Research Article

The Analysis on the Current Situation of the Utilization Mode of Microalgal Biomass Materials

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In recent years, global warming caused by the greenhouse effect has become one of the greatest threats to mankind. This will have a serious impact on the environment and human body, such as land desertification, increase in ocean acidity, sea level rise, and increase in pests and diseases; affect people’s normal work and rest; and make people feel dizzy and nauseated. Excessive emissions of carbon dioxide (CO₂), the main component of the greenhouse gas, have contributed to the continued rise in Earth’s temperature. Although the world is vigorously developing clean energy to reduce carbon emissions, it will not replace fossil fuels in the short term. The conversion of biomass into energy is the most important way of energy utilization. Biomass energy refers to the solar energy stored in biomass in the form of chemical energy and is the fourth major energy source after oil, coal, and natural gas. At present, biofuels have gone through three developmental stages, which can be divided into first-generation biofuels, second-generation biofuels, and third-generation biofuels according to the types of raw materials and development history. The first generation of biofuels produced from food crops, such as bioethanol derived from sucrose and starch, has already entered the energy market. However, because the first generation of biofuels uses food crops as raw materials, there is a phenomenon of “competing with people for food,” and it is difficult to achieve large-scale application. To avoid the problem of food shortages, second-generation biofuels produced from nonfood crops, such as wood fiber, have been developed. Microalgae biomass energy is favored by governments and scholars all over the world because of its unique advantages of fast reproduction speed and high oil content. The cultivation of microalgae does not occupy traditional farmland, and the marginal land such as mountains, oceans, and deserts can cultivate microalgae, or develop microalgae cultivation in the air through the innovation of microalgae photosynthetic reactors. When municipal wastewater, food industry wastewater, and aquaculture wastewater are used as the medium for large-scale cultivation of microalgae, and waste gas from biogas power generation, flue gas from coal power plants, and industrial waste gas from fermentation are used as the CO₂ gas source for large-scale cultivation of microalgae, it can be further reduced. The comprehensive production cost of microalgae bioenergy plays a significant emission reduction effect. Combining the above advantages, the use of microalgae to produce first- or second-generation bioenergy has become a new research direction. This study focuses on the review of microalgal biomass in fuel, nonfuel, wastewater treatment, and fuel cell.

1. Introduction

Energy and environment are two major themes in the process of human development. With the rapid development of human society in recent years, the excessive use of fossil energy has led to serious environmental pollution and ecological damage. The global energy consumption increased by 2.3% compared with the last year in 2018, and CO₂ emission only by fossil fuel is 33.1 Gt; also, the mass fraction of CO₂ increased from 340 µg/g in 1980 to 412 µg/g in 2020 [1]. The large amount of CO₂ accelerates the greenhouse effect, which also causes many problems like sea level rise, food security crisis, species extinction and biodiversity crisis, and so on [2], as shown in Figure 1.

Due to the decrease in fossil energy and the aggravation of environmental pollution caused by the utilization of fossil energy, scientists have focused their attention on the development of new energy and renewable energy. Biomass
energy as the only promising and sustainable carbon energy has been researched by the scientists and experts all around the world. There are some efficient methods, which could convert biomass materials like wood, straw, and leaf into high value-added products through the biological method, chemical method, thermal pyrolysis, and so on [3]. At present, the main development and utilization directions of biomass are as follows: (1) energy regeneration: we use the heat generated by biomass combustion to generate electricity or conduct pyrolysis to produce biomass and biological natural gas, etc. (2) Feed: we convert biomass into feed through drying, crushing, fermentation, pelletizing, and other processes. (3) Fertilizer: we use harmless pretreatment and technical processing of biomass to produce biomass solid molding fertilizer. (4) Composite materials: biomass can be used to make carbon materials, battery-based thin-film materials, and construction and packaging materials, etc. In particular, the research on the preparation of biomass oil and carbon materials will maximize the application value of biomass materials, as shown in Figure 2.

However, traditional terrestrial biomass materials are affected by many factors (such as production scale and geographical location); the cost of large-scale recycling is relatively high; and algal biomass is the most ideal biomass for energy regeneration and CO2 emission reduction because of its variety, fast reproduction speed, and not limited to geographical location, and does not occupy land resources [4]. Chlorella and Spirulina are the two most common types of microalgae in the ocean. They have low culture cost and fast reproduction, which have been widely used in medicine, food, and wastewater treatment field [5]. Microalgae have the fastest photosynthesis rates and are high in lipids, thus attracting increasing attention in the field of biofuels (as shown in Figure 3). Microalgae have high carbon-fixed efficiency to convert it into biomass energy with carbon balance, and the carbon sequestration efficiency of microalga in closed reactors is listed in Table 1. Chlorella and Spirulina have already been used as raw materials for biomass oil production, which will greatly ease the pressure on crops to produce biomass oil. Microalgae have high photosynthesis efficiency, up to 50 g/(m²·d), which is equivalent to 10–50 times the carbon sequestration capacity of deep forests. Instead of occupying crop paddy fields and arable land, microalgae can be cultivated in saline-alkali land, domestic sewage areas, and tidal flats. It is recognized as the third-generation biomass energy material [6, 7]. The main microalgal species and compositions are listed in Table 2.

We reviewed the status of the main utilization of microalgal biomass, mainly focusing on the preparation of bio-oil and carbon adsorption materials, which will have broad prospects and great application value in sustainable energy development and carbon dioxide capture and utilization, respectively.

2. Microalgae Biomass Fuel Product

Microalgae can produce bio-oil, bioethanol, biomethane, and biohydrogen [8]. Compared with macroalgae with an oil yield of 30% (70,0001/ha/y), the oil yield of microalgae could achieve 70% (70,0001/ha/y) due to its rich lipid, which is highly competitive and fascinating.

Luangpipat and Chisti [9] found that the lipid productivity of microalgae in nutrient-sufficient seawater exceed 37 mg·L⁻¹·d⁻¹ and was nearly 2-fold greater than in freshwater, which could magnify the advantage for microalgae to produce bio-oil because seawater is cheaply available and in large amounts, whereas there is a global shortage in freshwater. Hydrothermal liquefaction (HTL) of wet biomass like microalgae is one of the most promising methods to produce renewable and sustainable energy as alternative
energies to fossil fuels, which significantly reduces the cost of drying and heating. The schematic process of HTL for microalgae is shown in Figure 4. Hu et al. [10] used the aqueous phase obtained from the catalytic/noncatalytic hydrothermal liquefaction of Chlorella as the reaction medium for cyclic liquefaction. Without recycling, the bio-oil yield under Na2CO3 catalysis was lower than the yield in pure water. However, the bio-oil yield increased by 32.6 wt.% after recycling of the aqueous phase without sacrificing oil quality. Leng et al. [11] used the liquefied aqueous solution as nutrients (C, N, and P) for microalgae cultivation, which provided the possibility for the efficient production of liquefied biofuels and the cultivation of algal biomass, enabling the microalgal hydrothermal liquefaction system to realize closed-loop biofuel production. Shen et al. [12] found that MgAl-layered double hydroxides/oxides (MgAl-LDH/LDO) with tunable acidic and basic properties are developed for catalyzing the HTL of microalgae to obtain bio-oil with a low oxygen content (as shown in Figure 4). Dandamudi et al. [13] conducted the HTL treatment of Nannochloropsis sp. to obtain the bio-oil yield with 43 wt% at 350°C, and in most cases, the oil yield improves with increasing temperature and achieves the maximum during the temperature range between 280 and 350°C, which was caused by the hydrolysis of microalgae. Arun et al. [14] prepared biomass oil by hydrothermal liquefaction (HTL) of Chlorella and used the biochar produced during the HTL process to remove pollutants (COD, NO3, NH3, and PO4) from wastewater. The study found that the oil production rate of Chlorella is 29.37%; the biochar produced in the process can effectively remove pollutants in wastewater; and the removal rate is about 55%. The elemental compositions of biocrude oil and solid residue from microalgae are listed in Table 3.

\[
\text{HHV} = 0.355[C] + 1.423[H] - 0.154[O] - 0.145[N]. \quad (1)
\]

Transesterification is a widely used method for converting oil into biodiesel, which converts the original viscous microalgae oil (triglycerides or free fatty acids) into fatty acid
alkyl esters with smaller molecular weight. The process of transesterification is mainly affected by reaction conditions, molar ratio of ethanol and oil, catalyst type, reaction time, temperature and purification reactants, etc., while alkali catalysts are easily affected by free fatty acids. The growing aviation demand consumes more than 5 million barrels of aviation fuel every day, and releases a large amount of carbon dioxide, nitrogen oxides, carbon monoxide, sulfur oxides, and other environmental pollutants. Therefore, biojet fuel that can reduce greenhouse gas emissions by 80% has attracted much attention. Among them, green biojet fuel products mixed with microalgae biodiesel and traditional chemical fuel have been produced and put into production. Microalgal oil is hydrotreated (fatty acid and ester hydrotreating) into aviation fuel, and the whole process is processed according to ASTM D7566 standard. Another production method for the conversion of microalgal oil into aviation fuel is the Fischer-Tropsch synthesis process, which can extract high-quality fuels from natural gas, coal mines, biomass, etc. Microalgal biomass is converted into liquid fuels through a gasification process, that is, gaseous components such as carbon monoxide and hydrogen are converted into liquid hydrocarbon fuels. The reaction path of microalgae through the HTL process is shown in Figure 5.

\[
\text{Biocrude yield} = \frac{\text{weight of biocrude}}{\text{weight of dry biomass}} \times 100\%,
\]

\[
\text{Solid residue yield} = \frac{\text{weight of residue yield}}{\text{weight of dry biomass}} \times 100\%,
\]

\[
\text{Other yield} = 100\% - \text{Biocrude yield} - \text{Solid residue yield},
\]

\[
\text{Solid conversion yield} = 100\% - \text{Solid residue yield},
\]

\[
\text{Energy recovery rate} = \frac{\text{HHV}_{\text{bio}} \times \text{Biocrude yield}}{\text{HHV}_{\text{feedback}}},
\]

Figure 5: The reaction path of microalgae through HTL process.

Compared with other plants, algae contain higher soluble polysaccharides and can be used to produce bioethanol. Microalgae are easy to be crushed and dried due to the lack of differentiation of roots, stems, and leaves during the growth process, and the pretreatment cost is low. The cellulose contained in microalgae cells is different from that contained in terrestrial plants, and its hydrogen bonds are weaker and more easily degraded. Relatively simple processing establishes the advantages of microalgae as a feedstock for fuel ethanol production. Dilute acid or enzymatic pretreatment can be used in the saccharification process. After ultrasonic treatment of microalgae, acid hydrolysis and enzymatic hydrolysis of starch were used, respectively, and *Saccharomyces cerevisiae* was further used to produce ethanol. Acid hydrolysis and enzymatic hydrolysis are the two main ways to hydrolyze polysaccharides for subsequent fermentation. Dilute acid pretreatment is a commonly used method. For different algae species, the type, concentration, and reaction temperature adjust time and other aspects to achieve a better preprocessing effect. After pretreatment of microalgal biomass, ethanol can be obtained by microbial fermentation such as yeast. Different fermentation strains were used according to the difference in the biomass content of each microalga. *Saccharomyces cerevisiae* is currently the most used, and *Z. mobiles* has also been extensively studied in recent decades. Fermentation methods are mainly divided into the hydrolysis fermentation (SHF) method and the simultaneous saccharification fermentation (SSF) method. Compared with the two, the SHF method has a higher yield of ethanol, but the SSF method takes less time, and the yield of fuel ethanol is relatively high. The SSF method is divided into continuous or semicontinuous processes, and the semi-continuous SSF method uses less enzyme.

### 3. Microalgae Biomass Nonfuel Application

Algal carbohydrates are synthesized by the immobilization of carbon dioxide in microalgae in the process of
photosynthesis. They mainly use adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH) to absorb and fix carbon dioxide in the air to synthesize glucose and other sugars through the Calvin cycle metabolic pathway. These carbohydrates accumulate in plastids as reserve substances (such as starch) or the main components of cell walls. Studies have shown that there is a direct competitive relationship between lipid and starch synthesis, because the main precursor of triglyceride synthesis, glycerol-3-phosphate (G3P, glycerol-3-phosphate), is synthesized through the catabolism of glucose. Therefore, increasing carbohydrate accumulation in microalgal biomass can be achieved by enhancing glucan storage and reducing starch degradation, i.e., cultivation techniques to increase carbohydrate content in microalgae, including irradiance, nitrogen depletion, temperature variation, and pH methods such as adjustment and additional provision of carbon dioxide. The carbohydrates of the microalgae are mainly composed of starch, glucose, cellulose/hemicellulose, and various polysaccharides, and the starch and glucose can be converted into bioethanol including bioethanol and biofuels including hydrogen products. The polysaccharides contained in microalgae are mainly galactan including carrageenan and agar, and carrageenan can be stably extracted from red seaweed. At present, microalgal polysaccharides can be used in food, cosmetics, textiles, stabilizers, emulsifiers, lubricants, thickeners, and clinical drugs. Microalgae sulfated polysaccharides exhibit a wide range of pharmacological effects, such as antioxidant, antitumor, anticoagulant, anti-inflammatory, antiviral, and immunomodulatory agents. Sulfated polysaccharides can be extracted from Porphyra and are applied to the skin due to their ability to inhibit the adhesion and migration of polymorphonuclear leukocytes, and anti-inflammatory treatment of the skin.

Microalgae are rich in many pigments related to light exposure; in addition to chlorophyll, most of them are Phycobiliproteins that contribute to the utilization of light-energy and light-protective substances such as carotenoids. Another important microalgal pigment is astaxanthin, which has a powerful antioxidant effect. Astaxanthin can prevent and treat chronic inflammatory diseases, cancer, neurological diseases, liver diseases, metabolic syndrome, diabetes, diabetic nephropathy, gastrointestinal diseases, etc. Haematococcus pluvialis has been found to have a high natural content of astaxanthin (1.5–3% dry matter content), which is also the main natural source of astaxanthin currently commercialized. There are also some microalgal pigments such as lutein, zeaxanthin, and canthaxanthin that are used for chicken skin coloring and pharmaceutical purposes. In addition, algal protein, phycocyanin, and phycoerythrin are used in the food and cosmetic industries; carotene is used as a prerequisite for vitamin A in health food; and many microalgal pigments are also used in natural food or beverage natural coloring agent.

Protein is an important component of human nutrients, and lack of protein is one of the main causes of nutritional deficiencies. Some microalgae contain up to 60% protein, and microalgal protein can be used as animal or fish feed, chemical fertilizer, industrial enzymes, bioplastics, and surfactants. At present, the most widely cultivated protein-rich microalgae are Spirulina belonging to the cyanobacteria species, which are not only rich in 60% crude protein, but also contain vitamins, minerals, and other biologically active factors. The cell wall of Spirulina is composed of polysaccharides; its digestibility can reach 86%; and it is easily absorbed and utilized by the human body. Spirulina can be processed into tablets, flakes, and powders as a human dietary supplement, but also as a feed additive in the aquaculture, aquarium, and poultry industries. In addition, Anabaena, Chlorella, Dunaliella, Euglena, etc. are also high in protein, and the blue-green microalgae Anabaena has been found to be a good source of protein.

High value-added biomaterials or bioproducts of microalgae have also been commercially used. Microalgae Arthrospira and Chlorella have been used in large quantities in the skin care market, and some cosmetic companies have carried out research work on their own microalgae product systems, which can extract antiaging, regenerating, emollient, anti-irritant, sunscreen, scalp care, and other cosmetic products. The most important pharmaceutical ingredient in Chlorella is 1, 3-glucan, which is an active immune stimulant, a free radical scavenger, and a blood lipid reducer, and can be effective in gastric ulcers, trauma, and constipation. Microalgal biomass, such as vitamins A, B1, B2, B6, and B12, is also the effective source of essential vitamins such as C, E, biotin, niacin, folic acid, and pantothenic acid. Carrageenan in microalgae can be widely used as an emulsifier and a stabilizer for food, such as chocolate milk, ice cream, evaporated milk, pudding, jelly, jam, and salad dressing. Due to its antitumor, antiviral, and anticoagulant properties, carrageenan also has potential pharmaceutical functions.

4. Microalgae Biomass Wastewater Treatment

In recent years, the population growth and the rapid development of urbanization and industrialization have resulted in an increasing shortage of water resources and serious pollution. Urban life, industrial production, and agricultural activities will produce wastewater with excess organic carbon, nitrogen, phosphorus, and metal elements. After discharge, it will cause eutrophication of the water environment, damage the soil structure, and cause harmful effects on aquatic organisms and human health. The discharge and treatment of wastewater have always attracted much attention (as shown in Figure 6).

As photosynthetic microorganisms, similar to plants, microalgae have chloroplasts and can provide energy for growth and metabolism through photosynthesis. Microalgae widely exist in various water environments such as freshwater, seawater, and wastewater from different sources. They can use nutrients such as nitrogen and phosphorus in wastewater for their own production while removing chemical oxygen demand (chemical oxygen demand, COD), ammonia nitrogen (NH₃ -N), total nitrogen (TN, TN), and total phosphorus (total phosphorus, TP) and other pollutants in wastewater and high removal rate [15].
Combining microalgae cultivation with wastewater treatment is an economical and environmentally friendly approach to improving microalgal oil production, simplifying wastewater treatment processes, reducing microalgal biomass production costs and wastewater treatment costs, removing pollutants, and reducing CO2. There are many aspects of capture, fixation, and utilization of advantages [16, 17]. Some algal species can fix nitrogen and phosphorus. Using organic and inorganic nitrogen compounds, microalgae cells can synthesize amino acids and proteins; as the growth cycle of microalgae cells increases, the absorption efficiency of nitrogen and phosphorus is gradually enhanced [18]. Microalgal biomass after wastewater treatment can be used to produce high value-added products such as carbohydrates, pigments, and proteins [19]. Compared with traditional oil plants, microalgae grow faster and have higher oil content; their oil content is generally 20%–70% (dry weight); microalgal oil is mostly neutral lipid suitable for biodiesel production; and after biorefining, it can be converted into biodiesel with the advantages of cleanness, environmental protection, carbon neutrality, etc. The oil derived from microalgal biomass is the third-generation biodiesel source with good development prospects. However, compared with the traditional raw materials for biodiesel production, the high production cost of microalgal oil is a major bottleneck for its industrialization. At present, the use of wastewater as an inexpensive alternative medium for microalgae growth can reduce the cost of microalgal lipids and achieve coupling with wastewater treatment [20].

5. Microalgae Biofuel Cell

Microbial fuel cell (MFC) is a technology that can directly convert the chemical energy of organic matter in wastewater into electrical energy by utilizing the metabolic process of microorganisms. The use of MFC for sewage treatment can not only greatly reduce the cost of sewage treatment but also bring certain economic benefits to the recovered electric energy, which is of great value to the sustainable development of human society [21, 22]. The MFC can use half of the organic and inorganic waste materials that cannot be used by fuel cells as fuel, and even use photosynthesis or directly use sewage as fuel. The operating conditions are mild, generally working in a normal temperature, normal pressure, and near-neutral environment, which makes the battery of low maintenance cost, strong safety, no pollution, and zero discharge; the only product of the battery is water. Without energy input, the microorganism itself is an energy conversion factory, which can convert chemical energy that cannot be directly used into electricity for human use (as shown in Figure 7).

The development of MFC has gone through several important stages. The research on microbial fuel cells can be traced back to the related research published by Potter et al. in 1911: in this study, after inserting platinum electrodes into the bacterial solution of yeast and Escherichia coli, a simple primary battery was successfully prepared and a weak current was obtained, thus verifying the feasibility of using bacteria to generate electric current [23, 24].

An ideal air cathode should have good electrical conductivity, corrosion resistance, and high mechanical strength. At the same time, the pore structure inside the cathode should also be able to provide sufficient channels for the transmission of ions and oxygen and the discharge of liquid water, so as to reduce the resistance of material transport and charge transport as much as possible, so that the cathode catalyst can play a maximum role, thereby obtaining the efficient cathode performance. Electrode support materials generally use conductive materials with a certain mechanical strength, which can realize the function of current collection while completing the electrode assembly. Therefore, its electrical conductivity is one of the very important factors for a good electrode support material. Currently commonly used electrode support materials can be mainly divided into two categories: carbon-based materials and metal materials. Carbon-based materials include carbon cloth, carbon paper, etc., and metal materials include stainless steel mesh, nickel mesh, foamed nickel, and copper mesh. At present, the commonly used preparation methods of air cathodes mainly include the
spraying method, drop-coating method, hot-pressing method, and rolling method. For the cathode with carbon cloth/carbon paper as the supporting material, PTFE is generally painted on one side as the gas diffusion layer, and the other side is supported with the catalytic layer by spraying, dripping, or hot pressing. For the supporting material of the metal substrate, carbon black and PTFE are generally supported on one side of the electrode as a gas diffusion layer, and a catalyst and a binder are supported on the other side as a catalytic layer by hot pressing or rolling. For example, Logan et al. used carbon cloth as the cathode substrate to form a catalytic layer by brushing a mixture of catalyst and PTFE and drying it naturally; the gas diffusion layer was made by high-temperature treatment after brushing PTFE, which effectively prevented the loss of moisture through the cathode. The stable operation of the MFC is maintained, which provides an idea for the preparation of the air cathode. Dong et al. used AC and PTFE as the catalytic layer, and CB and PTFE as the gas diffusion layer, which were pressed on both sides of the stainless steel mesh by roller pressing, and prepared a composite material with rich air cathode at a three-phase interface. Compared with the brushing method, the rolling method has more precise control of the catalyst loading, and the results are more reproducible. For carbonaceous catalyst cathodes, the rolling method can further improve the performance of MFC cathodes by further increasing the catalyst loading. However, the existing cathode preparation methods also have certain limitations. For example, due to the limitation of the cathode preparation method, when the catalyst loading is increased to a certain amount, the catalytic layer may peel off; in addition, the use of the binder will not only increase the cathode preparation cost, but also due to its poor conductivity, it will also increase the ohmic internal resistance of the cathode that leads to a decrease in the cathode performance; in addition, since the binder is a high molecular polymer, the dried binder will cover the catalyst surface, which will reduce the effective ORR active sites of the catalyst and reduce the cathode ORR performance, thereby reducing the output power density.

Due to the above problems of binders, some researchers avoid the use of binders in the catalytic layer by in situ formation and growth of catalysts on support materials. For example, Cao et al. [25] painted a gas diffusion layer on one side of carbon cloth, then used the electrodeposition method to in situ grow nickel oxide nanosheets on the carbon cloth to prepare a low-cost binder-free air cathode, and achieved a maximum power density of 645 mW/m$^{-2}$ in the MFC, which was 12.96% higher than that of commercial Pt/C cathode MFC (571 mW/m$^{-2}$); Wang et al. [26] reported using the chemical vapor deposition method and growing graphene on a nickel mesh as a catalyst layer yielded a maximum power density 32% higher than that of a commercial Pt/C cathode; and Chen et al. [27] used a water bath method to in situ grow Pd nanocatalysts on stainless steel fiber mats and then used carbon black. Pore filling was performed to obtain a monolithic binder air cathode. Avoiding the use of binders during the preparation of the catalytic layer can greatly improve the electrode conductivity. However, the above method requires the use of expensive equipment and additional preparation of the gas diffusion layer, which must be combined with the support layer, the structure is relatively complex, and the preparation process is relatively cumbersome. In order to solve the above problems, Yang et al. [28] used the method of carbonizing corrugated paper to prepare an integrated binder-free air cathode with low cost and good scalability, and by doping FePc, the ORR catalytic performance of the integrated cathode was further improved, achieving 830 mW/m$^{-2}$ maximum power density. Furthermore, Yang et al. [29] fabricated an integrated binder-free tubular air cathode with high mechanical strength by directly carbonizing bamboo tubes. The preparation method has the advantages of a simple and convenient preparation process. However, the cathode prepared by a natural bamboo tube is greatly limited by the natural material itself, which cannot be flexibly regulated in terms of cathode size and structure, and the cathode ORR is
6. Conclusions and Outlook

Microalgae, as a potential raw material for energy production of fuels, are favored by governments and scholars all over the world due to their unique advantages. The energy microalgae currently studied are mainly green algae and diatoms, such as Chlorella, Botrytis brauneni, Dunaliella salina, Phaeodactylum tricornutum, and Nannochloropsis. Compared with other bioenergy sources, the use of energy microalgae to produce biological energy has the following obvious advantages: wide variety, fast reproduction, short growth cycle, high-photosynthetic carbon fixation efficiency, and high yield of microalgae oil, which can synthesize a large amount of protein, fat, carbohydrate, and other biologically active substances in cells, with good energy efficiency, ecological, and economic benefits. However, there are many cost and technical problems in the production of biodiesel by microalgae cultivation. First, a large amount of nutrients such as nitrogen, phosphorus, and trace elements need to be added to maintain the normal growth and metabolism of microalgae in the process of microalgae cultivation. Statistics show that microalgae cultivation accounts for 70% of the total production cost. Second, due to the small particle size of microalgae, generally in the micron size, the concentration of microalgae reaching the stable phase after cultivation is not high, and the surface of algal cells is negatively charged and uniformly dispersed in the medium, which makes the recovery process of microalgae impossible, more difficult, and costly. Statistics show that the recovery cost of microalgae accounts for 20%–30% of the total cost of microalgae biomass energy oil production. Therefore, the cost of microalgae cultivation and collection has become the biggest problem in the large-scale development of microalgae biodiesel.

Microalgae biomass energy has great research and application prospects, but most of the current research results are based on a laboratory scale, and there are still many key technologies in industrial-scale microalgae cultivation that have not yet been broken through, mainly including cultivation costs such as nutrition and water costs, and low light utilization. Future research should cover as much as possible the selection of microalgae strains, microalgae genetic engineering, microalgae wastewater culture, microalgae photoreactor design, light-energy regulation, microalgae circulatory culture, microalgae separation and recovery, and subsequent oil extraction and purification. In all aspects, we strive to explore and solve various problems existing in microalgae bioenergy, build a microalgae bioeconomic industrial chain, and achieve low-carbon green ecological industrialization.

In this review, we mainly focus on the application of microalgae in biomass fuel production, nonfuel, wastewater treatment, and microalgae biofuel cells, which has an excellent performance in the future application and industry practice.

Data Availability

The labeled dataset used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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