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Microalgae as sources of biofuel production through waste water treatment

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Abstract

The shortage of fuel in the near future and the change in climate due to greenhouse gases are serious challenges of a global concern, thus it is imperious to explore new sustainable ways to overwhelm these challenges. The need of a new sustainable energy sources has increased the importance of the third generation biofuel produced from non-food stocks such as algae, which possibly represent a great opportunity in the long term. The major challenge of the algae based bio-fuel production is their extraordinary cultivation costs, which make their commercialization economically infeasible. Algal spp. especially *Chlorella* spp. are capable of thriving in waste water and can accumulate high lipid contents. The aim of the current review was to highlight the possible integration of waste water treatment and algae based bio-fuel production, as a sustainable option for cost effective bio-fuel production along with lower environmental impact.

Keywords: Algae, Waste-water, *Chlorella* spp., Biofuel

1. Introduction

Fossil fuel fulfills about 80% of the total energy demand worldwide which includes petroleum, coal, and natural gases. These fuels represent the major threat to the environment due to their greenhouse gases emission which is the principle cause of global warming. Annual demand for fuel is estimated to increase to 80-90% in 2030, and thus CO_2 emissions are anticipated to be doubled. Adeniyi *et al*., (2018); El-Shimi and Moustafa, (2018) reported that the European Union has planned to reduce the emission of greenhouse gases by 10% till 2020. Kandiyoti *et al*., (2017) reported that there are new renewable energy sources including the wind, the solar and geo-thermal energy, which play important roles in competing with the global warming, but they are unable to fulfill its demands.

In this regard, biofuel is considered as the best renewable alternative to fossil based fuels, due to its sustainable features to overcome the global energy demand (Adeniyi *et al*., 2018; El-Shimi and Moustafa, 2018). However, biofuels sustainability is always questioned due to their competition with food crops as well as agricultural lands (Mishra *et al*., 2018).

In reference to Shuba and Kifle, (2018), life cycle assessment studies (LCA) revealed that the use of the third generation of biofuels such as microalgae as fuel sources can overcome the drawbacks related to the former generations of biofuel. Chen *et al*., (2015); Qari *et al*., (2017) previously documented that microalgae are capable of storing high lipid contents (up to 80%), thus shows their potential as a renewable energy source for sustainable fuel production. Their lipid storage capacity is 100 times more than the conventional oil crops such as; *Brassica napus* and *Jatropha curcas*. Moreover, they can be cultivated on barren land as they do not compete with food crops, and in a variety of water types (i.e. saline, fresh, brackish and waste water) throughout the year, thus contribute to low water requirements for fuel production.

According to Stephens *et al*., (2010); Hannon *et al*., (2010); Collotta *et al*., (2018), microalgae fast growth rate, vigorous vivacity along with their ability to bio-remediate the pollutants from waste water without the use of fertilizers or pesticides, make them a strong candidate for biofuel production especially for the fossil fuel importing countries. USA has planned to run 20% of its road transport through the use of biofuel by 2022 (Collotta *et al*., 2018). From these mentioned algal features, it can be surmised that microalgae are one of the world's most commendable, renewable and sustainable fuel resource which can also play their role to reduce the environmental pollution (Adeniyi *et al*., 2018).

Algal biodiesel has not gained commercial value till now because of its extraordinary investment costs. However, El-Shimi and Moustafa, (2018) pointed out that feedstock expense represents 80% of its total production expenses, which thus makes it the bottleneck of biodiesel production. According to the studies of Komolafe *et al*., (2014); El-Shimi and Moustafa, (2018), algal biodiesel is being used in combination of conventional diesel in a level of more than 15%, thus its efficiency needs to be improved to displace the conventional diesel.

2. Algae

Algae are diverse group composed of more than 3000 aquatic spp.; the majority of them are autotrophic while the remaining is heterotrophic in their modes of nutrition. They have the ability to convert almost all the food stock into their biomass. Their bodies are designed to convert and store energy instead of using it in their growth and development. Marine algae are responsible for about 35-40% of carbon fixation in nature. They have been cultivated and used by human being as sources of proteins, oils, vitamins, chemicals, fertilizers, fuel and bioremediation (Qari *et al*., 2017; Chen *et al*., 2018).

Algae can survive in any harsh environment, thus they can be grown in saline, fresh, and waste water. *Chlorella zofingiensis*, *Chlorella protothecoides*, and *Schizochytrium limacinum*, are the main species which can store oil up to 50% of their dry body weight. Adeniyi *et al*., (2018) added that *Phaeophyceae* sp. can store high sugar contents in their body. Algal species are known for their bioremediation activities, as they can effectively utilize the nutrients from the waste water as energy sources. Moreover, their nutrients storage ability increases in the presence of metal ions especially iron (Adeniyi *et al*., 2018).

3. Cultivation of microalgae

Algae grow at a fast rate with the need of little or no supervision. They convert the solar energy into chemical energy through carbon fixation in the presence of water, CO_2 and nutrients. Adeniyi *et al*., (2018); Khan *et al*., (2018) added that they rapidly converts all the nutrients into different forms of biomass including proteins, lipids, and carbohydrates. The four different cultivation methods of algae are; photoautotrophic, heterotrophic, photoheterotrophic, and mixotrophic cultivation.

According to Qari *et al*., (2017), the most effective cultivation method of algae for biofuel production is the heterotrophic cultivation, where the algae convert the supplied nutrients into their biomass in a very little time. Algae can be cultivated in natural water bodies such as lakes, ponds, or lagoons. These water bodies need paddle wheels to enable circulation of CO_2 and nutrients. This is a cost effective method of cultivation, but algal growth can be affected due to contamination and poor regulation of the abiotic factors like temperature (Shuba and Kifle, 2018). However, Adeniyi *et al*., (2018) pointed out a possible method to overcome all these limitations is through artificial cultivation, in which algae are cultivated in closed photo-bioreactors that provide controlled environment for best cultivation results.

4. Waste water treatment

The incorporation of waste water treatment with microalgae for biofuel production has both an environmental and economic benefits. One of the major limitations of biofuel production is the cost of the food stock and water for cultivation of these microalgae. Maga, (2017) reported that waste water of different types has been successfully used to grow microalgae, which can significantly lower the operational costs of biofuel production. Waste water contains nitrogen, phosphorus and carbon sources, in addition to macro- and micronutrients. Thus, there remain no requirements of fertilizers or related burdens for algae cultivation.

According to Chen *et al*., (2015); Collotta *et al*., (2018), the addition of CO_2 along with waste water enhance the algal growth at a high rate. The algal genera such as *Chlorella*, *Scenedesmus*, and *Chlamydomonas* are reported effectively to utilize the nutrients of waste water accompanied with biofuel production. Accordingly, Maity *et al*., (2014); Arora *et al*., (2016) reported that incorporation of algae for biofuel production and associated waste water remediation will not only decreases the capital costs, but will also reduce the eutrophication simultaneously. Different types of waste water have been investigated for algal production. Chiu *et al*., (2015); Collotta *et al*., (2018) revealed that waste water can be grouped into three main categories depending on its origin including; municipal, agricultural, and industrial waste water.

4.1. Municipal waste water

Municipal waste water (also known as domestic waste water) is produced by the domestic premises. In recent decades, there has been an increase in the municipal waste water due to the expansion of urbanization. It usually consists of human wastes, food wastes, and chemical wastes from households (Chiu *et al*., 2015; Arora *et al*., 2016). Low amounts of nitrogen and phosphorus are found in municipal waste water as compared to other waste water types, where their concentrations range between 10-100 mg/ L. Chen *et al*., (2015) added that it may have significant concentrations of heavy metals as well, due to the local small-scale factories. Microalgae are found to be effectively grown in raw concentrate.

Several algal genera such as; *Chlorella kessleri*, *Chlorella vulgaris*, *Chlamydomonas reinhardtii*, *Auxenochlorella protothecoides*, and *Botryococcus* sp., can convert the nutrients in the municipal waste water into their biomass effectively as stated by Caporgno *et al*., (2015); Chiu *et al*., (2015); Mohan *et al*., (2015); Chen *et al*., (2018). About 6.2 million tons of wet scum is produced every year in the United States within the waste water treatment plants, as they contain domestic waste products including food, oils, and soaps. Ma *et al*., (2016) study showed that 70% of this wet scum can be converted into biofuel.

4.2. Agricultural waste water

Most of the water all around the world is used for the agricultural activities. Large scale farming operations in recent decades have rigorously increased the generation of agricultural waste water. This agricultural waste water majorly consists of animal and plant wastes, which contain high concentrations of ammonia, nitrogen, and phosphorus that may reach 1000 mg/ L. Microalgae thrive in the agricultural waste water, but they cannot flourish in concentrated waste water due to the reduced penetration of light. Mohan *et al*., (2015); Zhu and Hiltunen, (2016); Nam *et al*., (2017) reported that *Chlamydomonas polypyrenoideum*, *Scenedesmus* sp, *Chlorococcum* sp., and *Chlorella* sp. cultivated in dairy and swine waste water, give an effective lipid productivity in this diluted waste water.

4.3. Industrial waste water

Different industries produce different types of waste water, but high concentration of heavy metals is found in almost all types of the industrial wastes. The concentration of phosphorus and nitrogen in this industrial waste water is much lesser as compared to the municipal and agricultural one. Only heavy metal resistant algal species were found to show limited growth in the industrial waste water.

However, Chen *et al*., (2015) study recorded the effective cultivation of microalgae in carpet mill waste water, palm oil mill effluent, and olive mill waste water. Soydemir *et al*., (2016) reported that mixed cultures of microalgae grew in secondary effluents and produced different types of lipids. *Chlorella vulgaris* was found to metabolize glycerol in industrial waste water and accumulate lipids (Ma *et al*., 2016).

5. Algal biofuel products

5.1. Bio-diesel

The bio-diesel is produced through the process of trans-esterification. All the algal lipid contents are extracted from the biomass by the use of non-polar solvents such as ethanol or benzene. This extracted lipid contents are majorly composed of triglycerides, which then react with alcohol to produce fatty acid methyl esters (FAMEs). During this process, the fluidity of the algal oil is increased to make the viscosity similar to the conventional petro-diesel (Adeniyi *et al*., 2018). Recently FAME is mixed in petro-diesel in a specific proportion (max 20%), and is directly used in the diesel engines without any engine modifications.

5.2. Bio-ethanol

Algae store sugars in their bodies in three different forms including; Mannitol, Alginate, and Laminarin However, Mannitol is the most abundant sugar in the algal biomass. Khan *et al*., (2018) pointed that the anaerobic fermentation of the algal biomass converts the carbohydrate (sugar) content into an alcohol (ethanol). Liquefaction is then carried out to increase the efficiency of the produced ethanol.

5.3. Bio-gas

Algal biomass is anaerobically digested to convert its organic contents into bio-gas. Adeniyi *et al*., (2018) stated that bio-gas is composed majorly of methane and carbon dioxide, which could be used for domestic as well as industrial purposes.

5.4. Bio-jet fuel

Fisher-Tropsch also known as hydro-treatment and gasification process is used to convert the algal oil into paraffinic kerosene through hydro treatment. All impurities however are removed from the oil during this process (Adeniyi *et al*., 2018). Bio-jet fuel offers improved energy efficiency along with reduced carbon emissions.

5.5. Bio-oil

Adeniyi *et al*., (2018) reported that thermal cracking of the algal biomass without oxygen converts it into liquid fuel (Bio-oil), and solid fuel (Biochar). Thermal cracking is carried out to extract the lipid contents from the biomass at a very low calorific (also known as heat content or energy density) power range.

5.6. Steam

Algal biomass that is of no use anymore for fuel production could be used directly to produce energy. Oxygen chemically reacts with the algal biomass in a steam turbine at 1000°C to produce steam. According to Adeniyi *et al*., (2018), this steam could be used to power a turbine or a generator to produce electricity.

6. Commercialization of algal biofuel

Chen *et al*., (2018) study recently revealed that more than half a century ago, a pilot plant for algal cultivation was constructed on the rooftop of

Manchester Institute of Technology (MIT). This was the world's first plant for algal cultivation; however it was constructed for food production purpose. Later on, waste water treatment plants were used to cultivate algae in raceway open ponds system to decrease the cultivation costs. In 2008, an algal bio-diesel production plant was built in Texas and named as 'PetroSun'. Moreover, the US navy showed interest in bio-fuels, thus invested Dynamic Fuels for bio-fuel production from microalgae. Every gallon of biofuel costs them about 27$, which was too high to afford. The European countries also showed their interests in algal bio-fuel production.

According to Su *et al*., (2017), many countries have been reported to build algal biofuel production plants; however no economically successful case has been reported up till now. Thus there is an urgent need to invest the studies to invent economically feasible system for algal-biofuel production.

7. Challenges in algal biofuel production

The main challenge in algal biofuel production is its production costs that need to be decreased up to 10 times in order to make it economically feasible. Although the cultivation costs of algae can be decreased by the incorporation of waste water treatment, however the costs associated with construction, operations, and maintenance of plants are still too high. The harvesting and conversion of algal oil into biofuel cost the most. Accordingly, there is a need to develop genetically improved algal strains and harvesting technologies, to decrease the biofuel production costs to 0.013 $/ gallon of gasoline (Qari *et al*., 2017).

Conclusion

Although algal biofuel production has been advised as the potential ecofriendly alternative of fossil based fuels, however the development of cost-effective technologies and genetically improved algal strains are required for its successful commercialization. Waste water could be utilized to cultivate the algae with the minimum costs. Thus the incorporation of waste water treatments with the algal biofuel production plants could be a promising option for commercial biofuel production, along with environmental sustainability.

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Conflict of interest

The authors declare no conflict of interest.

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