO and CO_2 generation by by 50 and 78%, respectively (19). Being a possible future fuel source, the viscosity of the bio-diesel is a major problem. The high viscous bio-diesel is difficult to combust and certainly leaves deposits on the fuel injector of the diesel engines. Thus, there is a requirement of blending biodiesel with conventional diesel prior to applications. Several techniques have been developed to overcome this problem. Among the techniques, transesterification offers the most promising (20). In spite of its suitability as a replacement to conventional diesel, it has other benefits in the environment. First of all, its application is better of human health due to its reduced emission. Independent biodiesel running tests have demonstrated a significant reduction of emissions. In 2000, biodiesel successfully clears the tests for tier-I and tier-II health effects of clean air regulations by USEPA. Secondly, it is for the environmental benefits such as nontoxic and biodegradable, and can result in a substantial reduction of carbon monoxide, unburned hydrocarbons and particulate matters. Photoautotrophic algae remove carbon from the atmosphere. Since biodiesel can be made from algae biomass, burning biodiesel does not add net carbon value to the atmosphere. In third, it is for the economy benefits and help to reduce the dependence on foreign oil (21).

GLOBAL ALGAL BIOFUELS RESEARCH AND DEVELOPMENT

The USEPA has confirmed that the use of biodiesel in the combustion engine reduces emission of greenhouse gas by 57 to 86% compared to traditional diesel. Biodiesel has more energy balance compare to that of fossil energy. The USEPA has also reported the biodiesel dramatically reduces toxic air pollutants compared to the traditional diesel (13). Worldwide, many industries have developed technology for production of low cost bio-fuels (14). In October 2009, the Terrapin Bright Green LLC and the Natural Resources Defence Council described the production of alga bio-fuels as cultivating clean energy. In 2011, a project called ‘ECOALGA’ funded by

the Ministry of Science and Innovation, under the National Plan for Scientific Research, Development and Technological Innovation (2008-2011) started in Cartagena, evaluates different aspects of algal bio-fuels, such as, the strains of microalgae and cyanobacteria, harvesting technique and optimum CO_2 concentrations. In addition, they have started evaluation of biomass residue post bio-fuel production for possible animal feed. The Enalg SpA. industry in Italy holds the rights for the production of bio-fuel. The Enalg SpA. is the first industrial pilot plant that produces blue petroleum from algae granted by Spanish BFS Bio-fuel System SL. In 2015, Origin Clear Inc. Collaborated with Idaho National Laboratory of the U.S. Department of Energy to develop the electro water separation process improving algal bio-fuel yield. The Spanish biotech company, Bio-Serentia, has followed microalgae strain modification for high biomass production rate in order to improve the bio-fuels production capacity. In October 2012, an M.O.U. was signed between Genesis Bio-fuel Inc. and Abundant Energy Solutions to develop different algal bio-fuels refineries. In the mean time, the AlgiCoat of Dutch supported by SenterNovem EOS programme developed an integral marine biorefinery for biodiesel production. In June 2010, EADS at the Berlin Air Show used 100% algal bio-fuel for the first time. The Bio Fuel Systems of Spain has developed a pilot plant for bio-petroleum production. In January 2010, US Department of Energy announced a $44 million investment in algal bio-fuels development. The consignment was undertaken by the National Alliance for Advanced Bio-fuels and Bio-products (NAABB) for demonstration of the objectives of the project (7).

INDIAN ALGAL BIOFUELS RESEARCH AND DEVELOPMENT

The Government of India (Ministry of New and Renewable Energy), in its National Policy on Bio-Fuels, has emphasized the need to develop bio-fuels in view of India's energy security, reduced dependence on imports and containment of carbon emissions and air pollution. It has laid down an indicative target of achieving 20% blending of bio-diesel in diesel and 20% blending of ethanol in petrol by the year 2017. The demand and consumption of diesel/petroleum is continuously rising at an alarming rate, therefore it is better to blend the traditional fuels with bio-fuels. This could certainly help in lowering the country's oil statement and can be the best alternative in terms of tax revenues. In this context, several efforts have made for setting bio-diesel pilot plants in Vizag, Kakinada, Hyderabad, Mumbai, Kolkata and

other places with some of the major leading companies such as Emami, Reliance, Indian Oil, Southern Online, Universal Bio-fuels, Royal Energy, Ruchi Soya, Garware and Nova.

Several institutions, such as IOC, ICAR, IIT-Delhi, have demonstrated the trial of biodiesel on automobiles. The demonstration confirmed that biodiesel could reduce wear and tear of engines, and oil pollution significantly (22). Field trials of biodiesel were done by Tata Motors Ltd, Mahindra & Mahindra Ltd, Wartsila India Ltd, etc. In Coimbatore an auto rickshaw was successfully ran on pure biodiesel prepared from Jatropha oil. In May 2013, Ministry of Railways of Government of India came up with a report called “The Indian Railways Organisation for alternate fuels, Bio-diesel a Concept paper on Alternate Fuels for Indian Railways”. In the report, efforts towards consumptions of biodiesel have shown in details. A train has successfully run on 5-10 % blends of biodiesel in association with IOCL. HPCL carried out field trials of running vehicles in association with BEST, Mumbai. Daimler Chrysler, India completed first phase of the field trials on two C-Class Mercedes-Benz cars powered by pure biodiesel under hot and humid conditions. CSIR plans to test vehicles on biodiesel developed from Jatropha in association with Tata Motors and IOCL. NOVOD Board has initiated test run by blending 10 % of biodiesel in collaboration with IIT, Delhi in Tata Sumo and Swaraj Mazda vehicles. Haryana State Transport had run buses using biodiesel successfully.

National Aluminum Company Limited (NALCO)

The National Aluminum Company Limited (NALCO) of India set up a carbon sequestration pilot plant by microalgae at their captive thermal power plant in an attempt to reduce the carbon foot prints in the coal based systems. The technology was obtained from the Indocan Technology Solutions. For the carbon sequestration purpose, the flue gas emitting from the furnaces were processed and supplied to the microalgae ponds with native strain selected and adopted by Indocan technology Solutions. The bioreactor system capable of open and closed system operation were supplied with processed flue gas as the carbon dioxide sources and sustain the mass cultivation cycles. The commissioning and operation cycles of the plant was carried out during different seasons of 2012 -14.

CSIR-Institute of Minerals and Materials Technology (CSIR- IMMT), Bhubaneswar

The CSIR-IMMT initiated a project for biodiesel production from microalgae. The project was funded by Department of Biotechnology (DBT) of Government of India. The experimental were collection, characterization and screening of potential microalgae from coastal belt states like West Bengal & Odisha coast and pilot scale demonstration of algal oil production.

CSIR-National Institute For Interdisciplinary Science & Technology (CSIR-NIIST), Thiruvananthapuram

The CSIR-NIIST developed an auto-flocculating algal cultivation technology with CO_2 fertilization. This process makes easy settling algal biomass and separation. Also they examined nutrient status of brackish water for algal cultivation and determination of biomass productivity in scalable reactor.

CSIR-*Central Salt Marine Chemicals Research Institute(CSIR-CSMCRI), Bhavnagar*

CSIR-SCMCRI is involved in mass cultivation of *Chlorella sps* from 11 ponds with a volume of 1,00,000 L through auto-settling. For the first time in India, The institute has able to produce ethanol using a seaweed polysaccharide.

CSIR-Central Food Technological Research Institute (CSIR-CFTRI), Mysore

A team CSIR-CFTRI have conducted extensive work on isolation and characterization of hydrocarbon producing micro alga *Botryococcus braunii* from Indian waters.

Phycore

A joint technology implementation programme between CORE BIOTECH of Colombia and Phycospectrum has been initiated with the successful installation of a 20000 L integrated tanks system at Pacific Rubiales oil drilling site near Bogota to treat petrochemical wastewater by employing microalgae.

Abellon Clean Energy, Ahmedabad

The company has designed and developed a dual operating pilot scale bioreactor system for comparative simulation studies on algal cultivation.

PERC-Kolkata algal farm

PERC has developed an open raceway cultivation pond to optimize the nutrient inputs and stabilize productivity contamination controlled harvesting accomplished by a combination of autoflocculation and chemical flocculation.

University of Madras, Chennai

Recently, Rengasamy and his team from University of Madras have successfully cultivated *Botryococcus braunii* in open raceway pond without any contamination - supported by ABAN.

CONCLUSIONS

Algae fuels is one of the most researched topics today at universities and colleges across the world. Microalgae are meant to be an important raw material for amino acids, vitamins and productions of other pharmaceuticals. It has several vital benefits, which has brought it into a category of profitable process. Being safe, clean and renewal source, it is right to quote ‘an advance zero waste fuel’. Additional value products from the microalgae, such as chemicals, can increase the cost competitiveness. The ability to remediate wastewater with their use for carbon sequestration or energy production offers an economically feasible process for the development of multiple products. Nevertheless, with diverse applications, microalgae could be considered as one of the foremost players in the clean energy market and also holds future promise for the developing countries in creating more jobs and opportunities.

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