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Research Article

An Overview of Production of Biofuels from *Algae*: Potential and Challenges

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Abstract

The rapid growth in the world's population and the rising demands for energy source are causing a rapid and ongoing depletion of the fossil fuel sources. Since the use of fossil fuels can cause various ecological imbalance, air pollution, and global warming, as well as health hazards, it is important to use them responsibly. The present goal of this study may help to fulfill the future needs of the world. Both macro *Algae* and micro *Algae* have enormous potential for a variety of industrial uses. We go into detail about the factors influencing *Algae* **g**rowth, such as pH, temperature, light source, and nutrient availability. The advantages that these new generation biofuels offer are also explored. The creation of *Algae*-based biofuel would transform not only how environmental pollution is controlled but also how producers advance economically and socially.

Keywords: Global warming, Ecological imbalance, Air pollution.

INTRODUCTION

Algae are aquatic organisms that produce biomass by utilizing sunlight as well as Carbon Dioxide (CO2). *Algae* are divided into two groups: macro*Algae* and micro*Algae*. Lipids are extracted from micro- and macro*Algae* in a variety of ways. Macro*Algae* have been used a lot in the past for extraction and optimization processes. Another interesting feature of micro*Algae* is to generate oil and lipids. Although the synthesis of biodiesel from micro*Algae* has enormous promise for use, the method is still far away from carbon neutral or economically viable. When compared to terrestrial crops, micro*Algae* grow much more quickly. Algal mass culture can be carried out on non-arable fields utilizing non-potable saline water and waste water. As a result, interest in using micro*Algae* as a substitute for traditional biodiesel feedstock is growing among academics, business people, as well as the general public. There is a desire for an alternative fuel source due to the growth in the cost of commercial gasoline and the increase in greenhouse gas emissions. Due to its attributes such being non-toxic, renewable, and biodegradable, biodiesel might be seen as a better and more suitable replacement for commercial fuel. Any fuel produced from biomass or plant, *Algae* or animal waste is called biofuel. Because such raw materials can be easily replenished, biofuels are considered a renewable energy source unlike fossil fuels such as oil, coal, and natural gas. In light of rising oil prices and growing concern about the role of fossil fuels in global warming, biofuels are often promoted as a viable and environmentally friendly alternative to oil and other fossil fuels Afify et al., (2010); Behera et al., (2015); Hannon et al., (2010).

The biofuels has been classified as first generation, second generation, third generation and fourth generation.

The first generation of biofuels refers to the earliest types of biofuels that were produced from conventional food crops or agriculture residues. These biofuels includes Ethanol, Diesel, Vegetable oil, Biogas etc. The class of biofuels made from non-food sources such *Algae*, agricultural waste, and non-edible plant matter treated as second generation Bussa et al., (2019). These biofuels are seen as more environmentally friendly and have the potential to alleviate some of the drawbacks of first-generation biofuels. They

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includes feedstock, conversion process etc. A sophisticated class of biofuels that are produced from non-food sources and make use of specific feedstocks and growth methods are referred to as the third generation of biofuels, comparing these biofuels to both first- and second-generation biofuels, they are thought to be even more efficient and sustainable Hannon et al., (2010). The use of microorganisms, such as *Algae*, to produce biofuels from sunlight and carbon dioxide is frequently the focus of third-generation biofuels (**Figure 1**).

Scope and Need for Biofuels

A renewable, clean-burning alternative fuel, biodiesel is made from organic materials including recycled cooking oil, animal fats, and vegetable oils. Several environmental, economic, and energy security concerns determine its extent and need: Environmental Benefits, Compared to traditional petroleum-based diesel, biodiesel is thought to be a more environmentally friendly fuel. It generates fewer toxic pollutants including carbon monoxide, sulfur oxides, and particulate matter, which improves air quality and lowers greenhouse gas emissions that can slow down climate change Hsueh et al., (2007); Mahmudul et al., (2017); Mubarak et al., (2015); Muthukumar et al., (2012). Renewable resource, renewable resources, primarily plant-based oils, may be cultivated and collected continuously and are used to make biodiesel. In contrast to the limited supply of fossil fuels, biodiesel offers a long-term, sustainable energy alternative. Energy Security, due to the domestic production of biodiesel, using it can lessen a country's reliance on foreign crude oil, improving energy security and lowering vulnerability to geopolitical risks connected with oil-rich countries. Agricultural Benefits, agricultural crops (such as soybeans, rapeseed, and palm oil) are frequently used in the manufacturing of biodiesel, offering farmers an additional market and possibly bolstering rural economies. Compatibility with Existing Infrastructure, A seamless switch from conventional diesel to biodiesel is possible thanks to the fact that biodiesel may be utilized in existing diesel engines and infrastructure with little to no modification. Diversification of Fuel Sources, incorporating biodiesel into the fuel mix diversifies energy sources, reducing the impact of price fluctuations in the global oil market. Waste recycling, recycled cooking oils and animal fats can be used to make biodiesel, which encourages waste reduction and provides a sustainable method of disposal.

Types and Sources of Biofuels

According to the biomass utilized in their production, biofuels are categorized in the following types:-

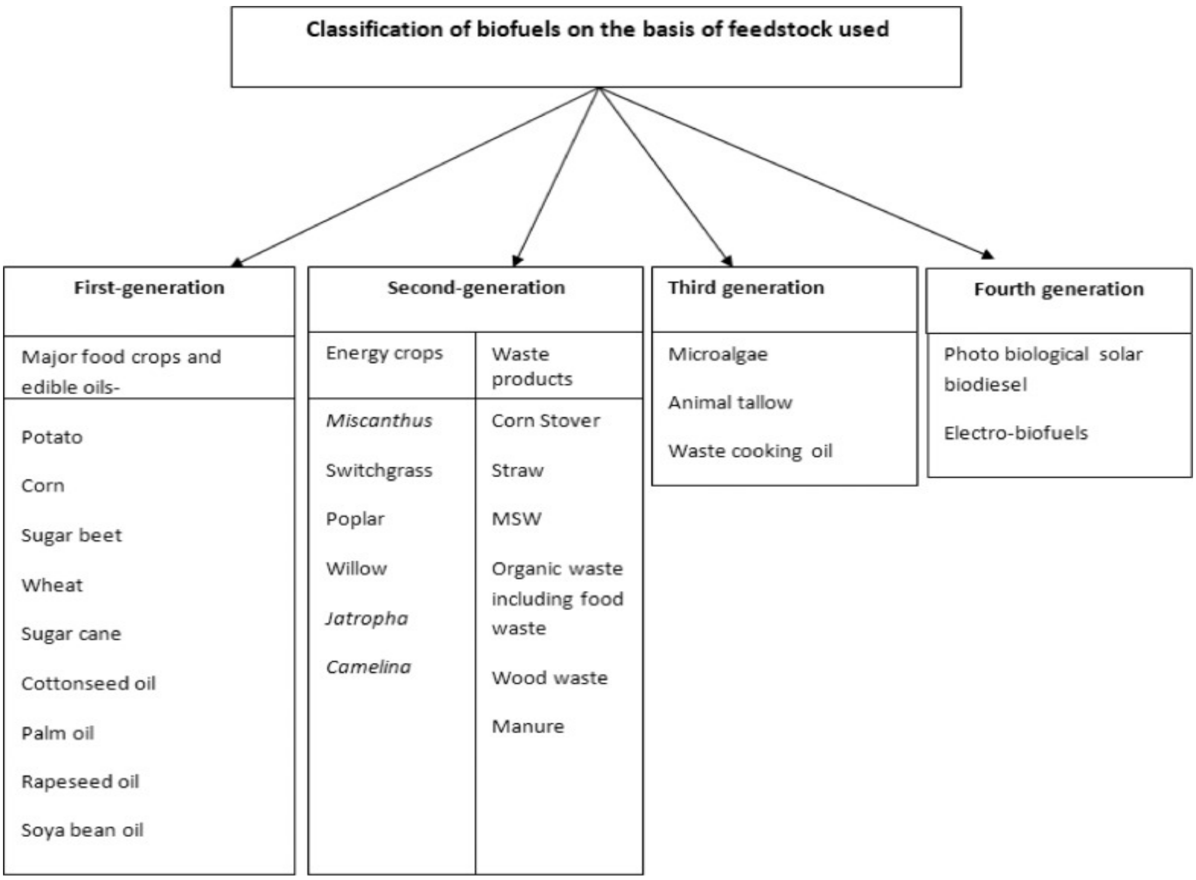

Figure 1: Classification of biofuel on the basis of feedstock used.

Solid biofuel: This biofuel is made from solid, organic, non-residual biomass derived from living organisms. This biomass is widely used in the production of electricity, energy and heat. These biofuels are made from renewable industrial waste such as coal, fuel, wood chips, wood chips and animal waste. One of the most prominent examples is biochar.

Liquid biofuel: These biofuels include all types of liquids made from natural biomass or biodegradable components. Due to their high energy density, liquid biofuels are significantly superior to solid and gaseous fuels, making them the best choice for transportation, storage and processing. Bioethanol, biodiesel and bio-oil are some of the most important examples of liquid biofuels. Other types of liquid biofuels include:

Triglycerides based biofuels: these include biomass such as vegetable oil, pyrolytic oil, biodiesel, bio-gasoline and hydrogenated oil.

Lignocellulosic based biofuels: these include biofuels feedstocks such as bio-oils, along with BTL diesel and drop-in biofuels.

Gaseous biofuel: Low-density gaseous materials form gaseous fuels. Biogas, biohydrogen and biofuels are notable examples. Pyrolysis, or gasification, is used to convert biomass into gaseous fuel. This bio fuel is then connected to an electrical generator to produce heat or electricity in an Otto engine.

Algae: *Algae* is a broad category of prokaryotic and eukaryotic organisms, ranging from unicellular species such as Chlorella and diatoms to multicellular species such as giant kelp, to giant brown *Algae* that can reach 50 meters in length. (Lee et al., 2008). Micro*Algae* are small organisms that usually grow in ponds or bodies of water and measure in micrometers. In nature, micro *Algae* grow fast and have a higher lipid content than macro*Algae* (Li et al., 2014). There are more than 50,000 microalgal species available for research, of which only 30,000 species have been identified for research (Surendhiran and Vijay, 2012; Richmond and Qiang, 2013; Rajkumar et al., 2014). Short *Algae* harvest cycle is the main advantage for its importance, better than other conventional crops with harvest cycle once or twice a year (Chisti, 2007; Schenk et al., 2008).

Algal biomass has several advantages for biofuel production: The productivity of algal oil is higher than conventional oilseed crops due to (a) its ability to grow throughout the year; (b) higher tolerance to high carbon dioxide content; (c) the rate of water consumption is too low; d) no need for herbicides or pesticides in *Algae* cultivation; (e) higher growth potential than other species; (e) Various wastewater sources containing nutrients such as nitrogen and phosphorus can be used for *Algae* cultivation in addition to providing additional nutrients; and (g) the ability to grow in harsh environments such as brackish, brackish, and coastal seawater that is not affected by conventional agriculture. (Spolaore et al., 2006; Dismukes et al., 2008; Dragone et al., 2010). *Algae* can be converted into a variety of renewable biofuels such as bioethanol, biodiesel, biogas, photobiologically produced biohydrogen, and processing for bio-oil and syngas production through liquefaction and gasification, respectively (Kraan, 2013).

These *Algae* species have potential to produce various types of biofuels, including biodiesel, bioethanol, and biogas (**Table 1**).

Process of Extraction

Processing *Algae* is necessary to convert *Algae* to biofuel. The harvested *Algae* have to undergo several steps in order to produce consumer-grade products, such as biodiesel and bioethanol.

Oil sepration: Lipids, which are oils contained in algal cell walls, must be separated in order to be extracted. The three typical methods listed below extract various amounts of oil from the *Algae*, albeit a higher extraction requires more equipment, which raises the cost.

Oil press or mechanical press: *Algae* can have their oil extracted using a mechanical press. Up to 70% of the algal oil can be extracted using this method, which drives the algal paste into a nozzle that extracts the oil and expel much drier biomass. However, this method typically needs a dry *Algae* feedstock. Dewatering results in dry *Algae*. This procedure is frequently used in conjunction with the hexane solvent technique (**Figure 2**).

Table 1: Various types of biofuels, including biodiesel, bioethanol, and biogas.

Algae species	Biofuel potential	Key features
Chlorella	Biodiesel, Bioethanol	Fast growth, high lipid content
Nannochloropsis	Biodiesel, Biogas	High lipid content, adaptable
Spirulina	Biodiesel, Biogas	Rich in protein, grows in various conditions
Haemaococcus	Astaxanthin, Biodiesel	High value pigment, can accumulate lipids
Botryococcus	Hydrocarbons(Botryococcenes)	Produce hydrocarbon for biofuels
Dunaliella	Biodiesel, Biogas	High lipid content, thrives in high salinity
Isochrysis	Biodiesel, Biogas	Rich in fatty acid, suitable for biodiesel
Scenedesmus	Biodiesel, Biogas	Rapid growth , potential for wastewater treatment

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Hexane solvent method: Oil from the *Algae* biomass dissolves in the solvent hexane, a molecule with six carbons. The solvent is then recycled through other procedures once the oil has been purified through distillation. Hexane solvents can be used to extract up to 95% of the oils at minimal cost and energy expenses, while there are some worries about the safety and health impacts of utilizing a caustic solvent repeatedly during the procedure.

Supercritical method: Supercritical fluids, as a whole, are fluids with extremely high temperatures and pressures that are neither obviously liquids nor gases. Algal cells can be ruptured and oil released using superfluid carbon dioxide. It is possible to extract up to 100% of the oil, but the energy and equipment requirements are quite high, limiting the method's commercial viability and appeal.

Other methods: There are many other ways to extract oil from *Algae*, but since *Algae* biofuel is not currently produced commercially, most of these are in the research and testing stage. Consequently, the scale required for commercial biofuel production has yet to be scaled up.

Bioethanol production: There is a large amount of solid material, known as biomass, left over after the oil is taken from the *Algae*. Bioethanol, which is ethanol made from biomass, may be produced using this leftover biomass, which is an additional *Algae*-based fuel product. The biomass's carbohydrate content can be converted into sugars. This can be done by fermenting yeast and releasing carbon dioxide, which can then be recycled back into the *Algae*'s growth process. The sugars continue to ferment after that to produce ethanol. Additionally, if the *Algae*'s biomass still retains any of the original oil, decomposition can be started to break down cell walls and release sugars, which can then be fermented (**Figure 3**).

Figure 2: Oil press or mechanical press.

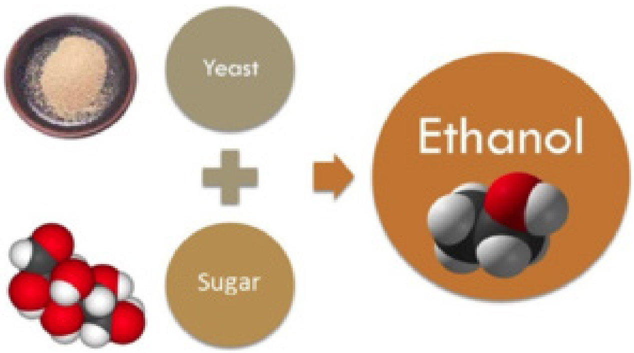

Figure 3: Ethanol Fermentation.

Economic viability: Economic viability is a critical factor in the success of any biofuel production method, including those based on *Algae*. For *Algae*-based biofuels to become competitive with traditional fossil fuels, several economic challenges must be addressed:

Capital costs: Establishing *Algae* cultivation facilities, whether open ponds or closed photobioreactors, requires significant upfront investment. This includes infrastructure, equipment, land, and technology. Operating Costs: ongoing operational expenses include labor, energy for lighting and temperature control (in closed systems), nutrient supply, water management, and maintenance.

Harvesting and dewatering costs: efficiently separating *Algae* from the growth medium and concentrating them for further processing can be energy-intensive and expensive. Developing cost-effective harvesting methods is crucial.

Lipid extraction costs: extracting lipids from *Algae* cells while maintaining the integrity of both the cells and the extracted compounds is challenging and can be costly.

Conversion costs: converting extracted lipids into usable biofuels (biodiesel or bioethanol) involves additional processing steps, which come with their own costs.

Yield and productivity: the amount of biofuel that can be produced per unit of cultivated *Algae* biomass directly impacts the overall economic feasibility. Higher lipid content and faster growth rates translate to better yields.

Market prices: the price of *Algae*-based biofuels must be competitive with or lower than conventional fossil fuels for consumer adoption. Fluctuations in oil prices and the availability of other renewable energy sources can impact market dynamics.

Byproduct value: maximizing the utilization of byproducts generated during the biofuel production process (such as residual biomass, co-products, and nutrients) can help offset costs and enhance the overall economic picture. Policy Incentives: government incentives, grants, tax credits, and subsidies for renewable energy production can significantly influence the economic viability of *Algae*-based biofuels.

Scaling challenges: transitioning from small-scale laboratory experiments to large-scale commercial production presents challenges in terms of maintaining consistent quality, efficiency, and cost-effectiveness.

Research and development: continued research to optimize *Algae* strains for higher lipid content and faster growth, as well as developing more efficient cultivation methods.

Technological innovations: advances in harvesting, lipid extraction, and conversion technologies to reduce costs and increase yields.

Integrated systems: developing integrated systems that recycle nutrients, minimize waste, and make the most of co-products to enhance overall efficiency and profitability. Economies of Scale: as the industry grows, economies of scale can lead to reduced costs in production, equipment, and operations.

Collaboration: partnerships between research institutions, industry players, and government agencies can foster innovation and knowledge sharing, driving down costs and accelerating progress. Life Cycle Analysis: comprehensive analysis of the entire biofuel production process, from cultivation to consumption, helps identify areas of high costs and environmental impact, leading to targeted improvements.

Challenges: There are many challenges to produce biofuels from *Algae*. Producing biofuels from *Algae* holds significant promise due to the high lipid content of many *Algae* strains and their rapid growth rates. However, there are several challenges that need to be addressed to make this process economically viable and environmentally sustainable:

Land use and food vs. fuel debate: concerns concerning resource and land rivalry between food and fuel production can arise from the manufacture of biodiesel from crops. To prevent detrimental effects on food security and prices, it's critical to strike a balance Rajvanshi & Sharma (2012); Saad et al., (2019).

Energy intensive production: biodiesel production can be energy-intensive, particularly if it relies on energy sources from non-renewable origins. It's crucial to ensure that the overall energy balance remains positive Sangeetha et al., (2011); Saqib et al., (2013).

Feedstock selection: the social and environmental sustainability of biodiesel production can be strongly impacted by the feedstock choice. For instance, there are worry regarding the sustainability of palm oil because it has been linked to habitat damage and deforestation Singh et al., (2011); Srithar et al., (2017).

Limited feedstock availability: access to sufficient feedstock, which might not be available in enough numbers in some places, is necessary for scaling up biodiesel production Sudhakar & Premalatha (2012).

Transesterification process: Transesterification, which produces fatty acid methyl esters (FAME) or Fatty Acid Ethyl Esters (FAEE) and glycerin, is the most widely used method for producing biodiesel. Triglycerides in the feedstock react with an alcohol (typically methanol or ethanol) in the presence of a catalyst (such as sodium hydroxide or potassium hydroxide). Reaction temperatures, times, alcohol-to-oil ratios, and catalyst type can all have an impact on how effectively transesterification occurs Trivedi et al., (2013); Tüccar & Aydın (2013).

Catalyst type and concentration: the transesterification reaction rate and biodiesel yield can be considerably influenced by the catalyst's selection and concentration. Different catalysts have varying levels of activity and can need particular circumstances for a reaction to occur Williams & Laurens (2010).

Alcohol quality: the caliber of the methanol or ethanol used for transesterification is crucial. To reduce the risk of adverse reactions and to enable a more effective conversion of triglycerides to biodiesel, high-purity alcohol with less water content is desired Yaashikaa et al., (2022); Yu et al., (2015).

Water content: the transesterification process may be negatively impacted by water in the reaction mixture. It may result in the creation of soap and lower the output of biodiesel. Alcohol and feedstock must be properly dried to reduce water content.

Reaction time: the amount of conversion is influenced by how long the transesterification process lasts. Higher biodiesel yields may result from longer reaction times, but too lengthy of a reaction time can raise the likelihood of adverse reactions.

Temperature: the reaction rate and quality of the biodiesel can be affected by the temperature at which the transesterification process is carried out. The ideal temperature is often set to strike a compromise between yield and reaction pace.

Free Fatty Acid (FFA) Content: the transesterification process can become more challenging when the feedstock contains a lot of free fatty acids. To lower the FFA concentration, the feedstock may need to undergo acid esterification or other pretreatment procedures. Washing and Purification: The biodiesel is often cleaned to eliminate contaminants and catalyst residues after transesterification. To get high-quality biodiesel, it is essential to follow proper washing and purifying procedures.

Scale of production: Small- or large-scale biodiesel production can have an impact on the process design, equipment selection, and overall efficiency.

CONCLUSION

As a third generation feedstock for biodiesel, micro*Algae* has much better yields than other crops. The generation of biodiesel from micro*Algae* has attracted a lot of attention in recent years. For micro*Algae*-based biodiesel production to be more affordable, the most effective method and ideal conditions for lipid extraction must be found. Since making biodiesel from micro*Algae* oil is equivalent to making it from any other oilseed, it's possible to make biodiesel using the same conversion techniques. With the exception of NOx emissions, biodiesel use in diesel engines results in a minor reduction in engine output. The operation state affects the engine output reaction. Finally, more funding and research are required to identify novel strategies that could reduce the cost of producing biodiesel from micro*Algae*. Additionally, studies on the combustion of micro*Algae* in internal combustion engines should be conducted to enhance engine efficiency and reduce emissions.

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