

# POTENTIAL OF ALGAE-BASED BIOFUELS FOR SUSTAINABLE ENERGY SECURITY

## Abstract

Fossil fuel supplies are not keeping up with the growing demand and are expected to run out in the near future. As a result, the search for renewable sources of energy has been driven by environmental concerns, such as pollution and global warming, as well as increasing oil prices. Algae has emerged as a potential source of sustainable energy sources, with its high protein, lipid, and carbohydrate content, rapid growth rate, and superior biomass yield. Algae are anticipated to be a third-generation feedstock for biofuels including ethanol, biodiesel, and ethanol from biomass and to have greater potential than the current generation of feedstock. There have only been a few thousand algae species examined as potential producers of biofuel, and none of them were perfect. The current state of algae-based biofuels, substantial production obstacles, and important manufacturing steps are all covered in this study.

**Key Words:** Microalgae, Biofuels, Algal cultivation, Conservation, Energy.

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## I. INTRODUCTION

The key driving forces behind the search for environmentally friendly, renewable biofuel alternatives to meet the expanding demand for petrol and diesel are an increase in greenhouse gas emissions, the depletion of fossil fuel supplies, energy instability, and challenges with global warming (Owusu and Asumadu-Sarkodie, 2016). Due to the urgent need for energy independence, efforts to produce energy from biomass attracted a lot of interest in the United States during the 1970s (Schelhas *et al.*, 2018). There has been a renewed emphasis on biomass energy as a way to slow down climate change during the second half of the 1990s. The U.S. Department of Energy (DOE) recently established the ambitious target of replacing 25% of organic chemicals with renewable biochemical by 2025 and 30% of petrol and diesel with biofuel. Micro algal biofuels are a third generation biofuel that is viable. Biofuels are promising alternatives because of the unique characteristics of algae, including their quick growth, high oil accumulation, low water needs, flexibility to a variety of environments, synergy with treatment of wastewater, and the ability of storing carbon dioxide (CO<sub>2</sub>) through photosynthesis, among other characteristics (Zhou *et al.*, 2014). Additionally, it is projected that microalgae will be able to produce enough oil to achieve the Energy Independence and Security Act's 2022 "advanced biofuels" output aim and create enough oil to equal more than 17% of US transportation fuel imports (Wigmosta *et al.*, 2011). Despite the fact that sophisticated biofuels can be produced from microalgae cells, a number of barriers have kept algal biofuel from becoming widely used. These challenges include the need for large amounts of freshwater, nutrients like nitrogen (N), phosphorous (P), and trace elements in the current agriculture processes, a shortage of energy- and cost-efficient ways to extract and convert algae into oil, an absence of established technologies for CO<sub>2</sub> mitigation via microalgae, etc. (Koller *et al.*, 2012).

Combining wastewater treatment with algae cultivation may provide an environmentally responsible and economically practical way to produce sustainable renewable algae-based biofuel and bio-based chemicals. This is because significant amounts of freshwater and nutrients needed for algae growth could be saved, as well as the associated life cycle burdens (Oliveira *et al.*, 2023). Algae, for instance, can utilize nutrients like N and P from a range of wastewater sources (including agricultural run-off, concentrated animal production activities, industrial and municipal wastewaters) to provide bioremediation while reducing treatment costs (Tambat *et al.*, 2023). Additionally, they can sequester CO<sub>2</sub> from power plants or other sources of emissions while also providing carbon credits by combining the production of carbon-neutral fuel with those activities (Rosa *et al.*, 2022).

There are many benefits to growing algae on waste streams as opposed to conventional algae farms. Algae biodiesels are gaining popularity all over the world due to their natural availability, ease of growth, high oxygen profiles, ability to minimize emissions, etc. One of the rapidly expanding biomasses to produce biodiesel is recognized as an algae species, which is known as a clean, renewable fuel. More than 60,000 species of algae are flourishing worldwide, and almost 35,000 species have been identified (El-Sebaaly *et al.*, 2021). According to Gundersen *et al.* (2016), there are seven different types of algae groupings, including red, green, blue-green (*Cyanobacteria*), brown, phytoplankton, seaweeds, and other species. Chlorophyta includes the green microalgae Spirogyra division, which can range in length from 10 to 100 m. Temperature and light exposure are the two key elements that must be taken into account for Spirogyra algae to develop as much as possible.

The atmosphere of the world contained CO<sub>2</sub> billions of years ago. As a result, there was no life on earth. Algae and cyanobacteria were the first forms of life on Earth. These lowly photosynthetic creatures began releasing oxygen and sucking in ambient CO<sub>2</sub>. As a result, the CO<sub>2</sub> levels began to drop to the point where life began to develop on earth. Once more, these little creatures are ready to protect us from the dangers of global warming.

## II. ALGAE

Aquatic creatures known as algae come in a variety of types and sizes, from microalgae to macroalgae. From single cells to multicellular formations like filaments and colonies, they come in a variety of morphologies. The majority of algae can thrive in any habitat and can endure harsh conditions (Kumari *et al.*, 2022). The development of algae into cyanoprokaryotes and eukaryotes determines their classification. Chloroplasts and a clearly defined nucleus are absent in cyanoprokaryotes. Eukaryotic algae are further subdivided into the Chlorophyceae, Phaeophyceae, Rhodophyceae, Xanthophyceae, Pyrrophyceae, Euglenophyceae, and Chrysophyceae families based on the composition of their cell walls, pigments, and storage products. Unlike higher plants, algae don't have a vascular tissue, an embryo, or a membrane that covers their sex organs. Multiple industries, including sewage treatment, fuel cogeneration, biological remediation, natural fertilizer, animal feed, medicines, and nutraceuticals. Proteins, vitamins, pigments, nutraceuticals, and distinctive oils (omega-3) can all be produced from algae (Peng *et al.*, 2023). Algae are 2–15 times more light-efficient than higher plants like *Jatropha*, rapeseed, and soybeans, and they grow more quickly and produce more lipids (Mehta *et al.*, 2023).

**1. Microalgal Cultivation:** Algae have rapid growth rates, high levels of photosynthetic activity, and high effectiveness in sequestering carbon dioxide. Additionally, they utilize phosphorus and nitrogen from industrial, agricultural, and municipal wastewater to lessen the nutrient load in the wastewater. They contain a significant number of lipids, which can be processed into biofuels that are completely nontoxic and biodegradable. Algal cultivation for the production of biofuel appears to be rather simple given that algae only need a few simple conditions to develop.

However, a number of factors, such as carbon dioxide, pH, temperature, light (intensity and photoperiod), and micro- and macronutrients (the accessibility and quantity), affect the optimal algal development and accumulation of lipids. Algae respond differently to these factors, particularly light and temperature. The majority of algae species are estimated to flourish between 20°C and 30°C. As the temperature rises, a physiological response causes the amount of unsaturated fatty acids to decrease (Chaisutyakorn *et al.*, 2018). Additionally, lubricity, stability under oxidation, melting point, and heating point of biodiesel are all influenced by the type of precursor fatty acids. Cetane and iodine levels are also impacted. The standard targets for legal biodiesel production are palmitic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3) (Fallen *et al.*, 2011). In response to limiting conditions, some microalgae alter their lipid production pathway to create considerable amounts of neutral lipids (20–50% of dry weight), principally as triacylglycerol (TAG), which are primarily stored in cytosolic lipid bodies (Rengel *et al.*, 2018). It is preferable to study a huge number of algae species for biofuel production before choosing the ones with the highest productivities and then optimizing all

circumstances to achieve maximum production for these species. Hundreds of tests can be carried out on a species to enhance biomass and biofuel production. Both the selection and optimization stages are frequently carried out in an *in vitro* bulk culture. Microfluidics or on-chip technology became important due to the laborious and time-consuming nature of standard lab techniques. The success of algae-on-chip depends on the ability to use a droplet as a vessel for growing, beginning with a single cell per droplet. The capacity of the microfluidic device to concurrently collect more than 100 droplets (this number can be adjusted depending on the design) is one of the method's most remarkable advantages. These 100 droplets represent 100 replicates in a location that is less than 4 cm, which is impossible to perform using conventional methods. They were recorded in the same device and represent 100 replicates. There are several designs that may be made, from testing different growing conditions to even harvesting oil and DNA. Microfluidics allows for high throughput single cell analysis, which reduces labour costs. Additionally, this technique offers speedy testing of numerous parameters. The disadvantages of the prior methods were all outweighed by this strategy, notwithstanding its faults. Microfluidic chips have been utilized in a variety of applications, including ecotoxicology screening, cell identification, growing under different conditions, lipid analysis, separating, capturing, survival of cells, and measuring self-secreted macromolecules like ethanol and lactate (Saad *et al.*, 2019).

Growing microalgae is a crucial step in the creation of biofuels. The choice of a cultivation system affects biofuel production. Photoautotrophic systems can, in general, be both closed and open. Photobioreactors (PBRs) are closed systems with perfect stirring and excellent light accessibility (Figure 3C). They are highly controlled, high yield systems. A variety of designs can be used to create bioreactors, with the tubular design being the most common (Singh and sharma, 2012). They can be built as towers, tanks, or plastic or glass bags. According to reports, microalgal biomass was reported to be significantly greater in bubble columns and airlift photobioreactors. An additional tank is typically added to segregate it since too much oxygen can harm algae development (Hargreaves, 2013). Despite the fact that contamination is removed, highly regulated facilities have a significant downside.

The cost of open systems, usually referred to as ponds, is lower than that of closed systems, but they provide less control. The most often used designs are the raceway pond, circular pond tank, closed pond, and shallow large pond. One of the important aspects of open systems is their ability to utilize ambient CO<sub>2</sub>. The position of the open system is important since it affects the quantity of sunlight that is available. For the culture to be regularly agitated, they also commonly have a rotating arm (Carvalho *et al.*, 2006). The main problem with these systems is contamination from bacteria or even from other microalgae.

An arrangement which includes an open system and a closed system is known as a hybrid system. Hybrid systems can achieve both high nutrient removal and excellent biomass productivity (Zhang *et al.*, 2019). They are made to get beyond closed systems' high startup and ongoing expenses as well as their constraints. Microalgae are first grown in a closed photobioreactor before being transferred to an open system in hybrid systems to boost yield. For hybrid systems, large-scale algae cultivation is ideal. Depending on their metabolic processes, algae can be autotrophic, heterotrophic, mixotrophic, or

photoheterotrophic. The autotrophic process, or photosynthesis, transforms inorganic carbon into organic energy in the presence of light (Mallen-Ponce *et al.*, 2022). The heterotrophic pathway needs organic carbon to feed in the dark in contrast to the mixotrophic system, where cells can develop either autotrophically or heterotrophically according to the available food sources. The photoheterotrophic process requires both light and organic carbon to function. When compared to autotrophic metabolism, heterotrophic metabolism promotes faster growth. The optimum strategy to get the highest biomass and lipid productivities is said to be mixotrophic metabolism.

- 2. Algal Harvesting:** Algal cells are extracted by taking them out of their medium without changing the amount of water in them (Zuo *et al.*, 2022). Algal biomass has been harvested using a variety of methods, including centrifugation, flotation, sonication, flocculation, filtration, flotation, and flotation. In rare circumstances, combining two harvesting techniques can increase biomass. Dewatering may come after harvesting in different circumstances. Dewatering involves taking the water out of cells to produce dried material (Bokov *et al.*, 2021).
- 3. Algal Fuels:** Due to their quick growth, strong biomass output, and high lipid and carbohydrate contents, microalgae have an important future for the manufacture of biofuel as the third generation feedstock. Biodiesel, biogas, bioethanol, and biomethane are a few of the practical biofuels that algae may make. Bioethanol is produced using algal carbohydrates, while biodiesel is produced using algal oils. The leftover biomass is utilized to produce fuel oil or methane. After being transformed into biofuel, the residual biomass can be used to produce drugs, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), biocontrol agents, fertilizers, and animal feed. The engine performance of biodiesel is equivalent to that of petroleum while minimizing emissions of sulfur and particulate matter. It is a biodegradable fuel. Biogas or biomethane is created during the anaerobic digestion of organic matter. Biogas primarily consists of methane (65-75%) and carbon dioxide (25-35%) (Verma *et al.*, 2019). The following steps are part of the anaerobic digestion process: (1) the fermentation of the monosaccharides into acids; (2) the hydrolysis of biopolymers by hydrolytic bacteria to monosaccharides; (3) the synthesis of acetate by the action of acetogenic bacteria; and (4) the formation of methane and carbon dioxide by the action of methanogenic bacteria (Li *et al.*, 2019). Kerosene, diesel, and gasoline can be produced by converting microalgal hydrocarbons. For instance, *Botryococcus braunii* generates hydrocarbons outside of the cell that offer great oil production and are easier to extract. Biomass gasification generates bio-syngas, which contains methane, hydrogen, carbon monoxide, water, and ashes when there is air, oxygen, or water vapor present. 800-1200 °C is the high temperature for the gasification process. The biomass water content should be less than 20% (Sakheta *et al.*, 2023). Microalgae are a viable source of renewable energy that doesn't produce greenhouse gases because they can directly produce hydrogen from sunlight and water in the absence of oxygen. Bioethanol is produced when yeast ferments carbohydrates. There have been reports of microalgae with starch contents above 50%. Seaweeds produced 3.6-11.7 g/L and 179-260 mg/g of polysaccharides. It is possible to turn microalgal cellulose and hemicellulose into sugars and ultimately ethanol (Neeraj and Shashikant, 2022).

**4. Conversion Methodology:** Algae are important contenders for the manufacture of biofuels. Algae can be used to make a variety of goods, depending on the species, growing conditions, and biomass processing. Energy products derived from algae include gasoline, ethanol, biodiesel, biokerosene (jet fuel), hydrogen, syngas, and methanol (Velidi, 2023). Algae can be processed in a variety of ways to yield a range of energy products with a variety of applications. After being harvested, algal biomass can be processed using processes such as thermochemical, biochemical, transesterification, and photonic microbial fuel cell conversion (Wang et al., 2022).

- **Thermochemical Conversion:** Thermochemical conversion involves the thermal breakdown of biomass, followed by the reformation of organic compounds into biofuels through gasification, pyrolysis, combustion, or hydrothermal liquefaction. Pyrolysis is the heat-induced decomposition of biomass to produce solid fuel (biochar), liquid fuel, and gaseous fuel products without the presence of oxygen (Egbosiuba, 2022). Different heating rates, such as slow (0.1-1 C/s for a long time), fast (10-200 C/s for a short time), and flash (over 1000 C/s for a very short time), can cause pyrolysis.

It typically moves at a speed of 300 to 700 C/s. Given the high ash content of algae, pyrolysis is the preferred conversion method, albeit the resultant oil still has some issues with stability, viscosity, and acidity (Osman et al., 2023). Microwave enhanced pyrolysis (MEP), a quick and efficient technique, has been proposed for the production of bio-oil. Syngas, a mixture of gases mostly made of H<sub>2</sub>, CO, CO<sub>2</sub>, and CH<sub>4</sub>, is produced by gasifying algal biomass at ranges between 700 and 1000 °C with a controlled proportion of oxygen, steam, or air (Pandey *et al.*, 2019). Direct combustion involves supplying oxygen to biomass in a boiler, combustion chamber, or steam engine at a temperature of roughly 1000 °C in order to generate hot gases. Before the combustion stage, pre-treatments like crushing and drying into smaller particles are required. During the hydrothermal liquefaction process, algal slurries are treated to temperatures between 300 and 400 °C and pressures between 40 and 200 bar, which produces biocrude, gas, and char (10 to 73, 8 to 20, and 0.2-0.5%, respectively). A number of compounds can be extracted from or depolymerized from the algal biomass by liquifying it. With an oil yield ranging from 9 to 77%, hydrothermal liquefaction produces more oil than pyrolysis does with bio-oil (Venkatachalam *et al.*, 2022).

- **Biochemical Pathways:** Bacteria hydrolyze cell walls as part of the biochemical conversion process to create fermentable sugars. Fermentation is the process of converting sugars anaerobically into biogas, bioethanol, or biohydrogen. Biogas is produced via the process of acetogenesis, which entails oxidizing all elements that can ferment into acetate, which is then converted into methane and carbon dioxide during the methanogenesis process (Bhatt and Tao, 2020). The ratio of carbon to nitrogen (C:N) in the feedstock, together with time, temperature, pH, solids, and feeding rates, all affect how much biogas is produced. The biogas yield is quite poor because to the algal vulnerability to bacterial breakdown and low C:N ratio, which results in the creation of ammonia (an inhibitor). It's interesting to note that raw biomass from *Scenedesmus* species produced less biogas than residual biomass free of lipids and amino acids. To make up for the decreased C:N ratio, the biomass is often co-digested

with waste papers and sewage sludge. Co-digestion enhanced CH<sub>4</sub> generation by 26%, according to one study (Lopez et al., 2023). It has been proposed that the negative effects of a high protein content on anaerobic digestion can be mitigated by utilizing salt-adapted microorganisms. Microwave pre-treatment of biomass can increase the production of biogas by 56% by altering the cell wall's structure. Pretreatments that are mechanical, thermal, or enzymatic can all boost methane production. Yeast ferments hydrolysed carbohydrates to create bioethanol. 350 mg/g and 6.5 g/L of bioethanol were created when cyanobacteria containing glycogen were tested for the production of the fuel (Debnath et al., 2021). Phaeophyceae is thought to be the most ideal feedstock for the production of bioethanol due to its high sugar content. Pre-treatments include milling, a hot-water wash, vaporization, hydrolysis with enzymes, and fermentation or alginate extractions are essential for efficient bioethanol synthesis. Although oxygen, a byproduct of photosynthesis, can inhibit the hydrogenase process, anaerobic digestion can solve this issue. It's interesting to note that continuous flow regime indicated a 20-fold improvement in hydrogen generation over batch production (Sivaranjani *et al.*, 2023).

- **Transesterification:** Triglycerides are transesterified with an alcohol (typically methanol or ethanol) in the presence of an acidic or basic catalyst to create biodiesel and glycerol. The molar ratio, kind of alcohol, and catalyst all have a significant impact on the reaction. It is essential to lessen the viscosity of the oil and increase its fluidity in order to mix algal oil with petroleum diesel and apply it directly to engines (Wu et al., 2020). In contrast to conventional transesterification, which involves the extraction of algal lipids followed by esterification, direct transesterification treats the wet biomass immediately without extraction. Despite saving reagents, energy, and time, direct transesterification often produces substantially less biodiesel than conventional processes.

The yield may be increased to 90% while using less energy by combining microwave and ultrasonic irradiation techniques. In situ supercritical methanol transesterification has been considered as an additional cost-saving measure. The main fatty acids used in the manufacturing of approved biodiesel are palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3). The quantity of fatty acids in biodiesel significantly affects its properties. Monounsaturated fatty acids (MUFAs) are the recommended lipids since saturated lipids have a tendency to raise the cloud point and viscosity of biodiesel (Helwani et al., 2023) and polyunsaturated fatty acids (PUFAs) are undesirable due to their sensitivity to oxidation.

The heat of combustion, melting point, and viscosity of biodiesel are all inversely related to unsaturation and are all influenced by the length of the fatty acid chain. With rising unsaturation, lubricity and autoxidation rise. As a transesterification catalyst, lipase helps exclude byproduct recovery and catalyzes both esterification and transesterification simultaneously. High lipid content cyanobacteria, diatoms, and chlorophytes offer enormous potential for producing biodiesel (Dahman *et al.*, 2019). Oleaginous variants (at least 20% fatty acids on dry matter basis) may produce excessive lipids (up to 70% lipids on dry weight basis)

under some severe stress circumstances, such as nitrogen and/or silicon (Si) deprivation.

### III. GENETIC ENGINEERING TOWARD BIOFUELS

Maximizing both of the aforementioned culture techniques requires the ability of genetically engineering algae farming, where all the standardized qualities of algae may be modified to produce huge yields of both the primary products and by-products. This approach of growing algae involves purposeful alteration in order to create a better feedstock for synthetic biology (Alishah Aratboni *et al.*, 2019). The majority of algal strains use light-harvesting complexes termed antennae in their cells to capture sunlight, and these complexes are what provide the yield. It might be possible to make the genes responsible for these antennae noticeably lighter, allowing more light to enter the cells.

The use of artificial transposons, electroporation, particle bombardment, viruses, agitation of a cell suspension in the presence of DNA and glass beads, grobacterium infection, silicon carbide whiskers, and, most recently, agrobacterium-mediated transformation have all been used to transfer DNA into algae cells. When the particle bombardment and electroporation techniques were combined, the process yielded the highest transformation rate. For sophisticated techniques of algae DNA rearrangement, algae genetic engineering has gotten steadily more effective and affordable. This is due to the prospect of tolerance to harsh conditions being created by DNA restructuring techniques like sequencing, hybridization, metagenomics, and accelerated evolution (Ben Khedher *et al.*, 2022). Algal genomic DNA can be altered to produce the necessary metabolism at a particular spot, which could enhance performance under difficult conditions. Non-transgenic techniques may also be used to produce new attributes, but these techniques may need to be properly evaluated in order to increase performance and create the best algal strains that could endure a variety of biotic and abiotic circumstances. The metabolic alterations may, however, favor one application over another. For instance, a higher yield for the production of fuel and energy could result in harmful strains of algae for both food and non-food applications (Akram *et al.*, 2023). This is because the majority of these genetic developments were first aimed at producing useful by-products from algae, such as cosmetics and medicines, to defray the cost of production. Because most algae strains can be screened, rebuilt, and hybridized with the aid of prevalent molecular techniques for rapid development even in hostile environments, genetically engineered algae technology is being used to complement both natural and artificial production (Ajingi *et al.*, 2022). To become a reality, this, however, needs investment from both the public and commercial sectors. With such assistance, the high operational costs of a commercialized PBR, which have been the PBR's principal technical challenge, might be significantly decreased. Companies like Monsanto and Sapphire Energy are creating new genes to encourage rapid growth and other advantageous features. However, in the event of an unintended escape, suicide genes are needed to stop dangerous algal populations from surviving in an open environment (Sebesta *et al.*, 2022). This is because these purportedly dangerous algal strains raise serious environmental issues.

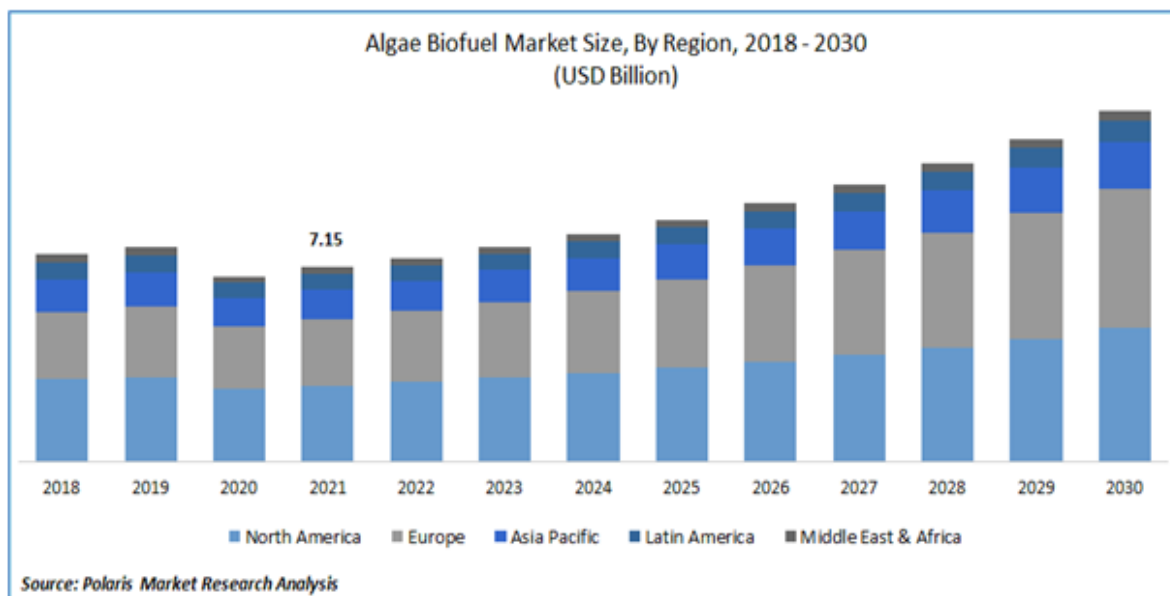
It has been observed that reducing the light antenna harvesting size and blocking hydrogenase can improve hydrogen generation through genetic engineering. A mutant strain of *Chlamydomonas reinhardtii* (Stm6) that had less competition for electrons due to inhibited cyclic electron transport through Photosystem I displayed increased starch accumulation and



decreased intracellular oxygen concentrations (hydrogenase inhibitor) . A nuclear transgene that responds to copper can induce anaerobiosis. All twenty of the *C. reinhardtii* light-harvesting complex (LHC) protein isoforms were successfully silenced by a single RNA interference construct, increasing light transmittance in the culture by 290% (Rojas-Pirela et al., 2020). This helped to overcome the light penetration limitation. The changed cell density, however, did not rise . Growing microalgae in heterotrophic or mixotrophic conditions results in higher cell densities, which lowers the cost of harvesting. Despite the fact that the majority of algae are strict autotrophs, *Volvox carteri*, *Phaeodactylum tricornutum*, *Cylindrotheca fusiformis*, and *C. reinhardtii* were effectively converted with a hexose transporter (HUP1), causing carbohydrate transfer into the cells (Poonia et al., 2022). Understanding algal behavior and structure is made possible by completed and ongoing initiatives for the whole genome identification of several algae species, such as *C. reinhardtii*, *Thalassiosira pseudonana*, and *Micromonas pusilla*. Possibilities exist for the development of environmentally friendly fuels that have no rivalry with the food industry, need fresh water, or need agricultural land, thanks to artificial biology, genetic engineering, and biotechnology.

#### IV. CURRENT STATUS AND CHALLENGES

A component of biological prospecting for plankton to produce economically viable biofuel is the identification of high-lipid producing microalgae from varied environments based on climate and location. Algal biofuels frequently have little or very little influence on the environment. In fact, the production of biofuels may be linked to other environmental purposes such as bioremediation (wastewater treatment), energy production, bio-fixation (CO<sub>2</sub> removal), biofertilizer, livestock feed, healthcare, and food goods. Algae is the most eco-friendly fuel that can help to lower greenhouse gas emissions (Merlo et al., 2021).



**Figure 1:** Algal Biofuel Market Size, Global Report 2022-2030

Due to the fact that CO<sub>2</sub> emissions from liquid fuels were 36% in 2012 and may rise to 45,000 mega tons by 2040 (Seck et al., 2022) the European Union Renewable Energy Directive (RED) recommended using up to 15% of the energy produced from renewable

sources in order to significantly reduce emissions of greenhouse gases to 20% by 2050. By 2020, the UAE proposed using biofuels for 10% of its transportation. For achieving the U.S. desire to replace 20% of its automobile fuel with biofuel by 2022, a Renewable Transport Fuel Certificate (RTFC) would be awarded (De Bhowmick and Sarmah, 2021). By 2070, renewable energy is expected to be the norm. Future algae biofuels depend on the creation of technology that is conducive to commercialization.

However, using genetically modified algae with high rates of precursor overproduction and quick growth is the most alluring alternative. These kinds of algae can be incorporated into the ecology in an open pond near a contaminated area. The facility's first stage of water treatment may be this open pond. The waste biomass from this pond will be used to produce biofuels, while the biomass sludge will be used to produce fertilizer or animal feed. Algal biofuels look to be expensive and unsustainable, as their production uses a lot of water along with nitrogen, phosphate, and CO<sub>2</sub>. But as we've already mentioned, they don't compete with other sources of energy for land or water because they are environmentally beneficial. Large-scale production of algal oil has many effects on the environment, economy, society, and culture. For each stage separately, massive amounts cultures for the production of biofuels require a lot of resources, including equipment, energy, water, and fertilizers. Algal cultures and large-scale agriculture may need comparable amounts of nutrients. Another challenge is deciding which algae varieties to utilize. It might be difficult and time-consuming to select the optimal location, isolate, purify, and identify natural microalgal assemblies. For superior microalgal multiplication, the medium and cultural conditions must be adjusted to the target species. Physical and molecular characteristics are frequently required for species identification. Environmental factors at the location of sampling must be taken into consideration for the *in vitro* tests to be as successful as possible. To create lipids and biomass, the single microalgal strain is further cultivated in advanced systems (Sun et al., 2021). One approach to solving this problem is to culture the organisms in sufficient inoculum in their native habitats.

Algae that thrive in a lab environment, especially bioengineered algae that are more prone to illness and predators, may not survive in the wild. Ten times more energy is used in the extraction of algae than in the extraction of soybean oil. Reports state that in 2012, the price per gallon was \$27 (Davila and Toranzos, 2020). Even with ideal setup and preparation, a barrel would cost \$800. The energy return on investment (EROI) is one metric for sustainability. A particular energy source's EROI is the ratio of the energy it produces to the energy needed to create it. A fuel requires more energy to produce than is present in the fuel and coproducts when the EROEI is less than 1.

Algae fuels with an EROEI of 1 are categorically unsustainable. A fuel must have an EROI > 3 in order to qualify as a sustainable energy source. The predicted EROI for algal biofuels generated in open-air lakes or bioreactors for ranges from 0.13 to 0.71. Scaling up the production of algal biofuels involves a number of energy-intensive processes, including creating the facility, compounds, motors, cooling, CO<sub>2</sub> pipes, filters, processing, centrifuges, retention, surface structure for open ponds, pH, salt content, utilization and transformation, shipping, recycling water and nutrients, and providing fuels (Peter et al., 2022).

## V. CONCLUSION

Algae are a desirable starting material for the creation of biofuels since it has the capacity to be utilized for a number of things, including the generation of sustainable energy. Biodiesel, biogas, bioethanol, pharmaceuticals, nutritional supplements, and other useful products can all be made from algae. Biofuels are environmentally benign, renewable, and biodegradable. Numerous advantageous characteristics of algae include their quick development and high lipid content. Chlorophytes, which make up the majority of algae, are employed for biological remediation, water purification, food production, drug synthesis, and energy production. Chlorophytes include both micro- and macro-algae. Many techniques for cultivation, harvesting, and processing has been discussed here. The primary obstacles seem to be costly infrastructure, operating, and maintenance expenses, the choice of high lipid-containing algae strains, commercial-scale harvesting, and problems with water evaporation. Making the production of algae-based biodiesel more appealing requires innovative and powerful techniques. More biofuel will be produced, which will help to safeguard the environment and preserve natural resources.

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