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Importance of algae as a potential source of biofuel

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Abstract

Algae have a great potential source of biofuels and also have unique importance to reduce gaseous emissions, greenhouse gases, climatic changes, global warming receding of glaciers, rising sea levels and loss of biodiversity. The microalgae, like *Scenedesmus obliquus, Neochloris oleabundans, Nannochloropsis* sp., *Chlorella emersonii*, and *Dunaliella tertiolecta* have high oil content. Among the known algae, *Scenedesmus obliquus* is one of the most potential sources for biodiesel as it has adequate fatty acid (linolenic acid) and other polyunsaturated fatty acids. Bio-ethanol is already in the market of United States of America and Europe as an additive in gasoline. Bio-hydrogen is the cleanest biofuel and extensive efforts are going on to bring it to market at economical price. This review highlights recent development and progress in the field of algae as a potential source of biofuel.

Key words: Algae, biofuel, bio-diesel, bio-ethanol and bio-hydrogen.

Introduction

The human beings across the world have expectation of a high standard of living which demanded high energy and fuel consumptions. The fossils fuel is being globally used, expensive and non renewable. The available literature confirms that world consumes about 15 terawatts of energy per year and renewable energy sources derived only 7.8% of total consumption. The total sunlight energy hitting Earth surface is approximately 85,000 terawatts per year providing a clue that utilization of only a fraction of solar energy by any mean would solve the energy crises (1). The excessive use of fossils fuel has already lead to environmental pollution, increase in greenhouse gas emissions, global warming, receding of glaciers, rising sea levels and loss of biodiversity (2). These factors had suggested a need for alternative, sustainable, cost-effective, efficient and cleaner-burning energy sources to fulfil the require demand. Biofuel is an excellent alternative to traditional fossils fuel, as they can be produced in bulk from abundant supplies of renewable biomass. The scientists across the world are putting their efforts to develop alternative sustainable energy sources. The two most common biofuels are ethanol which is being produced from corn or sugarcane and biodiesel which is being produced from a variety of oil including soybeans and oil palm (3, 4, 5). Now, ethanol is being used as an additive in Europe and United States of America. The biodiesel from algae has been an area of considerable interest in last few years (6, 7).

Algae are one of the alternative platforms for renewable energy production which does not have harmful effect on agriculture. Algae utilize solar energy for photosynthesis, rapid growth and biomass accumulation (as proteins, lipids, carbohydrates, hydrocarbons, small molecules and pigments). Microalgae also help in cleaning the environment by producing the oxygen, by utilizing the CO_2 from atmosphere (reducing the greenhouse gases), reducing pollutants (nitrate and phosphate) and toxic chemicals from water bodies (8) (Fig. 1). Some species of microalgae like *Neochloris oleabundans* (fresh water microalga) and *Nannochloropsis sp*. (marine microalga) have high oil content 29.0 % and 28.7% of total dry weight, respectively. These microalgae had already been reported to accumulate upto 50% oil content of total dry weight when grown under nitrogen shortage (9). The oil content (triacylglycerols or long chain hydrocarbons) can be converted into biodiesel by trans- esterification (10). It has been reported that some macroalgal species store low lignin containing sugars which can be fermented into bioethanol/ butanol (11). This review highlights up to date efforts and progress for algae as a potential sources of biofuel.

Importance of algae for biodiesel production

Biodiesel is a mixture of fatty acid alkyl esters which is being produced by a mono-alcoholic trans-esterification of triglycerides derived from oleaginous

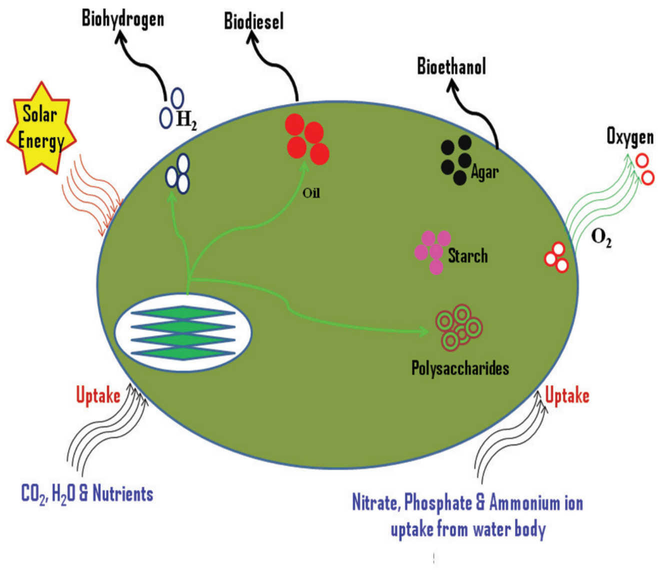

Figure 1. Potential role of algae.

crops, such as rapeseed, sunflower, soybean and palm. The transesterification reactions are carried out between triglycerides and a short chain alcohol (commonly methanol or ethanol) with catalysis of enzymes (12). The major challenge to the researchers is to reduce the price of biodiesel which is over \$ 0.5 L^{-1} as compared to \$ 0.35 L^{-1} of fossils diesel fuel (13). However, microalgae and cyanobacteria are potential alternative as being most efficient biological producer of oil on the planet. Algae are well documented to grow in marine water as well as in fresh water and can become one of the most important renewable fuel crops on Earth (12). The productions of biodiesel from algae are preferred as they have high photosynthetic efficiency, excellent biomass productivity, high carbon dioxide fixation and oxygen evolution in comparison to higher plants. The microalgae can be harvested on daily basis, had high oil content than higher plants and have no competition for arable land as can be grown easily in any water bodies. The selection of high-oil content algal strains, effective methods of biomass harvesting, oil extraction and conversion of oil to biodiesel are essential steps for biodiesel production from algae (14, 15, 16). There are reports that microalgae like *Scenedesmus obliquus* and *Neochloris oleoabundans* (containing 30% oil w/w) yield (58,700 l/ha) as compared to rapeseed and canola (1190 l/ha) (17), for jatropha (1892 l/ha) (18); for corn (172 l/ha); for Soybean (446 l/ha) and for oil palm (5950 l/ha) (18). In general, microalgae can produce 10-20 times higher biodiesel yield in comparison oleaginous seeds or vegetable oils (14).

The microalgae (unicellular algae) can be easily grown either in fresh water or sea water or waste water but major hurdle remain in harvesting of these algae from water. The efficient biodiesel production depends on the selection of algal species which has high lipid contents and easy downstream processing (19). The algae, *Scenedesmus obliquus, Chlorella emersonii*, *Dunaliella tertiolecta,* Neochloris oleabundans, Nannochloropsis sp. and *Tetreselmis* sp.are reported to have high lipid contents and are suitable for biodiesel production (8). The lipid contents of fresh water microalgae Neochloris oleabundans (29%) and marine microalgae, Nannochloropsis sp. (28.7) are enhanced upto ~50% when cultivated in nitrogen deficient medium. The excellent strain for production of biodiesel is Scenedesmus obliquus which represent most adequate fatty acid profile (linolenic and other polyunsaturated fatty acids) (9). The advancement in genetic engineering would further enhance the lipid content in Scenedesmus obliquus by deletion of responsible gene for nitrogen fixation or optimizing culture conditions.

Importance of algae for hydrogen production

The earlier algae biofuel research was focused on biodiesel and bioethanol due to transportation issue. However, algae also have a great potential to produce biohydrogen (20). Biohydrogen is the cleanest biofuel, does not evolve “greenhouse gas” CO_2 in combustion, environmental friendly and liberates high amounts of energy per unit weight in combustion. A green alga, *Scenedesmus obliquus*, is known to produce hydrogen during photosynthesis (21). The hydrogen production in green alga is dependent on presence of photosynthetic apparatus; hydrogenase enzyme and anoxic conditions. Photosynthetic microalgae produce biohydrogen through a process called photofermentation involving the oxidation of ferredoxin by the hydrogenase enzyme. The light energy helps in photolysis of water (H_2O) by photosystem II (PSII); and release of electrons and protons. The release electrons transported to ferredoxin in anoxic conditions which serve as electrons donor to hydrogenase and subsequently transfer to photosynthetic electron transport chain (22). The hydrogen production rate was established to be maximum in light after anaerobic induction establishing an important role of anaerobic condition (23, 24). Although, mechanisms of hydrogen production in microalgae are still not completely understood but scientists are focusing on identification of hydrogenase with robust activities, study the interaction of hydrogenase with ferredoxin and genetic modification of its interactions to increase the efficiency of biohydrogen production (25, 26). Macroalgae have fast growth rate, ability to grow in oceanic condition and also have potential to produce biohydrogen. The *Gelidium amansii* (red alga) and *Laminaria japonica* (brown alga) are known to produce high biomass which can be used for biohydrogen production utilizing anaerobic fermentation (19).

Cyanobacteria also have a great potential to produce biohydrogen (27, 28). The hydrogen gas can be produced by cyanobacteria in two natural ways: i) H_2 production as a byproduct during nitrogen fixation with the help of Nitrogenases (ATP requiring process) ii) H_2 production by bidirectional hydrogenase (Non ATP requiring process) (29). The unicellular diazotrophic cyanobacterium, *Cyanothece* sp. (ATCC 51142) is known to produce high levels of hydrogen under aerobic conditions (30). The rates of hydrogen production in wild type *Cynothece* sp. is reported as high as 465µmol/mg of chlorophyll/h in presence of efficient nitrogenase system. The common interests of scientific and public communities in biohydrogen are increasing across the world and rapid progress would be made in understanding of regulation of cynobacterial hydregenases at both genetic and proteomic levels (31).

Importance of algae for bioethanol production

Algae have a great potential of producing ethanol due to low content of lignin and hemicellulose as compared to lignocellulosic plants (32). In addition to low lignin content, macroalgae are known to have high sugars content (~50%) which can be fermented for production of ethanol (33). The marine red algae like Gelidium and Gracilaria are rich source of agar, a carbohydrate (polymer of galactose and galactopyranose). The release of simple sugars from agar is quite difficult, thus, current research should focus to develop methods of saccharification from agar. Saccharification is a process of breakdown of complex carbohydrates into simple monomers. The enzymatic hydrolysis is very specific, requires less energy and mild conditions. The enzyme cellulase cleaves the bonds of cellulose into glucose and hemicellulase cleave the bonds of hemicelluloses into mannose, xylulose, glucose, galactose and arabinose. The ethanol industry uses cellulase and hemicellulase from fungus *Trichoderma reesei* (34). The development of efficient method for release of glucose from cellulose would also lead to enhance ethanol yields during fermentation (33). There are reports that blue-green algae like *Spirogyra sp.* and *Chlorococum sp*. accumulate starch and also have high content of polysaccharides in their complex cell walls. The *Chlorella vulgaris*, a microalga is also known to accumulate high content of starch (37% of dry weight). The accumulated starch can be used for production of ethanol (35). The microorganisms commonly used for ethanol production in fermentations are *Saccharomyces cerevisiae* (yeast) and *Zymomonas mobilis* (bacterium) with limited substrate range. There are needs for development of ethanol producing improved strains using genetic manipulation so that high efficiency and high ethanol tolerant strains can be created. The productions of ethanol with different algae are only feasible when its total biomass would be utilized. The photosynthetic cyanobacteria can be genetically engineered for highly efficient ethanol production by a combination of gene transformation. The pyruvate decarboxylase and alcohol dehydrogenase II genes of *Zymomonas mobilis* has been transformed into Synechocystis sp. PCC 6803. This engineered strain of Synechocystis sp. has the capability to phototrophically convert CO2 into ethanol. Algae are being used as an excellent alternative to bioethanol crops (corn, sugar and soybean) as they can be grow in water bodies (18, 6). Algae can be cultivated easily in sea water, fresh water and industrial waste water for the purpose of biofuel production. Thus, cultivation of algae in water bodies ensures the availability of free arable land for food crops.

In literature it has been reported that total ethanol production in 1975 was less than a billion litters and its production has been increased to 39 billion litters in 2006; and is expected to increase upto 100 billion litters in 2015. Ethanol is being used either as pure form or as mixture with gasoline in the vehicle in United States, Brazil and other European countries. The most of Brazilian vehicles are utilizing ethanol either in pure form or as 25% mixture with the gasoline. Whereas, in United States a mixture of ethanol and gasoline (10% ethanol + 90% gasoline or 15 % ethanol + 85% gasoline) are being used (36, 26).

Conclusions

Fossils fuel is expensive, non renewable and harmful to environment. The current research in the area of biofuel is focussing on biodiesel, bioethanol and biohydrogen production. Algae have a potential source for biofuel and are renewable. There are several companies, putting their target to produce economical algal biodiesel within next few years. In addition to biodiesel, algae can reduce pollutants such as ammonium (NH_4^+), Nitrate (NO_3^-) and phosphate (PO_4^{3-}) from the water bodies (8). Moreover, CO_2 sequestrations by algae or microalgae can utilize CO_2 from environment and reduce greenhouse effect. There are already report for limited use of bioethanol in United States of America and Europe as a mixture in gasoline. Since, biohydrogen is the cleanest biofuel and leave no environmental pollution after use, thus, extensive research should be focussed on biohydrogen in the future. The recent focus of scientists should be to enhance (optimize) biofuel production. The genetic engineering technology should be used to modulate metabolic pathways to improve strains favouring synthesis of either more triacylglycerides (lipid) for biodiesel or high ethanol production and high ethanol tolerance or higher biohydrogen producing efficiency.

Other articles in this theme issue include references (37-52).

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