THE ROLE OF MICROALGAE BIOTECHNOLOGY IN CLEAN ENERGY ADVANCEMENT

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ABSTRACT

Rapid population growth and technological advances have led to an increase in energy demand and are expected to increase by more than 50% by 2030. As a result, the importance of identifying potential renewable energy sources for sustainable energy production has recently gained momentum. Algae biofuels are economically and technically cost competitive and viable, do not require additional land, require very little water and reduce atmospheric carbon dioxide. However, due to low biomass concentrations and expensive downstream processes, the commercial production of microalgae biofuel is still not feasible. The feasibility of microalgae biofuel production can be achieved by designing advanced photobioreactors and developing low-cost technologies for biomass collection, drying, oil extraction and fermenters. Commercial production can also be achieved by improving genetic engineering strategies to control environmental stress conditions and to create metabolic pathways for high-lipid and carbohydrate production. In addition, emerging technologies are being explored, such as algae-bacterial interactions for enhancing microalgae growth and lipid production. This review aims to provide a comprehensive report on the production, application and refining process of microalgae. It also tends to look at the various culture techniques, culture mechanisms, harvesting techniques, and finally the concepts and processes of microalgae biorefinery.

1. INTRODUCTION

Rapid population growth and technological progress have led to an increase in energy demand and are expected to increase by more than 50% by 2030 [1]. Natural oil cannot compensate for current consumption rates that are 105 times faster than those that are naturally available [2]. In addition, the use of fossil fuels damages the environment through greenhouse gas emissions and the resulting global warming [3]. Rittmann [4] has described the danger of fossil fuel dependence from three points of view: the depletion of fossil fuel reserves, the depletion of resources leading to geopolitical conflicts, and climate change caused by increased concentrations of atmospheric carbon dioxide. As a result, the search for "clean" energy has become one of the biggest challenges [2]. Since then, several alternative energies, including solar, hydroelectric, geothermal, wind and biofuels, are being researched and implemented. Among these potential sources of energy, biofuels are considered as a real means of achieving the objective of replacing fossil fuels in the short term [5].

It is estimated that about 90% of China's energy consumption currently comes from coal, natural gas and oil, less than 10% of which comes from renewable sources [6]. Based on current consumption patterns, it is likely that there will be no more oil reserves after 2050 [7, 8]. Moreover, even with adequate oil reserves, the associated environmental pollution, including the release of carbon dioxide, is generally considered a serious threat to the current world order, especially for climate change [8]. The fixation of carbon dioxide by photosynthetic organisms on Earth has made a significant contribution to the global carbon cycle. Carbon dioxide produced by natural or human activities can be consumed by plants and algae and converted into biomass and other metabolites through photosynthesis and the Calvin cycle. Photosynthetic growth of microalgae can transform atmospheric carbon into a loop formed without additional carbon dioxide. Because microalgae-based carbon dioxide fixation is much faster and more effective than terrestrial plants, it is considered potentially viable to become a commercially viable method of reducing carbon dioxide emissions [6]. Most microalgae are unicellular photosynthetic microorganisms capable of immobilizing dissolved inorganic carbon and carbon dioxide in gaseous effluents to form chemical energy by photosynthesis. Most microalgae have much higher cell growth and carbon dioxide uptake (about 10 to 50 times higher) than terrestrial plants. In addition, the fixation of carbon dioxide associated with microalgae biomass production can be converted into various biofuels, pigments, cosmetics, nutraceuticals and animal feeds that represent the additional benefits of microalgae carbon dioxide fixation [8].

Biofuels are fuels that geologically contain the energy most recently fixed by carbon (that is, living organisms). Biofuels can be produced from starches, vegetable oils, animal fats, residual biomass or algal biomass, which are non-toxic, biodegradable and renewable [2]. Biofuels are divided into first, second, third and fourth generation biofuels, depending on the type of feedstock used and their current / future availability [9]. They bring environmental benefits because their use reduces harmful emissions of carbon dioxide, hydrocarbons and particulates and eliminates emissions of sulfur oxides, reducing the greenhouse effect. In fact, the burning of biofuels increases the amount of carbon in the environment that fossil fuel combustion, because the carbon released by burning biofuels already exists as part of the modern carbon cycle [2].

Microalgae biofuels belong to the third generation of biofuels and are considered as alternative sources of fossil fuels without any defect of first and second generation biofuels [10]. In general, first-generation biofuels come from crops such as soybeans, corn, maize, beets and sugar cane; Palm oil; rapeseed oil; vegetable oils; and animal fats [11]. These types of biofuels have caused many conflicts over their adverse effects on food security, global food markets, water scarcity and deforestation [12]. In addition, second-generation biofuels derived from non-fatty oils (Artemisia annua L, curcas, Fagusia, Jatropha.), lignocellulosic biomass and forest residues require large areas of land that could otherwise be used for food production. Currently, second-generation biofuel production also lacks efficient commercial waste development as a source of biofuel production [13]. Based on the above shortcomings associated with first- and second-generation biofuels, microalgae biofuels appear to be viable alternative sources of energy to replace or supplement fossil fuels. This review aims to provide a comprehensive report on the production, application and refining process of microalgae. It also tends to look at the various culture techniques, culture mechanisms, harvesting techniques, and finally the concepts and processes of microalgae biorefinery.

2. MICROALGAE BIOMASS PRODUCTION

Microalgae biomass production is generally more expensive than growing plants. If the production of micro-algae biomass relies on free sunlight, the cost can be minimized despite daily and seasonal light changes. In addition, the combination with other uses, the targeting of high value-added products and the use of residual by-products can increase the economic efficiency of production [14]. From this point of view, sufficient sunlight in tropical countries like Ethiopia can be an ideal place to efficiently produce micro-algae biomass. In fact, Rodolfi et al. [15] reported that Nannochloropsis sp. In the sunny tropics, more than 30 tonnes of fat per hectare can be produced each year, while in the Mediterranean climate it can produce only 20 tonnes.

Micro-algae biofuels are promising alternative renewable energy sources that are environmentally friendly because they have no major drawbacks related to oilseed crops. However, commercial production of micro-algae biofuels is still not feasible due to low biomass concentration. The viability of its production can be achieved by designing advanced photobioreactors and developing low-cost technologies for harvesting, drying and extracting high-biomass oil. Commercial scale production can also adapt to environmental conditions by improving genetic engineering strategies and achieving high lipid production through modified metabolic pathways [2]. Therefore, for the commercial production of microalgae biofuels, we must harness our creativity and take advantage of available resources such as agricultural run-off, effluents, coal-fired power plant emissions and even residues from production plants of microalgae biodiesel [16].

2.1 Microalgae cultivation mechanisms

Microalgae can develop using different metabolic pathways. The production system used to produce biomass is designed to follow the natural growth process [17]. Microalgae can be grown as shown in Figure 1: photoautotropic, using light as a source of energy, using carbon dioxide as an inorganic source of carbon; mixing nutrition with microalgae for photosynthesis. As the main energy, organic compounds and carbon dioxide are essential. Mixotrophy is a special case in which microalgae can grow autotrophically or heterotrophically, depending on the source of organic carbon and the availability of light, heterotrophically using organic substrates as a source of energy and C; and symbiosis system with bacteria for better growth and biomass yield.

2.1.1 Phototrophic culture

Under phototrophic growth conditions, microalgae absorb solar energy and assimilate carbon dioxide in air and inorganic nutrients in aquatic habitats. The phototrophic culture of microalgae has the added advantage of growing outdoors and capturing carbon dioxide from the environment; however, the availability of sunlight limits its use in areas where solar input is constant and strong enough to support algal growth. Photosynthetic nutrition is generally preferred when the purpose of the biomass culture is to co-synthesize the product, with less risk of contaminants and impurities in the culture medium compared to heterotrophic cultures. The productivity of light grown biomass and by-products is highly dependent on lighting conditions. In light conditions, the highest efficiency of FAME was obtained under illumination, while the highest FAME under blue exposure was due to higher biomass [18]. Phototrophic methods are considered technically and economically viable for cultivating microalgae on a commercial scale, usually in a sun-rich, freestanding outdoor environment.

2.1.2 Mixotrophic culture

Many microalgae organisms are able to photosynthesize and grow with organic materials. In mixed organisms, light energy is not an absolute limiting factor and sources of organic carbon can support growth. Compared to autotrophic and heterotrophic cultures, mixed vegetative growth can reduce photoinhibition and increase growth rate. In addition, for many algae, polyclonal biomass is more productive than heterotrophic biomass [19, 20, 21]. Organic substrates such as monosodium glutamate wastewater, whey permeate, sodium acetate, bark, glucose, fructose, glycerol, etc. have been used successfully for the growth of polyculture algae [19, 20-25]. Mixed farming in fed-batch and semi-continuous mode is a successful strategy for the high synthesis of biomass, lipids and by-products [22, 23]. The concomitant use of photosynthesis and organic matrices to maintain algal growth makes mixed nutrition more economically attractive than heterotrophic nutrition because of its high caloric conversion efficiency. These features indicate that mixed nutrition production can be an important process for producing biofuels from microalgae; however, assessing the viability of mixed vegetative growth in large-scale biomass production is an area that needs further investigation. Alternative and cheaper sources of carbon, tools to avoid bacterial contamination, energy conversion analyzes, and the development of mathematical tools to predict biomass and lipid accumulation are all areas that require further exploration [17]. Organic carbon is required during heterotrophic and mixed vegetative growth of microalgae. Glucose has been shown to be the most preferred carbon source for microalgae growth [19]. However, higher initial glucose concentrations have a negative effect on lipid accumulation in microalgae under mixed nutrient conditions [26]. On the other hand, growth was stopped after four days due to glucose depletion in mixed nutritional conditions, where phosphate was also depleted at the same time [19]. Throughout the incubation process, fed-batch strategies can be used to control nutrient levels. In the fed-batch culture, the glucose concentration is kept low and the dry weight of the chlorella cells is slightly reduced. However, lipid production increased by 52% compared to batch culture [26]. In another work, the productivity of biomass fed with a dynamic increase in light intensity increased by 323.7% compared to the batch mixed nutrition test [19]. The chemical composition of the microalgae biomass can be adjusted by controlling different variables that affect the metabolism device of microalgae cells. Carbon dioxide and light are important factors affecting the composition and productivity of biomass in autotrophic and polyculture systems. The availability of organic carbon in the medium depends on the production of chemicals of interest during heterotrophic culture and polyculture of the biomass factor [17].

2.1.3 Heterotrophic culture

The heterotrophic culture of microalgae provides an immediate solution to light availability problems, as some strains of microalgae can grow in dark environments and have high productivity. In this process, microalgae supplement organic carbon substrates with C and energy, and cell growth has nothing to do with light energy. The system allows for high growth control and high cell density, which reduces the costs associated with dehydration during the harvesting stage. On the other hand, the possible contamination of the substrate by organic media by the culture medium and the increased production costs associated with the addition of organic substrates are a disadvantage associated with the heterotrophic growth of microalgae. Heterotrophic cultivation can provide many applications, such as wastewater treatment combined or separated from biofuel production. The efficient production of biomass, lipids and starch by heterotrophic micro-algae has been widely reported. In order to obtain higher productivity, the heterotrophic growth of microalgae is also carried out in a two-step culture, a fed-batch culture system or a light-induced heterotrophic culture system [20, 21]. Heterotrophic growth is attractive for the high availability of inexpensive carbon sources (glucose, acetate and glycerol) commonly used in the fermentation industry and the possibility of using wastewater with a high organic load (or other cheaper nutrients).

2.1.4 Symbiosis culture system

Bacterial communities associated with microalgae cultivation can be very useful for their growth, for example they can provide vitamins for better growth of microalgae, which can result in low microalgae biomass production costs and increase the microalgae biomass efficiency of production. In recent years, microalgae-bacteria systems for wastewater treatment have attracted attention because of their ability to process and recover waste stream resources at the same time. On the one hand, microalgae produce oxygen and consume carbon dioxide, while bacteria produce benign interactions, avoiding the use of external aeration and reducing carbon dioxide emissions [27]. In addition, the energy required for operation is collected by the sun, making it a low power solution for wastewater treatment. Recent studies have shown that microalgae and bacteria can form easily precipitated aggregates under appropriate operating conditions [28], opening up the possibility of harvesting this biomass and using it as an alternative source of energy. Therefore, the microalgae bacterial system has broad prospects as a zero or even negative energy system. Figure 2 shows the mechanism and interaction between microalgae-bacteria consortia culture system.

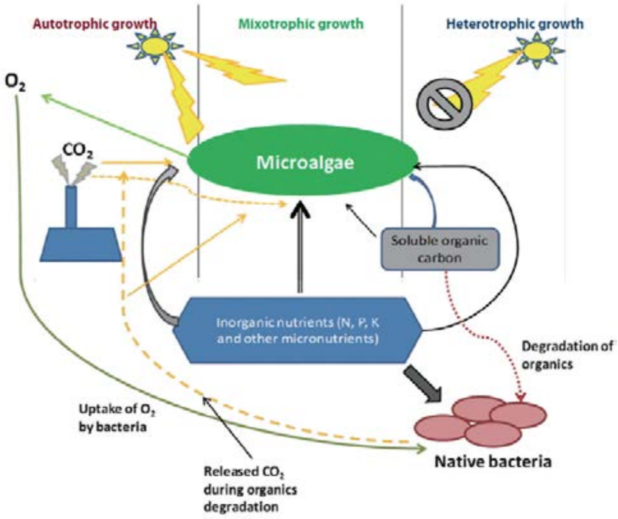

Fig. 1. Different culture environmental condition of microalgae [29]

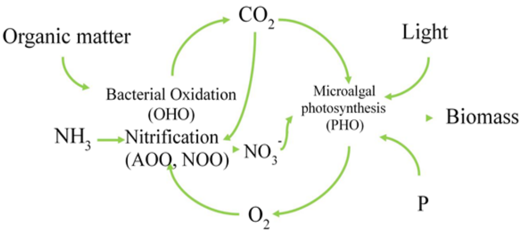

Fig. 1. Interaction between microalgae and bacteria consortia in symbiosis culture system [30]

2.2 Microalgae cultivation systems

The cultivation of microalgae seems easy enough, as only simple nutrients are provided. Most research on microalgae cultivation focuses on algae grown in clean or expensive photobioreactors or open ponds that remain cheap but easily contaminated [31]. As a result, various microalgae cropping systems are currently used: Open pond systems, photobioreactors systems, hybrid culture systems and biofilms culture systems [32]. The choice of system depends on the product to be produced and the strain to be grown [33-38].

2.2.1 Open pond farming system

The open pond farming system is the lowest cost and the most widely used. However, some disadvantages appear correspondingly. First, the bubbles are held in the bubble for a short time by the addition of carbon dioxide because of the shallow depth, which prevents mixing and gas-liquid circulation, and the carbon dioxide absorption is low. Secondly, photosynthesis of algal cells continues with low spatial efficiency due to a sharp decrease in light transmission. In addition, the collapse of a pond can occur in pond-based liquid culture ecosystems. The evaporation of the fermentation broth and the invasion of the species is responsible for the loss of algae in the environment [39]. These problems are major constraints in the energy culture of microalgae in open ponds on a large scale. At the pilot and commercial scale, Sapphire Energy built a 100-acre algae pond in its demonstration project to grow algae in outdoor ponds. The company's research team believes that the biggest obstacle to large-scale algal biomass production is the defects of microalgae biology [40].

2.2.2 Photobioreactor (PBR)

The photobioreactor is a closed system in which a microalgae medium is contained in a recycling reactor. The system has the following characteristics: volumetric support cell density, controlled culture conditions and less evaporation. The microalgae grown in this system are not contaminated by "alien" algae. Because PBR systems provide a consistent inoculum, Mark E. found that large-diameter, large-volume PBRs are an economical method of algae culture [41]. Plane, tube and bubble plate reactors are widely used, and the fastest growing tubular reactor has become one of the most appropriate outdoor growing methods. A new tube photobioreactor developed by Liao et al. [42] achieved a higher light-to-biomass conversion efficiency. It creates a controlled light / dark cycle and promotes the growth of microalgae. However, the size of the reactor is much smaller than the size of the runway pool, making scaling difficult. In addition, not only the high cost of construction and operation, but also the subtle interference caused by the fixation of algae. [43] The University of Minnesota has introduced a new multilayer table photobioreactor that can reduce footprint. The multilayer structure creates a space for microalgae, thus reducing sun penetration caused by algae binding [44]. This promising method has been reported to use two-stage heterotrophic-photosynthetic methods in sewerage, carbon dioxide fixation, and algal biofuel production [45]. NASA has proposed a new microalgae culture system called Offshore Algae Growth Membrane (OMEGA). They built a plankton photobioreactor in the Gulf of California, United States. Microalgae are grown in concentrated municipal wastewater and in cities rich in carbon dioxide [45]. Bioreactors floating on the sea surface provide a stable temperature for microalgae, provide mixed energy with the tides and significantly reduce the energy consumption of algae culture.

2.2.3 Biofilm culture

Biofilm culture methods are evolving rapidly based on the fact that microbes are easily attached to the container. Biofilm culture is a different method of suspension culture. The dense algal cells are fixed and attached to the artificial support material, and the liquid medium is provided to the biofilm to maintain the algal cells in a wet state. This method was initially used for wastewater treatment [46]. Numerous studies have shown that biofilm systems are a promising, long-term, non-polluting, low-energy method [47-50]. More recently, Liu et al. [34] proposed a new technique of "hooking" to cultivate the Nodule (Cylinderotheca) by combining this immobilized biofilm approach with a slightly diluted PBR construct. Successfully applied to the culture of Haematococcus [48] and Botryococcus [51]. In order to take full advantage of the sunlight, they reported a networked bioreactor structure to obtain high dilution in the sun and then obtain the highest productivity of 50-80 $gm^{-2}d^{-1}$ outdoors in *Scenedesmus obliquus*, equivalent to 5.2-8.3% photosynthetic efficiency.

2.2.4 Hybrid cultivation systems

In hybrid culture systems, photobioreactors provide high cell density algae to open ponds [37], which can take advantage of the open pond and photobioreactors. Although hybridization must consume raw materials and compete with other biofuel technologies. Cellana LLC has demonstrated a hybrid system at the Kona demonstration plant, where large photobioreactors continue to inoculate microalgae at outdoor ponds [41].

In general, open-air reactors and photobioreactors have advantages and disadvantages, respectively. The selection of cultivation methods must take into account the characteristics of the algae, the geological environment and the target product. Runway ponds have lower material and construction costs [35, 36]. However, they need large scale food crops. Photobioreactors are easier to control and produce more biomass than deep basins. Although they are associated with higher construction and operating costs. Jorquera et al. [52] proposed a comparative analysis of life cycle methods for open-basin biomass, tubular biomass and plate photobioreactor. The results show that the net energy ratio (NER) of the plate photobioreactor and the runway basin is > 1 and can therefore be used for large scale culture. Ideally, the NER> 7 is considered economically viable for algal biofuels [53]. Therefore, an efficient cropping system and intensive use are still under study.

2.3 Harvesting techniques of microalgae

Harvesting and subsequent production processes require a culture of high density microalgae. Diluted microalgae cultures should be at a concentration of 0.1-2.0 wt.% to at least 10-30 wt.% of dried biomass, an energy intensive process [54, 55] and therefore have a high impact on the cost of dehydration for lipid extraction, which represents 20 to 30% of the total cost of production [56]. Before investing in large scale production, excessive costs and energy consumption should be reduced. Common methods of harvesting include flocculation, filtration, centrifugation, sedimentation or any combination of these methods [57].

Autoflocculation is being studied due to its lack of chemical contaminations. During this process, extracellular biopolymers, such as glycosides and polysaccharides, secreted on the cell surface [58] interact with surrounding algal cells and cause spontaneous flocculation [59]. Alam et al. [60] identified cell wall polysaccharides as flocculants and began producing more than 80% of *C. vulgaris* and *S. obliquus* at low doses of 0.5 mg/L.

Ultrasound methods (ultrasonic extraction by solvent extraction) and electric field (extraction by liquid under pressure) have been used [59, 61]. Microalgae can form aggregates and flow until harvest. NAABB tested a pilot ultrasound harvester using the Nanlaochloropsis Solix Algae culture facility. The productivity was 18 times higher than the initial stock concentration and the electrolytic aggregation was tested using a commercial unit, recovering 95% of Nannochloropsis Salina using 25% of the energy of the basic centrifugation strategy [62]. However, it is reported that only a limited number of microalgae exhibit autofluorescence, as well as the biochemical and genetic basis for cell development.

Most microalgae and cyanobacterial strains have a cell diameter of less than 10 µm. Filtering applied to microalgae is a unique challenge [57]. Molina and Uduman estimate that filtration is not sufficient to recover microalgae strains less than 10 µm in diameter [63, 64]. For commercial purposes, Global Algae Innovations has developed a membrane filtration system that combines harvesting and dewatering. It has been shown that at 20,000 liters/hour, the energy consumption is 0.04 kWh/m^3. This system has been commercialized and can filter hundreds of millions of liters of several strains per day [62].

3. MICROALGAE BIOREFINERY

3.1. Concepts of biorefinery

The biorefinery is the process of obtaining biofuels, energy and high value products through biomass processing and transformation equipment [65]. The biorefinery concept is a promising way to reduce greenhouse gas emissions, as fossil fuel emissions have contributed significantly to global warming [66]. The main bottleneck in biorefineries is to separate different fractions without harming other fractions. This can be overcome by using a simple, low energy, low cost and scalable separation process. Due to the ability to produce several products [67], microalgae are listed as potential candidates for the biorefining process. They are considered as renewable sources of biomass, which is beneficial both for rapid growth and to reduce competition and selective composition with the food industry. Fig. 1 shows the application of a fully integrated aquaculture system [65]. Petroleum, minerals, carbohydrates and protein components can be used to produce chemicals, fuels, animal feed, biogas and value-added products. Residues such as glycerol and digestive juices can also be converted into value-added products. The lower value components for proteins and carbohydrates will probably be converted to a refinery combining CHP energy (Fig. 1).

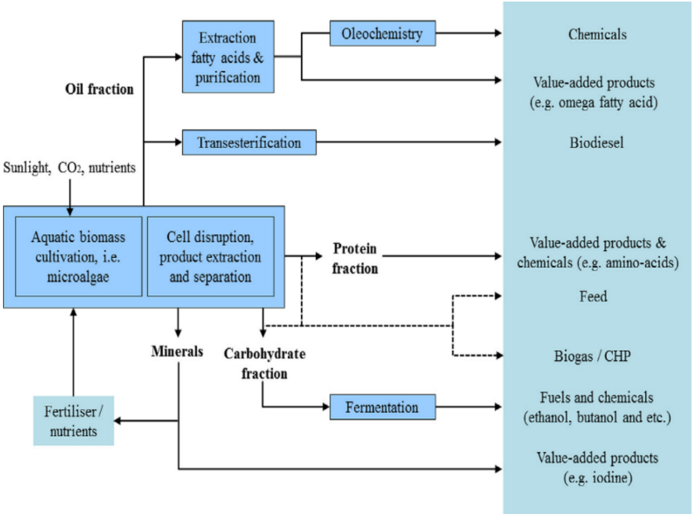

Fig. 1. Microalgae biorefining applications [65]

3.2. Microalgae biorefinery

Many studies have successfully used microalgae to produce organic products. Upstream processing and downstream processing are the main phases of the microalgae biorefinery. The effectiveness of the upstream process includes four important factors: the microalgae strain, carbon dioxide input, nutrient sources such as nitrogen and phosphorus, and light sources [68]. Nutrient sources are essential for the production of microalgae because they provide the conditions necessary for the growth of microalgae. In addition, it is reported that in the culture of Chlorococcum sp. A higher growth rate has been observed. In artificial light conditions rather than in direct sunlight [69]. This proves that light intensity and light source are important because they can directly affect the rate of photosynthesis of microalgae.

The traditional downstream process is a unitary process that takes place in a photobioreactor. An example of downstream processing is the method of extraction and purification of precious compounds obtained from micro-algae. Traditional methods, such as threshing beads, homogenizers, high-pressure heating and chemicals, can lead to high production costs and the absence of economic processes leading to the need to integrate several stages [70]. Biomass harvesting through biorefinery technologies has played an important role in the integration of biomass conversion processes. The use of gentle separation techniques that do not involve high pressures and solvents is important to produce the desired compound without compromising other fractions [68]. Choosing the right biorefining technology for microalgae depends on the energy input required and the availability of the prior art. The addition of a coagulant also improves the harvest of microalgae, where the coagulant prevents clogging of the membrane surface and increases the filtration flow [71]. The integration of enhancement technologies into the downstream process should also improve pro-management in terms of economy, simplicity and ease of subsequent processing steps.

Microalgae biomass transformation technologies can be divided into four categories: thermochemical conversion, biochemical conversion, transesterification, and photosynthetic microbial fuel cells (Figure 2) [65]. The main factors influencing the choice of the conversion process are the quantity and type of biomass feedstock, the economic factors, the project specifications and the final form of the desired product.

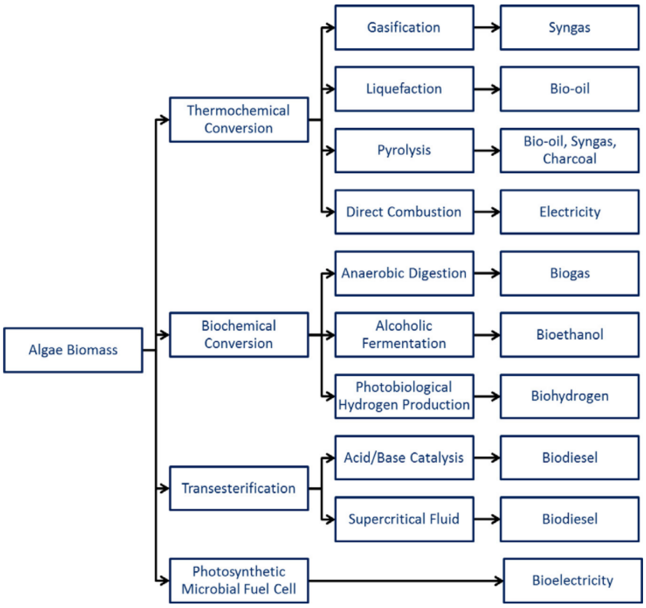

Fig. 2. Conversion process of microalgae biomass for biofuel production [65].

2.3.1 Transesterification

Transesterification is the reaction of triglycerides with alcohols in the presence of a catalyst to form chains of fatty acids and glycerol. This process produces fatty acid methyl esters (FAMEs) using ethanol and methanol [65]. Determining the reaction is also a factor that can influence the process of transesterification [72]. The reaction of triglycerides with FAME and glycerol is usually catalysed by the acid or the base by homogeneous or heterogeneous catalysis [73]. In addition, transesterification under supercritical conditions weakens the hydrogen bonding of alcohols, allowing complete conversion of triglycerides to accelerate rapidly under supercritical conditions.

2.3.2 Biochemical conversion

Biochemical conversion and conversion of biomass to biofuels for energy conversion biological treatment. Examples of biochemical conversion processes include anaerobic digestion, alcoholic fermentation, and photobiological hydrogen production (Figure 2). Anaerobic digestion involves converting organic waste into biogas. Biogas produced from algal biomass has been due to rising energy costs, anaerobic digestion of biomass is becoming increasingly attractive as a substitute for fuel production [73]. Alcoholic fermentation is an organic substrate of metabolic processes that are caused by the activity of enzymes produced by microorganisms. Biomass materials containing sugar, cellulose or starch are converted by yeast into ethanol [74]. Production of photobiological hydrogen is the process whereby microalgae converts water into hydrogen ions and oxygen. Under normal conditions of photosynthesis and subsequently produce hydrogen by inducing anaerobic conditions. Second, while producing hydrogen and photosynthetic oxygen, these gases will be separated in space [65].

2.3.3 Photosynthetic microbial fuel cell

Microbial fuel cells are bioelectrochemical devices that generate electricity from the biological degradation of organic materials under anaerobic conditions. The integration of microalgae with photosynthetic microbial fuel cells in the production of oxygen-rich environments and the elimination of carbon dioxide by the photosynthetic activity of microalgae [75]. Photosynthetic microbial fuel cells consist of an anode and a cathode separated by a proton exchange membrane. Anode oxidize the organic compound and generate electrons that are transferred to the cathode by external circuits to produce electricity. In addition, cathodic microalgae can be used to immobilize carbon dioxide, nitrogen and phosphorus simultaneously with bioelectricity [76].

2.3.4 Thermochemical conversion

Thermochemical conversion uses the principle of thermal decomposition of organic matter in biomass to extract combustible products. Examples of thermochemical conversion processes include gasification, thermal liquefaction, pyrolysis and direct combustion (Figure 2). Gasification is the chemical conversion of the carbonaceous material into synthesis gas (synthesis gas). Synthetic gas can be used to make a variety of fuels and chemical intermediates, but it can also be used directly as a combustion fuel for gas engines. For thermal liquefaction, the algal biomass will liquefy to break down the biomass into smaller molecular densities with higher energies. On the other hand, pyrolysis describes the thermal degradation of biomass without the presence of oxygen. This process has the potential to produce low-calorie biofuels on a large scale [74]. Direct combustion involves the chemical reaction in the presence of air between fuel and oxygen. This process produces carbon dioxide, water and heat as products [77]. Energy is generated by burning biomass and higher yields can be achieved by using co-combustion technology in coal-fired power plants.

3.3. Microalgae potentials and applications

Microalgae biorefineries progress has been made in converting biomass into fuels, cosmetics, chemicals, food products, animal feed and value-added compounds (Table 1) [78, 79]. Microalgae-based carbohydrates, including mainly lignin-free, cellulose and starch, allow EM to be used as a fermentation industry ready to supply carbon sources as well as biobutanol and bioethanol production [65]. Some microalgae, such as Tetraselmis, Isochrysis, Chaetoceros, and Nannochloropsis can be reversed to produce long-chain fatty acids such as eicosapentaenoic acid and docosahexaenoic acid as useful health food supplements. In addition, there is great potential for various medical and pharmaceutical applications from microalgae proteins and pigments. However, when the product is primarily used for biomedical purposes, microalgae must be well controlled to avoid microbial contamination or the presence of impurities to meet regulatory requirements. From this perspective, open-field cultivation systems, such as open-air ponds or ponds, may not be suitable for growing microalgae for medical or pharmaceutical use, although they are more cost-effective and large-scale crops [33, 80]. On the other hand, the growing demand for control of the closed culture systems (e.g. photobioreactors) with cultivation conditions higher control (e.g. temperature, pH and concentration of carbon dioxide, etc.) will be more important. To achieve this goal, investment costs and operating costs will be higher. Microalgae from renewable sources through biotechnological processes have shown great potential for energy production for food security and agricultural compromise. It is necessary to high yields of land per plot compared to other crops, low water consumption, high oil prices and the ability to cultivate on land. The main focus is on the production of microalgae biofuels, as well as in the medical, pharmaceutical, food industry [70]. In addition, recent studies show that the development of microalgae biofuels is economically viable.

Table 1: Microalgae biorefineries bioproducts potential utilization.

Activity	Application
Biofuels	Transesterification to obtain biodiesel, digestion of biomass to produce natural gas in fermenters
Anti-inflammatory, nutraceutical, antimicrobial	Anti-proliferative, nutritional supplement capable of combat diseases and infections
Molecules of high-values	β-carotene, biochemically stable isotopes, chlorophyll-a, linolenic acid, eicosapentaenoic acid, and phycocyanin
Natural pigments, antioxidant	Food ingredient and supplement for fish and shellfish feed and humans
Chemical industry	Volatile organic compounds
Fertilizers	Nitrogen and phosphorus from biomass to fertilize farmlands

4. CONCLUSION

Biofuels from microalgae are promising to replacement of fossil fuels in light of the intrinsic efficacy of microalgae for converting solar energy into chemical energy, and their significantly higher potential yield of oils suitable for biofuel production than terrestrial crops. However, due to the potential of the current competition of limited agricultural fossil fuel resources, energy security, greenhouse gas emissions and other raw materials biofuels increasing concern around the world in the interest of biofuels microalgae in full growth. Therefore, transgenic strains, with harvest and efficient recovery mechanism, in connection with the production of high value-added products, residual byproduct to promote the use of production economy, microalgae can be amplified at the level of industrialization.

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