

Review on biofuel oil and gas production processes from microalgae

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ABSTRACT

Microalgae, as biomass, are a potential source of renewable energy, and they can be converted into energy such as biofuel oil and gas. This paper presents a brief review on the main conversion processes of microalgae becoming energy. Since microalgae have high water content, not all biomass energy conversion processes can be applied. By using thermochemical processes, oil and gas can be produced, and by using biochemical processes, ethanol and biodiesel can be produced. The properties of the microalgae product are almost similar to those of offish and vegetable oils, and therefore, it can be considered as a substitute of fossil oil.

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1. Introduction

Recently, there are two kinds of important issues, environment and energy crisis issues. The environmental issue is global warming. Everybody knows that using fossil fuels has caused global warming; therefore renewable clean energy is required for replacing fossil fuel with biomass to reduce the CO₂ emission. Another issue is the energy crisis, where increasing global petroleum crude oil prices have impacts on domestic energy situations as well as on local society life. Therefore, for solving the important issue above, a renewable energy should be developed.

Global warming, induced by increases of greenhouse effect gases concentrations in the atmosphere, has become an important environmental concern [1]. Reducing the build up of atmospheric CO₂, the major driving force in the projected global warming, can be accomplished by three conceptually different methods [2]:

- Reducing the use of fossil fuels.
- Removing CO₂ from the atmosphere.
- Capturing and sequestering or utilizing the CO₂ emitted by fossil fuel combustion before it enters the atmosphere.

Energy from biomass would contribute to a stable energy supply and to local society due to an increase in commercial

activities [3,4]. Biomass can be derived from cultivation of dedicated energy crops; by harvesting forestry and other plant residues; and from biomass wastes [5]. Even garbage from domestic houses and food industries can be used as raw material of oil production by thermochemical liquefaction [6].

According to Shay in Ref. [7], among the biomasses, microalgae usually have a higher photosynthetic efficiency than other biomasses such as trees. If fuel is recovered efficiently from them, microalgae can be used as fuel instead of fossil fuel.

The production of fuel from photosynthetic organisms is a renewable process using solar energy; therefore, biomass is a highly promising resource, according to Hall in Ref. [3,8].

Biological CO₂ fixation and energy production are expected to be potential measures that will mitigate the increase of atmospheric CO₂ and serve to avoid future energy crises [9,10]. It is well known that microalgae can assimilate CO₂ gas as the carbon source for growth [11]. Reduction of carbon dioxide concentration in the atmosphere is an important task, and many physical or chemical approaches have been proposed.

By using microalgae, beside their capability of fixing CO₂, microalgal oil can be produced through either biological conversion to lipids or hydrocarbons or thermochemical liquefaction of algal cells [11,12]. Microalgae contain lipids and fatty acids as membrane components, storage products, metabolites and sources of energy [11].

This paper will describe a number of methods to convert the microalgae to liquid fuel and gas, either using biochemical processes or using thermochemical processes. Energy conversion using biochemical processes will produce ethanol and biodiesel, whereas conversion using thermochemical processes will produce

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oil and gas. This paper also describes the use of microalgae oil products.

2. Energy conversion from biomass

The advantages of culturing microalgae as a resource of biomass are [13]:

- Algae are considered to be a very efficient biological system for harvesting solar energy for the production of organic compounds.
- Algae are non-vascular plants, lacking (usually) complex reproductive organs.
- Many species of algae can be induced to produce particularly high concentrations of chosen, commercially valuable compounds, such as proteins, carbohydrates, lipids and pigments.
- Algae are microorganisms that undergo a simple cell division cycle.
- The farming of microalgae can be grown using sea or brackish water.
- Algal biomass production systems can easily be adapted to various levels of operational or technological skills.

In fact, microalgae have the highest oil yield among various plant oils. It can produce up to 100,000 l oil per ha year, whereas palm, coconut, castor and sunflower produce up to 5950, 2689, 1413 and 952 l per ha year, respectively [14].

The Aquatic Species Program (ASP) considered three main options for fuel production [15]. They are methane gas, ethanol and biodiesel. A fourth option is the direct combustion of the algal biomass for production of steam or electricity, but the ASP did not focus much attention on direct combustion.

Many algae are exceedingly rich in oil. The oil content of some microalgae exceeds 80% of the dry weight of algae biomass [16,17], and according to Oilgae [14], some have about 15–40% (dry weight), whereas palm kernel has about 50%, copra has about 60%, sunflower has about 55%. Oil content itself can be estimated to be 64.4% of the total lipid component [18].

The energy conversion reaction of biomass can be classified into biochemical, thermochemical and direct combustion [4,19]. Biochemical conversion can be further subdivided into fermentation, anaerobic digestion, bioelectrochemical fuel cells and other fuel producing processes utilizing the metabolism of organisms. Thermochemical conversion can be subdivided into gasification, pyrolysis and liquefaction. Fig. 1 shows the energy conversion processes from microalgae. Biomass can also be converted into three main products: two of them related to energy and one as a chemical feedstock [5].

It is well known that microalgae have high water contents (80–90%) [16]; therefore, not all energy conversion processes of biomass can be applied to microalgae. For example, direct combustion of microalgae is feasible only for biomass with moisture content

below 50%. High moisture content biomass is better suited to biological conversion processes [5].

3. Microalgal production

Microalgae can be cultivated by a large number of systems [20]. For small scale or laboratory scale, cultivation uses a small fermenter or internally illuminated photobioreactor [11,21] or box type water tanks [11]. The fermenter uses four fluorescents lamp as external irradiation, in which the degree of irradiation at the inner surface of the fermenter vessel is 10,000 lx or 20,000 lx [11] or by using other light distributors [21].

One of the major advantages of an internally continuously illuminated photobioreactor or by using a flat plate photobioreactor is that it can be heat sterilized under pressure, and thus, contamination can be minimized [21]. For large scale cultivation, algae can be grown either in open culture systems or closed systems [21,22]. Open ponds can be categorized into natural water (lake, lagoons, ponds) and artificial ponds or containers. The most commonly used systems include shallow large ponds, tanks, circular ponds and raceway ponds [21,22].

A tubular photobioreactor is one of the most suitable types for outdoor mass cultures. Most outdoor tubular photobioreactors are usually constructed with either glass or plastic tubes, and their cultures are recirculated either by a pump or an air lift system [21]. Tubular photobioreactors have advantages over conventional open ponds as they can be erected over any open space, can operate at high biomass concentration and keep out atmosphere contaminants [23] and they seem to be most satisfactory for producing algal biomass on the scale needed for biodiesel production [16]. The solar collector tubes are generally 0.1 m or less in diameter. Tube diameter is limited because light does not penetrate too deeply in the dense culture broth that is necessary for ensuring a high biomass productivity of the photobioreactor [17]. Instead of being laid horizontally on the ground, the tubes may be made of flexible plastic and coiled around a supporting frame to form a helical coil tubular photobioreactor [17]. The illustration in Fig. 2 [16] is a conceptual model for integrated biomass production that can be adopted for microalgal biodiesel production.

4. Harvesting and processing algal biomass

Algae can be harvested by using microscreens, centrifugation, or flocculation. Alum and ferric chloride are chemical flocculants used to harvest algae [24]. Other flocculant material is chitosin [25,24]. Harvesting by chemical flocculation is a method that is often too expensive for large operations. Interrupting the carbon dioxide supply to an algal system can cause algae in it to flocculate on its own, which is called autoflocculation [24]. The algal cells grown for a liquefaction process can also be harvested by a centrifugal separator [7].

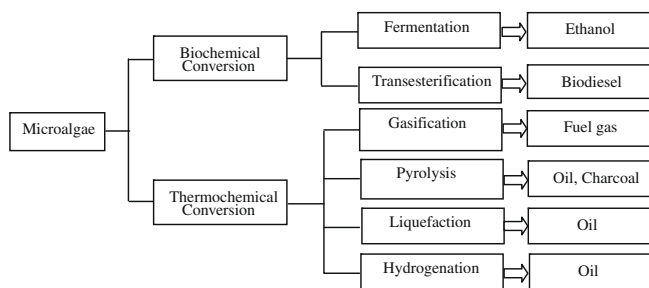


Fig. 1. Energy conversion processes from microalgae.

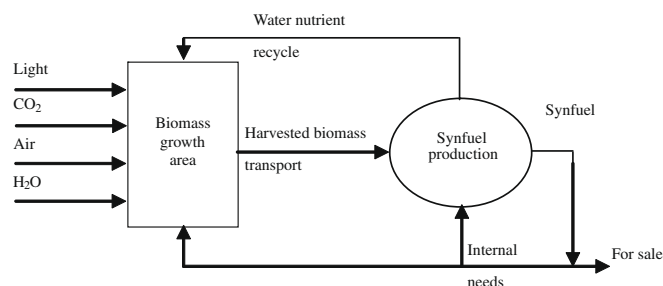


Fig. 2. A conceptual model for integrated biomass production.

- Algae oil can be extracted through a wide variety of methods [24,26].
- When algae are dried, it retains its oil content, which then can be pressed out with an oil press.
- Algal oil can be extracted using chemicals such as benzene, ether or hexane. This method can be combined with cold press. The processes together will be able to derive more than 95% of the total oil present in the algae.
- Enzymatic extraction uses enzymes to degrade the cell walls, which makes fractionation of the oil much easier.
- Osmotic shock is a sudden reduction in osmotic pressure; this can cause cells in a solution to rupture.
- For the supercritical fluid, CO_2 is liquefied under pressure and heated to the point that it has the properties of both a liquid and gas. This liquefied fluid then acts as the solvent in extracting the oil.

Algae oil can also be extracted by other methods [27]. Algae were ground with mortar and pestle. The ground algae were dried for 20 min at 80 °C in an incubator for releasing water. A solution of hexane and ether were mixed with the dried ground algae to extract oil, and then, the mixture was kept for 24 h for settling.

5. Energy production

5.1. Thermochemical conversion

5.1.1. Gasification

Gasification is a term that describes a chemical process by which carbonaceous materials (hydrocarbon) are converted to a synthesis gas (syngas) by means of partial oxidation with air, oxygen and/or steam at high temperatures, typically in the range 800–900 °C. A flow diagram of a microalgae system for fuel production by low temperature catalytic gasification of biomass is shown in Fig. 3 [4].

A novel energy production system using microalgae with nitrogen cycling combined with low temperature catalytic gasification of the microalgae has been proposed [28]. Elliot has also developed a low temperature catalytic gasification of biomass with high moisture content [29]. Biomass with high moisture is gasified directly to methane rich fuel gas without drying. In addition, nitrogen in the biomass is converted to ammonia during the reaction [28].

5.1.2. Liquefaction

Microalgal cell precipitates derived from centrifugation, which are of high moisture content, are thus good raw materials for liquefaction [11]. Direct hydrothermal liquefaction in sub-critical water conditions is a technology that can be employed to convert wet biomass material to liquid fuel [16].

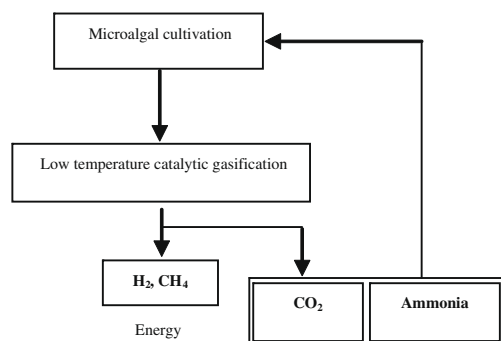


Fig. 3. Flow diagram of a microalgal system for fuel production by gasification.

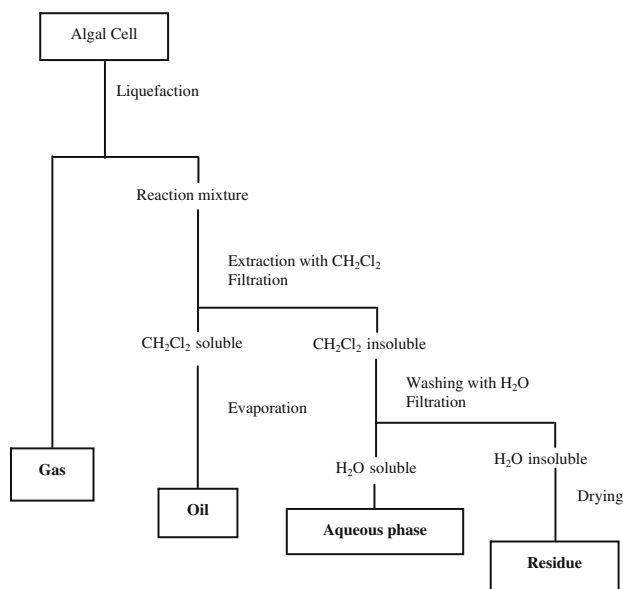


Fig. 4. Separation scheme for liquefies microalgal cells.

The separation scheme is presented in Fig. 4 [7,11,30,12,31,32]. The liquefaction is performed in an aqueous solution of alkali or alkaline earth salt at about 300 °C and 10 MPa without a reducing gas such as hydrogen and/or carbon monoxide [7].

Liquefaction can be performed by using a stainless steel autoclave with mechanical mixing. The autoclave is charged with algal cells, following which nitrogen is introduced to purge the residual air. The reaction is initiated by heating the autoclave to a fixed temperature and by elevated nitrogen pressure. The temperature is maintained constant for a 5–60 min period, following which it was cooled with the use of an electric fan.

The reaction is extracted with dichloromethane in order to separate the oil fraction. The dichloromethane extract was filtered from the reaction mixture, following which the residual dichloromethane is filtered and evaporated at 35 °C under reduced pressure, yielding a dark brown viscous material (hereafter referred to as the oil). The aqueous phase resulting after dichloromethane extraction (insoluble fraction) is washed with water and filtered from the dichloromethane insoluble [7,11].

5.1.3. Pyrolysis

Pyrolysis is conversion of biomass to biofuel, charcoal and gaseous fraction by heating the biomass in the absence of air to around 500 °C [5,33], or by heating in the presence of a catalyst [34], at high heating rate (10^3 – 10^4 K/s) and with short gas residence time to crack into short chain molecules and then being cooled to liquid rapidly [35]. Previous studies were using slow pyrolysis processes; they were performing at a low heating rate and a long residence time. The longer residence times can cause secondary cracking of the primary products, reducing yield and adversely affecting the biofuel properties. In addition, a low heating rate and long residence time may increase the energy input [33]. In recent years, fast pyrolysis processes for biomass have attracted a great deal of attention for maximizing liquid yields, and many researches have been performed [33].

The advantage of fast pyrolysis is that it can directly produce a liquid fuel [36]. If flash pyrolysis is used, the conversion of biomass to bio-crude with an efficiency of up to 80% is enabled. A conceptual fluidized bed fast pyrolysis system is shown in Fig. 5 [36].

Since algae usually have high moisture content, a drying process requires much heating energy [12]. Microalgae are subjected

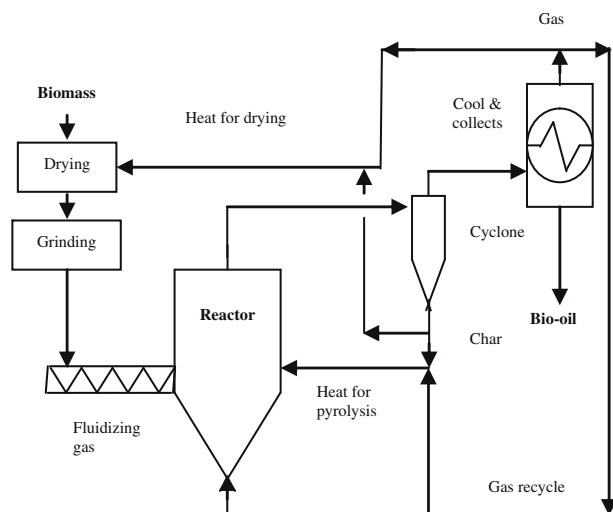


Fig. 5. Fast pyrolysis process principles.

to pyrolysis in the fluid bed reactor. The result of the reaction then flows to a cyclone and is separated into char, biofuel and gas. The resultant gas can be used for heating for drying the raw material or for heating for the pyrolysis process.

5.1.4. Hydrogenation

Hydrogenation is a reductive chemical reaction that results in an addition of hydrogen (H_2), usually to saturate organic compounds. The process consists of the addition of hydrogen atoms to the double bonds of a molecule through the use of a catalyst [37].

Algal hydrogenation is performed by using an autoclave under high temperature and pressure conditions in the presence of a catalyst and a solvent. Algal hydrogenation is a three-phase operation in which contact must be established between the gaseous phase (hydrogen and hydrocarbon phase), liquid phase (mixture of solvent and liquid product), and solid particle phase (algal and catalyst) in order to achieve algal conversion and to promote the transfer of momentum, heat and mass [11].

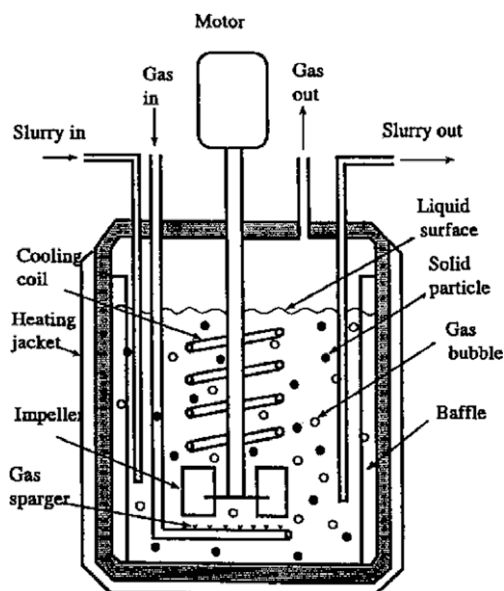


Fig. 6. Apparatus used for hydrogenation within an autoclave.

A stirred slurry reactor, illustrated schematically in Fig. 6 [11] was employed to perform the three-phase operation. The gaseous reactant was bubbled through the liquid from a sparger at the bottom of the reactor, and the solid particles, slurried with the liquid, were fed to the reactor. The gaseous reactant and the solid reactant first dissolve in the liquid phase and diffuse with the liquid reactant towards the catalyst. All these reactants then interact at the surface of the catalyst.

The liquid products, solid particles and unreacted materials were continuously drawn off to maintain a constant liquid level within the reactor, and a constant composition in the liquid phase. Gaseous products and unreacted gaseous reactant entered the space above the liquid surface and flowed out through a gas pipe.

5.2. Biochemical conversion

5.2.1. Fermentation

The principle of ethanol production from microalgae is shown in Fig. 7. It consists of microalgal cultivation, algal cells' harvest, slurry preparation, fermentation and ethanol separation process [9].

Fermentation is used commercially on a large scale in various countries to produce ethanol from sugar crops and starch crops. The biomass is ground, and the starch is converted by enzymes to sugar. The sugar is converted to ethanol by yeast. The purification process of ethanol by distillation is an energy intensive step [5].

Production of ethanol by using microalgal as raw material can be performed according to the following procedure. In the first step, the starch of microalgae is released from the cells with the aid of mechanical equipment or an enzyme. When the cells begin to degrade, *Saccharomyces cerevisiae* yeast is added to the biomass to begin fermentation. The product of fermentation is ethanol. The ethanol is drained from the tank and pumped to a holding tank to be fed to a distillation unit.

Another research [38] investigated ethanol production by dark fermentation in the marine green alga *Chlorococcum littorale*. Under dark anaerobic conditions, 27% of the cellular starch was consumed within 24 h at 25 °C, the cellular starch decomposition being accelerated at higher temperature. Ethanol, acetate, hydrogen and carbon dioxide were obtained as fermentation products. The maximum productivity of ethanol was 450 $\mu\text{mol/g-dry weights}$ at 30 °C.

5.2.2. Transesterification

Transesterification is a process of exchanging the alkoxy group of an ester compound by another alcohol. The reactions are often catalyzed by an acid or a base [34], using a homogeneous or heterogeneous catalytic process [39]. Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. The alcohol combines with the triglycerides to form glycerol and esters [34]. The result of the transesterification process is biodiesel. In order to get high yield of the ester, the alcohol has to be used in excess [40].

Many reports mention that they produced biodiesel with simple processes and equipments available at home. A few websites

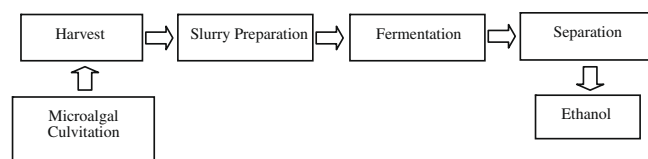


Fig. 7. Fermentation process of microalgae.

presented biodiesel production methods, such as Journey to forever [43], B [44], and D [45]. They explained in detail how to produce biodiesel by using either virgin vegetable oil or waste vegetable oil or animal fat.

However, according to our experience, the production results were not always the same as the websites explanation. The yields of production were about 70% to 90% or even lower; meanwhile, the websites informed that the yields of production were always more than 90%.

Fig. 8 shows the schematic process of biodiesel production. The first step is removing water content from the oil by increasing its temperature to 120 °C for about 5–10 min. After that, it is allowed to cool, and by using a catalyst tank with mixed sodium hydroxide and methanol and stirring, sodium methoxide is produced. Meanwhile, clean oil is heated to 60 °C for 5 min, mixed with the sodium methoxide and the mixture transferred to ultrasonic or mixer equipment. This equipment agitates the solution for 30 min. After the mixing process, the solution is allowed to cool and separate. The separation process takes approximately from 15 to 60 min. The methyl ester (ME) or biodiesel would float on the top layer, while the denser glycerin would be in the bottom layer. In the last step, the biodiesel is washed, dried, and then quality tested.

6. Result of processes

6.1. Gasification

Gasification is the conversion of biomass into combustible gas such as H_2 , CH_4 , CO_2 and ammonia. The product gas has low calorific value (about 4–6 MJ/N m³), and it can be burned directly or used as a fuel for gas engines and gas turbines, or it can be used as a feedstock (syngas) in the production of chemicals (e.g. methanol) [5].

Although syngas has a lower heating value than natural gas, it can still be used in highly efficient combined cycle electric power plants, or it can be used to make many products including ammonia fertilizers, methanol-derived chemicals and clean burning synthetic fuels.

6.2. Liquefaction

According to FAO, the result of liquefaction of microalgal cells is heavy oil or tarry material with the yield of 35.6% [11], or in the range 31–44% [7] or in the range 30–40% [19]. This heavy oil consists of carbon (73%), hydrogen (9%), nitrogen (5%) and oxygen (13%). The heating value of the heavy oil was 34.7 kJ/g, which is almost the same as that of C heavy oil. The heavy oil had a viscosity of 860 cps, which was similar to that of castor oil. This heavy oil was of higher nitrogen content than ordinary petroleum, thus necessitating requirements for flue gas treatment in order to prevent the formation of NO_x .

Minowa et al. [7] reported an oil yield of about 37% (organic basis) by direct hydrothermal liquefaction at around 300 °C and 10 MPa from *Dunaliella tertiolecta* with moisture content of 78.4 wt%. The oil obtained at a reaction temperature of 340 °C and holding time of 60 min had a viscosity of 150–330 mPas and a calorific value of 36 kJ g⁻¹, comparable to those of fuel oil. In a similar study on oil recovery from *Botryococcus braunii*, a maximum yield of 64%, dry weight basis, of oil was obtained by liquefaction at 300 °C catalyzed by sodium carbonate [16,46].

The calorific value can be calculated according to the Dulong formula [7,31]. The produced gas consisted mainly of methane and carbon dioxide. As shown in Table 1, the concentrations of the components in the produced gas were higher, indicating that the algae were changed by gasification under the conditions of high temperature and high pressure [12].

6.3. Pyrolysis

The product of pyrolysis is bio-oil. The bio-oil can be used in engines and turbines and as feedstock for refineries [5]. Many investigators have also studied the pyrolysis of triglycerides to obtain products suitable for diesel engines [34].

The bio-oil has a higher heating value of about 17 MJ/kg, as compared to around 42–44 MJ/kg for conventional fuel oil [36]. According to Miao et al. [33], the heating value of bio-oil from microalgae is 29 MJ/kg on average, which is about 1.4 times that of wood.

Table 2 is a comparison of the typical properties of fossil oil and bio-oil from fast pyrolysis of wood and microalgae [33].

The physical properties of bio-oil of microalgae make it more suitable for fuel oil use than oils from lignocellulosic material. The lower oxygen contents of microalgae bio-oil will make them have better storage stability than that of wood. The liquid fuels from fast pyrolysis of microalgae can be used in many applications as direct substitutes for conventional fuel or as a source of chemicals [33].

6.4. Hydrogenation

Algae can be converted to liquid hydrocarbons at temperatures between 400 and 430 °C and operating hydrogen pressures of about 7–14 MPa in the presence of a cobalt molybdate catalyst. The highest oil yield obtained was 46.7 wt% on the basis of algae charged. In addition, up to 10 wt% liquid products and 34 wt% hydrocarbon rich gases were obtained. In general, higher temperatures and longer reaction times increase the degree of conversion and oil yield and decrease the asphaltene yield in the overall hydrogenation of algae. The oil yield and the degree of conversion also increase proportionally with hydrogen pressure to a maximum of about 8.2 MPa, and then level off [11]. Another researcher reported that by using a very high temperature, high pressure, catalyzed hydrogenation process, the resulting yield of liquid hydrocarbon was close to 50% [19].

6.5. Fermentation

The fermentation product of microalgae is ethanol. Ethanol can be used as fuel (100% alcohol) or as gasohol or a mixture of 90% gasoline and 10% ethanol. Flex-fuel engines in Brazil are able to work with all ethanol, all gasoline or any mixture of both. In the US, flex-fuel vehicles can run on 0% to 85% ethanol (15% gasoline) since higher ethanol blends are not yet allowed [47].

The energy of ethanol is 31.1 MJ/kg with an octane number of 129, whereas regular gasoline is 44.4 MJ/kg with an octane number of 91 minimum, and gasohol (90% gasoline and 10% ethanol) is 33.7 MJ/l with an octane number of 93/94 [47]. Ethanol may be

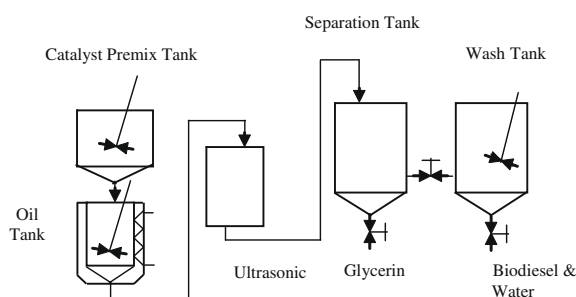


Fig. 8. Schematic process of biodiesel production.

Table 1

Production of methane and carbon dioxide in the thermochemical liquefaction of algae.

Holding time (min)	Na ₂ CO ₃ dosage (wt%)	Reaction temp (°C)	Gas volume (l)	Concentration (ppm)	
				CH ₄	CP ₂
30	0	300	1.1	56	625
	0	340	1.1	376	1250
	5	300	1.4	31	625
	5	340	1.5	227	1300
60	0	300	1.7	65	250
	0	340	1.5	352	1300
	5	300	1.5	74	750
	5	340	1.8	283	650

Table 2

Comparison of typical properties of fossil oil and bio-oil from fast pyrolysis of wood and microalgae.

Properties	Typical value		
	Bio-oils		Fossil oil
	Wood	Microalgae	
C (%)	56.4	61.52	83.0–87.0
H (%)	6.2	8.50	10.0–14.0
O (%)	37.3	20.19	0.05–1.5
N (%)	0.1	9.79	0.01–0.7
S (%)	n.d. ^a	n.d.	0.05–5.0
Density (kg l ^{−1})	1.2	1.16	0.75–1.0
Viscosity (Pas)	0.04–0.20 (at 40 °C)	0.10 (at 40 °C)	2–1000 (depends on temperature, density and its contents etc.)
Heating value (MJ kg ^{−1})	21	29	42
Stability	Not as stable as fossil fuels	Not as stable as fossil fuels, but more stable then the bio-oil from wood	

^a n.d.: Not determined.**Table 3**

Comparison of properties of biodiesel, diesel fuel and ASTM standard.

Properties	Biodiesel from microalgae oil	Diesel fuel ^a	ASTM biodiesel standard
Density (kg l ⁻¹)	0.864	0.838	0.86–0.90
Viscosity (mm ² s ⁻¹ , cSt at 40 °C)	5.2	1.9–4.1	3.5–5.0
Flash point (°C)	115	75	Min 100
Solidifying point (°C)	–12	–50 to 10	–
Cold filter plugging point (°C)	–11	–3.0 (max –6.7)	Summer max 0 Winter max <–15
Acid value (mg KOH g ⁻¹)	0.374	Max 0.5	Max 0.5
Heating value (MJ kg ⁻¹)	41	40–45	–
H/C ratio	1.81	1.81	–

^a The data about diesel fuel was taken from published literature as indicated in the text.

used as a fuel to power a direct ethanol fuel cell in order to produce electricity [47,48]. Ethanol was also used as a fuel in early bipropellant rocket vehicles in conjunction with an oxidizer such as liquid oxygen [47].

6.6. Transesterification

The conversion of triglycerides or oil to biodiesel can achieve 98% [41] or greater than 98% [42] as an alternative fuel for Diesel engines.

The results of the biodiesel product should be quite similar to those of conventional Diesel in its main characteristics or compatible with conventional petroleum Diesel, and it can also be blended in any portion with petroleum Diesel.

The standard specification for biodiesel fuel for B100 is ASTM D6751 [45,49,50]. The level of blending is designated Bxx, where xx indicates the amount of biodiesel in the blend.

The physical and fuel properties of biodiesel from microalgae oil, in general, were comparable to those of Diesel fuel. The biodiesel

from microalgae oil showed a much lower cold filter plugging point of –11 °C in comparison with that of Diesel fuel, as shown in Table 3 [51].

A side product of the transesterification process is soap formation and glycerin. It is well known that utilization of lye in vegetable oil transesterification will produce soap. An attempt to minimize the soap formation was by using a catalyst-free, supercritical methanol method [52]. Glycerin is one of the side products, for which, according to Refs. [53,41], the rule of thumb is 79 ml of glycerin per liter of oil used, but according to experience, the glycerin content range is 80–120 ml per liter oil.

7. Conclusions

Microalgae are a sustainable energy resource with great potential for CO₂ fixation. For biofuel production, a large quantity of algal biomass is needed. The microalgae could be grown in photobioreactors or in open ponds.

Microalgae have the highest oil yield among various plants such as palm oil coconut, castor bean and sunflower seeds. The oil content of microalgae is between 15% and 40% of dry weight, but some microalgae have up to 80%. Oil content can be estimated to be 64.4% of the total lipid component. Algae oil can be extracted through a wide variety of methods or combinations of some methods.

The gasification process produces combustible gas such as H_2 , CH_4 , CO_2 and ammonia, whereas the product of pyrolysis is biofuel. The biofuel can be used in engines and turbines and as feedstock for refineries. The fermentation product of microalgae is ethanol. Ethanol can be used as fuel (100% alcohol) or as gasohol.

By using a transesterification process, algae oil can be converted to biodiesel. The biodiesel product has its main characteristics quite similar to those of conventional Diesel or compatible with conventional petroleum Diesel, and it can also be blended in any proportion with petroleum Diesel.

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