Algal Fuels: A Green Alternative To Combat Climate Change

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A B S T R A C T

Anthropogenic activities are one of the major possible driving factors for climate change which have led to increase in CO2, and other greenhouse gases. The largest known contribution of humans towards climate change comes from burning of fossil fuels such as coal or gasoline and also natural gas and other common fuels to make electricity or drive cars. It has been estimated that for every litre of fuel a car burns, there is 3 to 4 times release of CO2 in atmosphere. Reducing the use of fossil fuels to a level that climate change can be slowed down or reversed is the most daunting challenge for today's world. There is a need to eliminate the burning of coal, oil and even natural gas. Although there is no perfect solution for reducing dependencies on fossil fuel, but one alternative is use of algal fuels which are obtained from algae. Algae are photosynthetic plants, grows in water and produce energy through photosynthesis. The algae and particularly microalgae such as Chlorella, Scenedesmus, etc. can be used to produce large amount of lipids, which can be converted into biodiesel. Algae ranges from microscopic cyanobacteria to large kelps and this diversity give an opportunity to harness the development of algal biofuel technology. The advantage of algal use is that, it can be grown in a given area with 10 to 100 times more productivity as compared to traditional bioenergy feed stocks. Moreover, algae do not affect the fresh water resources and can be grown with waste and sea water. When algae is grown and used as fuel feed stock, it consumes CO2 present in atmosphere, which is main culprit for climate change. Also, the biofuels obtained from algae contains 30 times more energy per unit area as compared to 1st and 2nd generation fuels and the combustion is almost carbon neutral. The present paper will review on use of algae as a source of biofuels keeping its environmental and economic aspects in view.

Key Words: Algae, bio-fuel, climate change

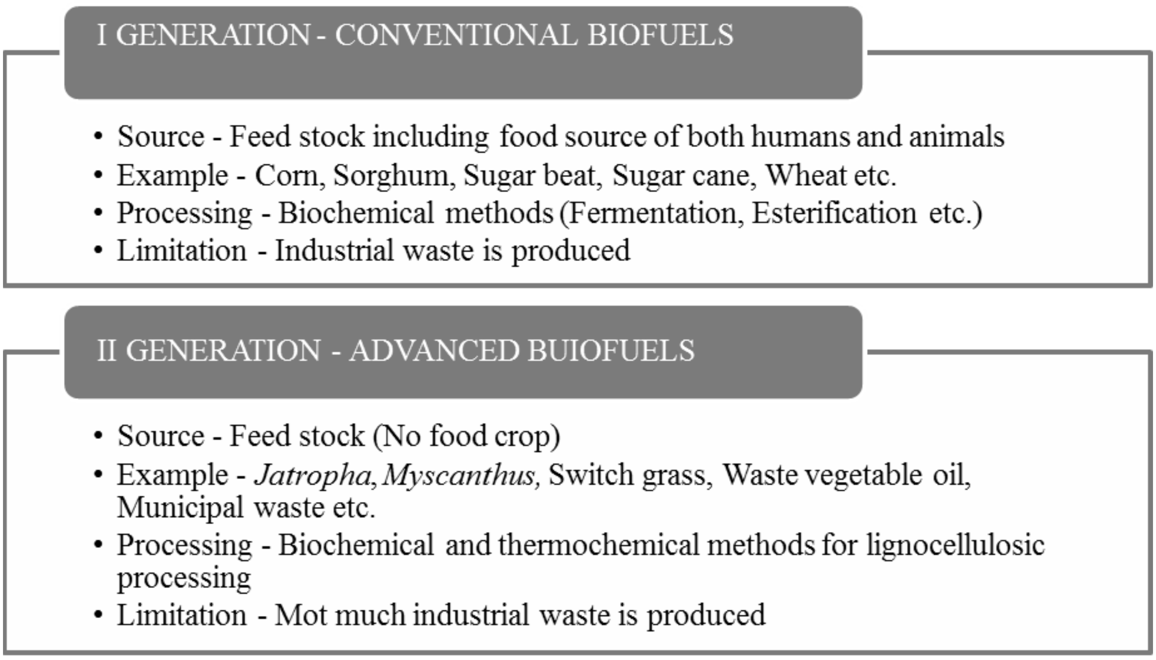
1. INTRODUCTION

Fuels are the concentrated store houses of energy, which are organic and release heat energy upon combustion. The fuels can be categorised as fossil fuels or bio-fuels. Some of the examples of conventional fossil fuels are coal, petroleum, diesel etc. which are of biological origin but are produced by various geologic processes over the years. On the other hand, bio-fuels are also produced by biological resources such as agriculture and anaerobic digestion but they do not take many years to come into usable forms. It has been reported in Bulletin for History of Chemistry that the first oil well was drilled by Edwin L. drake in 1859 at Titusville, Pennsylvania (http://www.scs.illinois.edu/~mainzv/HIST/bulletin_open_access/v25-1/v25-1%20p64-66.pdf). Since then 1.5 trillion barrels of fuel oil has been produced and it is expected that similar quantity is required in near future due to increasing demands (Kumar et al., 2015). The rising dependencies on fossil fuels will increase pressure on earth and dream of sustainable development will become impossible, as the fossil fuels are non-renewable and their resources are limited. Therefore, there is a need to look for alternative sources of fuels which are not only renewable, low cost and easily available, but also their combustion does not cause that much of pollution related problems.

Biofuels are one of those promising renewable alternatives, which can be commercialised as they have the potential to replace the fossil fuels. Biofuels are either produced from plants directly or through agricultural, commercial, domestic, and/or industrial wastes indirectly. The renewable biofuels are produced generally by carbon fixation during photosynthesis or through the conversion of biomass. The biomass can be used directly and also can be converted thermally, chemically or biochemically into energy containing substances or fuels in solid, liquid, or gas forms.

1.1 CLASSIFICATION OF BIOFUELS

Biofuels are classified into different generations as first, second, third and fourth (Figure 1). There are different generations of biofuels, where the source of extraction is different but the chemical composition and structure remains same (Sikarwar et al., 2017).



III GENERATION - ALGAL BIOFUELS

- Source - Algae
- Example - Both micro and macro algae
- Processing - Biochemical and thermochemical methods
- Limitation - Downstream process is involved where huge amount of water is required

IV GENERATION - GEETICALLY MODIFIED ALGAL BIOFUELS

- Source - Genetically engineered algae
- Example - Both micro and macro algae
- Processing - Recombinant DNA technology, Biochemical methods (Fermentation, Esterification etc.)
- Limitation - Hogh cost of production initially, Downstream process is involved where huge amount of water is required

Figure 1: Different generations of biofuels and their sources:

1.1.1 First Generation

The I generation biofuels are the fuels which are made from the feedstock which can also be consumed as human food. They are the first kind of fuels which contain high energy organic matter such as starch, sugar or vegetable oil present in plants. These fuels are easily extracted and are also thus termed as "Conventional biofuels". The plants which are used for the production of I generation fuels are Corn, Sugarcane, Sorghum, Wheat, Sugar beet etc. (http://resources.opencleantech.com/our-blog/biofuels-1st-2nd-and-3rd-generation). The examples of I generation biofuels are:

- Biodiesel – It is basically vegetable oil, which is extracted, with or without esterification, from the seeds of plants like soybean, rape seed (canola) or sunflower
- Biogas – It is produced by the anaerobic fermentation of organic waste and crop residues as energy crops
- Ethanol – It is produced by the fermentation of simple sugars obtained from sugar crops such as sugarcane or starch crops such as corn, and wheat
- The extraction process of fuels is costlier and inefficiency is more so the knowledge, technological advancements and evolutionary processes lead to the development of second-generation biofuels.

1.1.2 Second Generation Biofuels

The second generation biofuels also known as "advanced biofuels" are also produced from the feedstock but in this case, the crop is not used for human consumption, like first-generation fuels i.e. it is not a food crop which is being utilised for the production of fuels. The examples of the second generation feedstock are woody crops, agricultural residues, agricultural wastes etc. Since the extraction of fuels is difficult in this case thus different advanced conversion technologies such as lingo-cellulosic processing including thermochemical and biochemical conversions, are used. The technologies used here do not produce as much industrial waste, as it is produced, in first generation fuels.

The commonly used crops are grasses such as Switchgrass (U.S.), Myscanthus (Southeast asia) and Indian grass; Jatropha, Waste vegetable oil and agricultural waste or municipal waste etc.

1.1.3 Third Generation Biofuels

These are the biofuels which are derived from the algae and are the latest known generation of biofuels. Earlier the algal biofuels were considered as the second generation biofuels, but the diversity of fuel, yield, space requirement, cost etc. has lead them to categorise separately. Algal fuels have the potential to decrease the demand of fossil fuels and also they can help to reduce the emission of greenhouse gases thus helping in controlling climate change. The potential of algae to produce fuels is unmatchable and no other feedstock can match algae in terms of quality, quantity and diversity of fuels. Both micro and macro algae are used for the production of fuels. There are various algae which are used for the production of fuels, some of which are listed in Table 1.

Table 1: Some common algae used for the extraction of various types of fuels.

S. No.	**Group**	Genus	References
1	**MICROALGAE**	*Ankistrodesmus, Botryococcus braunii, Chlamydomonas reinhardtii,Chlorella sp., Chlorococcum sp., Crypthecodinium cohnii, Cyclotella Dunaliella tertiolecta, Hantzschia, Nannochloris, Nannochloropsis, Neochloris oleoabundans, Nitzschia, Phaeodactylum tricornutum, Scenedesmus sp. Schizochytrium, Microcystis, Stichococcus, Tetraselmis suecica, Thalassiosira pseudonana*	Kumar et al., 2015, Matsumoto et al., 2003; Sahoo et al., 2012,
2	**MACROALGAE**	*Alaria esculenta, Ascophyllum Fucus serratus, Gracilaria Kappaphycus, Laminaria sp Oedogonium, Sargassum Spirogyra sp. , Ulva lactuca*	Vivekanand et al., 2012; Schumacher et al., 2011

1.1.4 Fourth Generation Biofuels

The IV generation biofuels are extension of III generation biofuels and uses algae as the bioresource. The algae in use is first genetically modified to enhance the fuel production. The biochemical and cellular metabolism is altered so that algae with high lipid content is obtained. The genetically engineered algae not only produce high yield, but also capture more CO2. Initially the investment cost is very high, but becomes economical in long run.

2. TYPES OF ALGAL FUELS

Algae produce diversified forms of fuels such as biodiesel, butanol, gasoline, methane, ethanol, vegetable oil, jet fuel, etc.

2.1 BIODIESEL

Biodiesel is made from long chain saturated hydrocarbons (lipids) extracted from biological materials. It can be used in its pure form or it can be mixed with other fuels at desired concentration such as petroleum diesel. The algae are preferred over the other crop plants for the extraction of biodiesel as it yields 30 times more per acre as compare to land crops. They also keeps earth clean and pollution free as it produce reduced levels of particulates, carbon monoxide and hydrocarbons (http://www.oilgae.com/algae/oil/biod/ biod.html). It is the most common biofuel in Europe.

2.2 BIOBUTANOL

It has an energy density of approximately 10% less than gasoline and higher than methanol or ethanol. Butanol has the capacity to replace the gasoline from the engines and can be used either directly or mixed with gasoline. It has been observed that when butanol is blended with gasoline, it has better performance and corrosion resistance. Butanol can be produced by the fermentation of the leftover of algae after oil extraction using Clostridia (bacteria) (Potts et al., 2012).

2.3 BIOGAS

The anaerobic digestion of both micro and macroalgae by bacteria is done. The biogas can be burned directly to produce heat or electricity or it can further be purified to produce biomethane.

2.4 GASOLINE

It is produced from the algal biomass, containing 6 – 12 carbon atoms per molecule. Gasoline can be used in internal-combustion engines (Mascal et al., 2014).

2.4 BIOMETHANE

It is produced from algal biomass by various methods such as anaerobic digestion using first acidogenic bacteria and then methanogenic bacteria, gasification and pyrolysis done under high temperature and pressure. Anaerobic digestion has been found to be very successful in the production of bio-gas (Lundquist et al., 2010).

2.5 BIOETHANOL

It is also known as Algenol. The ethanol produced from algae has various advantages over the ethanol produced from land plants as it produces less harmful gases. Ethanol is produced by the conversion of starch and cellulose. Species which are used for ethanol production are Sargassum, Gracilaria, Prymnesium parvum, Euglena gracilis.

2.6 HYDROCARBONS

Produced by unprocessed algae with high pressure and temperature. It is used as aviation fuel.

2.7 HYDROGEN

It is produced by some species of algae and bacteria in the absence of oxygen.

3. ADVANTAGES OF USING ALGAE AS A FUEL RESOURCE

There are large number of benefits associated with algae, which makes them an attractive and promising alternative as sustainable source for the production of biomass and extraction of biofuel from it (Figure 2).

3.1 ALGAE GROW EASILY AND FAST

Microalgae can reproduce very fast and can double within few hours therefore a good harvest with large volume of biomass is achieved with in a day.

3.2 ALGAE DO NOT COMPETE WITH AGRICULTURE

The algal cultivation can easily take place in areas which are not required or used for agricultural processes. It can easily be grown easily in bioreactors or sea, brackish water and even waste water which is not suitable for agricultural crops.

3.3 ALGAE CAN HAVE HIGH BIOFUEL YIELDS

The yield from algae is much more in comparison to land crops. The yield can vary from 2000 to 5000 gallons per acre per year which is many times greater.

3.4 NUTRITIONAL REQUIREMENT IS LESS

Algae uses CO2 as a primary requirement to produce starch and other compounds which are utilized as raw material to produce biofuels. More the supply of CO2 more is the production. The CO2 can be supplied from any source and is cost effective. Even the industrial or vehicular exhaust can be utilized.

3.5 ALGAL RESIDUE CAN BE USED AS AN ENERGY SOURCE

The residue left after the extraction process can be further utilized as a source of solid fuel in the pelletized form.

3.6 IMPACT ON ENVIRONMENT

Algae can be grown on marginal land where food crops cannot be grown and, the water resources are salty aquifers which are not utilized for drinking or other agricultural processes. Algae can also be grown on ocean surface in bags or floating screens (https://medium.com/@twef/nasa-omega-project-9f1af2ef8d31), thus providing a clean energy with little impact on biodiversity and other resources. Also, to grow algae, there is no requirement of insecticides or herbicides to be added. In addition algal biofuels are less toxic and degrade readily in comparison to other petroleum based fuels. Although many environmentalists are of opinion that the CO2 captured by the algae is again emitted in the atmosphere during combustion of algal fuels, but the CO2 has to be entered in the air which otherwise would have. Also in comparison to either fossil fuels or other biofuels, the algal fuels do not produce harmful gases such as sulphur gases or nitrous oxides and lesser amount of carbon monoxide (Hemaiswarya et al., 2012). The microalgae which is cultivated in waste water has the potential to produce clean water as a by-product. Microalgae can absorb various organic matter and heavy metal contaminants. The algal turf scrubbers can clean point as well, non-point source of pollutants such as nitrogen and phosphorus contaminations (Dixner, 2013; Downing and Leibold, 2002).

4 DISADVANTAGES OF USING ALGAE AS A FUEL RESOURCE

4.1 COMMERCIAL VIABILITY

The large scale extraction of fuels from algae is a relatively new technology. Efforts are being done to harvest and extraction from algae, it still lacks the implementation at commercial level. Further researches are required to make algal fuels more efficient and viable.

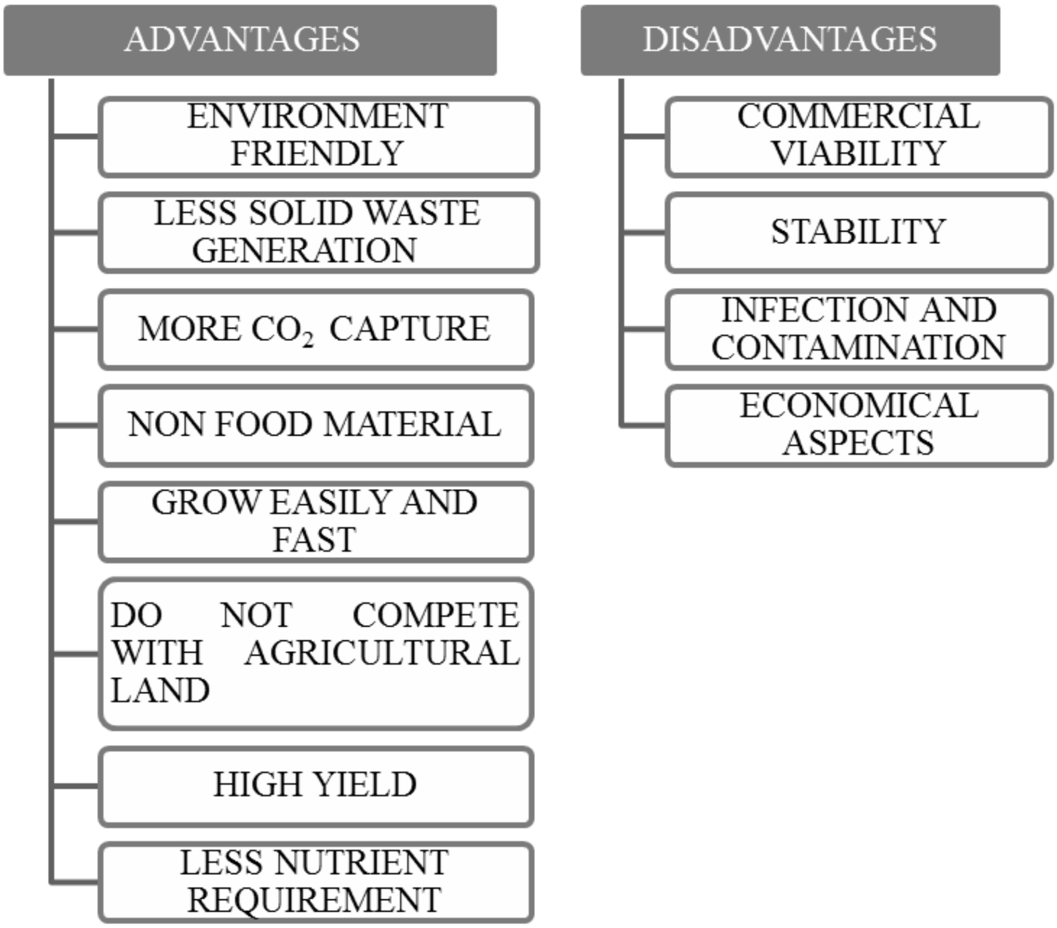


Figure 2: Advantages and Disadvantages of algae as a raw material for biofuels

4.2 STABILITY

Although the chemical composition of biodiesel produced from algae is similar to the biodiesel extracted from other biological resources, its content of polyunsaturated fats is different, therefore the biodiesel obtained from algae result in lower stability during seasonal fluctuation.

4.3 HUGE MONEY IS REQUIRED

The production of algal fuels is too expensive till date, and thus commercially it's not viable and thus is difficult to sustain. The raw material itself costs in addition to the money required in various technological processes used.

4.4 POSSIBILITY OF CONTAMINATION

If not cultivated with care there are always chances of contamination in open pond system and also in bioreactors. In closed loop systems the chances of contamination is less but still they require a cheap source of sterile carbon dioxide which is difficult.

5. CULTIVATION METHODS OF ALGAE FOR THE EXTRACTION OF ALGAL FUELS

As algae are diverse in nature, habitat, form and structure, its cultivation methods are also very diverse. It can be grown in various ways such as:

5.1 OPEN PONDS

The simplest way to grow algae is in the open pond in open air. It does not require much input of cost and maintenance expenses. The algae growing in open pond utilizes atmospheric CO_2. But this method is not efficient method, as there are always chances of contamination and infections.

5.2 CLOSED-LOOP SYSTEMS

In this the algae are grown in closed ponds with an artificial supply of sterile CO_2. The system has advantages over the open ponds as the chances of contamination are less. The source of CO_2 can be industrial emissions which are directed towards the cultivation sites. Thus before being released in the atmosphere the CO_2 is captured by the algae growing there.

5.3 PHOTOBIOREACTORS (PBRs)

The photobioreactors are closed systems, with controlled environments, which are used for high productivity of algae. All the growth requirements are introduced in the system such as CO_2, water, temperature, light, culture density, pH levels, gas supply rate, mixing regime, etc., which, facilitates the growth of algae. The PBRs are the most advanced systems and produce high yield.

5.4 OPEN SEA CUTIVATION

The macroalgae is cultivated in open in seawater and can also be cultivated onshore or deep in the sea. The advantages of open sea cultivation are that there is no requirement for the addition of supplements or fertilizers etc. The advantages and limitations are similar to growing microalgae in open pond system. There are chances of infection and grazing by the sea animals.

6. HARVESTING AND PROCESSING

The algae are harvested considering the species being collected and is further processed for the extraction. Generally harvesting is completed in two steps for microalgae i.e. bulk harvesting and thickening. The bulk biomass is separated using either The extraction can be done either by centrifugation, flocculation, foatation, or ultrasound etc. (Brennan and Owende, 2010). The macroalgae is collected manually from the cultivation sites.

Once the collection is done, algae is dried and purified immediately. The biomass is perishable and disintegrates fast so the further processing must be done rapidly. The biomass can be converted to fuels by various physical or chemical methods as shown in Figure 3.

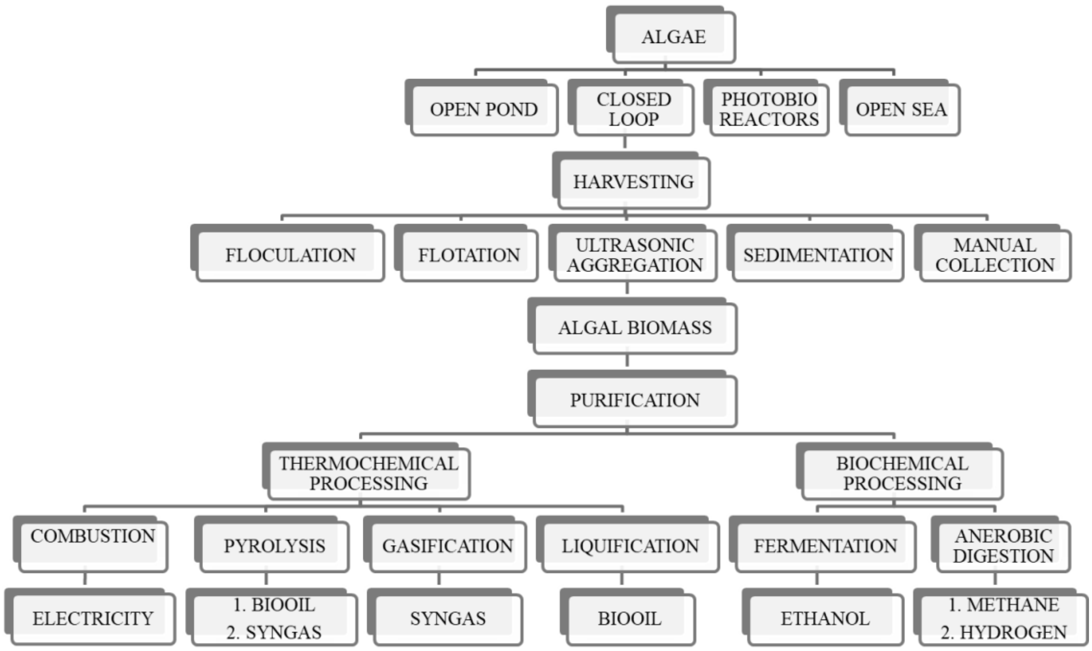


Figure 3: General process for biofuel production from algae. (Adapted from Brennan and Owende, 2010)

7. CONCLUSION

Algae is diverse in nature, has potential for fuel generation, with outstanding yields. It has been reported that algae can produce fuel 10 fold in comparison to feedstock. It can also use diverse array of carbon sources for its growth and development. Even, it can grow in waste water and clean the heavy metals and other organic compounds. Although, the algal biofuel sector is still evolving, there is no doubt that with time and introduction of innovative research methodologies with advanced technology, and need to fulfil the demand of future generations the algal fuel sector will reach to a phase where it will be able to meet the demands.

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