Chapter 12

The Role of Microalgae in Renewable Energy Production: Challenges and Opportunities

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Additional information is available at the end of the chapter

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Abstract

Microalgae are one of the most effective sources of renewable energy production. It can grow at high rates and capable of producing oil along the year. Microalgae biomass was first suggested as a feedstock for biofuel production and received early attention for commercial application. Microalgae are expected to be a vital raw material for amino acids, vitamins and productions of valuable byproducts. The cultivation of microalgae is known to be the most gainful business in the biotechnological industry. It is a waste less, environmentally pure, energy and resource saving route. Biodiesel production from algal lipid is non-toxic and highly biodegradable. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: thermal, chemical and biochemical methods, in addition to the large number of different agents for decomposing and hydrolysing. We can obtain the low-cost energy production from the wastewater treatment by using microalgae. Finally, biodiesel production by microalgae in Egypt is not practical at the economical level. In order to improve biodiesel fuel quality, the alga must be subjected to genetic engineering for up-regulation of fatty acid biosynthesis and/or by down-regulation of β-oxidation. Economically, the algal biomass must be processed for bio-refinery to maximize its utilization for different applications.

Keywords: microalgae, cultivation, biomass production, conversion, challenges and opportunities

1. Introduction

Recently, algae have become the latest feasible source being targeted for biofuel production since they exhibit several attractive features [1]. Microalgae are capable of producing oil all year long. Oil productivity of microalgae is greater compared to conventional crops [2].

The oil content of microalgae which ranged from 20 to 50% is more than other competitors; microalgae yield 15–300 times more oil for biodiesel production than traditional crops on an area basis. Creation of biodiesel from algal lipid is non-toxic and greatly biodegradable. Microalgae can propagate at great rates which can be 50 times more than that of the fastest growing terrestrial crop [3]. They can complete their growth cycle in few days by photosynthesis process that converts sun energy into chemical energy. They have higher photon conversion efficiency; it is about 3–8% against 0.5% for terrestrial plants. Microalgae do not vie for land with food crops [4]. They grow in fresh water, seawater, wastewater or non-arable lands, and can be grown almost anywhere [5]. Therefore, they have minimal environmental effect such as deforestation. So, microalgae are an alternative fuel feedstock that could avoid fuel versus food conflict [6]. Comparing with other renewable energy sources such as solar, geothermal, wind, tidal energy, etc., algae are more controlled and stable for production of energy compared to land-based biomass, algaculture has the potential to produce larger amounts of biofuel with no use of good water or fertile land [1].

Microalgal biomass was first suggested as a feedstock for biofuel production in the 1960s [7] and received early attention from the US National Renewable Energy Laboratory (NREL) in the 1980s. This interest resurged based on their potential for cultivation near coal, petroleum and natural gas power plants. In the last few years, many research and commercial applications of microalgae have gained more interest. Recently, renewable energy source is organic matter derived from microalgal biomass [8]. Newly, high value microalgae and products are commercially cultivated in both closed photobioreactors (PBRs) and open raceway ponds although over 90% of current production is from open raceways. Of course, PBRs have several advantages over open ponds as a cultivation system. However, an open pond is considerably cheaper. Microalgae, which are using in cultivation, is microscopic single cell and have a possible to produce large amounts of lipids (40–50% w/w oil) suitable for biodiesel production. Using sunlight, carbon dioxide and nutrients alone, algae can create and accumulate large amounts of neutral lipids, carbohydrates and other valuable co-products [9]. Studies show that algae could yield up to 10,000 gal/acre (about 94,000 l/ha) of biofuel per year, while corn would only yield 60 gal/acre (about 560 l/ha) annually and potential algae-derived biodiesel yields range from 5000 to 100,000 l/ha/a. Microalgae can also produce up to 60% of their biomass in the form of oil or carbohydrates, from which biofuel and many other industrially important products can be obtained, In addition to, potential use of algae for CO_2 sequestration process. The emissions of CO_2 from industrial unit are the primary nutrient for growing microalgae. This provides the opportunity for the algae to turn pollutants into lipids [10]. Research and scientific studies carried out at several universities and research institutes around the world regarding the benefits and potentials of algaculture have proven that algae can provide future global energy needs in a sustainable and cost-effective way. Many researchers considered biodiesel produced from microalgae as the third-generation biofuels. Microalgae can be a sustainable renewable energy source for biodiesel to overcome the limitations of first- and second-generation biofuels. Biodiesel production using microalgae is attractive in a number of respects and is the most obvious choice. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: thermal, chemical and biochemical methods [11].

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Biotechnology-based conversion processes can be used to ferment the biomass carbohydrate content into sugars that can then be further processed. As one example, the fermentation path to lactic acid shows promise as a route to biodegradable plastics. Biomass can be fermented to provide ethanol and biogas [12]. Unconventional is to employment thermochemical conversion processes, that use gasification or pyrolysis of biomass to yield a hydrogen-rich synthesis gas that used in a widespread range of chemical processes. Therefore, a bio-refinery is a facility that contributes biomass conversion processes and tools to produce fuels and chemicals from biomass. Concept of bio-refinery is equivalent to the petroleum refinery, which harvests numerous fuels [13].

2. Energy

Energy is essence of life. Broadly, it is defined as the ability to do work or the ability to cause alteration, such as manufacturing molecules or moving substances. Potential energy can be believed of as kept energy. Chemical energy, in the bonds among atoms in a molecule, is a form of potential energy. Kinetic energy can be believed of as free energy, and is commonly linked with motion. Heat (dynamic motion of molecules) and movement of large objects (such as ourselves) are formulae of kinetic energy.

There are many forms of energy, including: chemical, electrical, gravitational, mechanical, nuclear, radiant and thermal energy. The official SI unit for energy is the joule (J); energy can also be measured in calories or British thermal units (Btu) [14]. In physics, energy is a property of objects which can be transferred to other objects or converted into different forms [15]. The "ability of a system to perform work" is a common description, but it is misleading because energy is not necessarily available to do work [16].

Public energy forms include the potential energy stored by an object's position in a force field (gravitational, electric or magnetic), the kinetic energy of a moving object, the chemical energy free out when a fuel burns, the elastic energy stored by stretching solid objects, the radiant energy approved by light and the thermal energy with an object's temperature. Entirely of the many forms of energy are exchangeable to other types of energy. In physics, there is a widespread law of conservation of energy which states that energy can be neither produced nor be damaged; however, it can alterated from one shape to another. Energy conversion includes creating electric energy from heat energy by way of a steam turbine, or by lifting against gravity which led to mechanical work on the object and accumulations gravitational potential energy in the object. If the object falls to the ground, gravity does mechanical work on the object which converts the potential energy in the gravitational field to the kinetic energy liberated as heat on impact with the ground. Living organisms want available energy to stay alive, such as the energy humans get from food. Civilization gets the energy it needs from energy resources such as fossil fuels, nuclear fuel or renewable energy such as solar energy which comes from the sun and required for survival all living organisms (**Figure 1**).

The procedures of Earth's climate and ecosystem are driven by the radiant energy Earth receives from the sun and the geothermal energy contained within the earth.

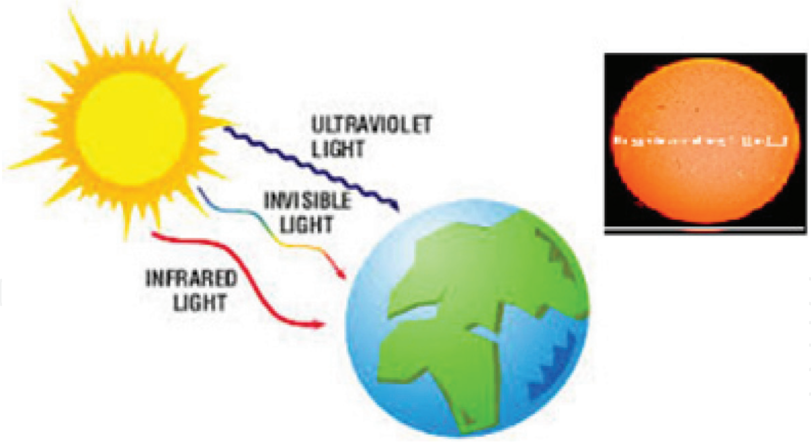

Figure 1. The Sun is the source of energy on the Earth.

2.1. History of energy

The term energy comes since the Ancient Greek: energeia "activity" [17] which perhaps seems for the first time in the work of Aristotle in the 4th century BC. In reverse to the recent definition, energeia was a qualitative philosophical theory, broad sufficient to include ideas such as gladness and pleasure.

In 1807, Thomas Young was possibly the first to use the term "energy" instead of vis viva or living force, in its recent common sense [18]. Gustave-Gaspard Coriolis termed "kinetic energy" in 1829 in its recent common sense, and in 1853, William Rankine created the word "potential energy". The law of energy conservation was also first recommended in the early 19th century, and put on to any isolated system. It was discussed for some years whether heat was a physical substance, dubbed the caloric, or simply a physical quantity, such as momentum.

In 1845, James Prescott Joule open the theory of energy conservation, formalized largely by William Thomson (Lord Kelvin) as the field of thermodynamics. Thermodynamics assisted the quick advance of clarifications of chemical processes by Rudolf Clausius, Josiah Willard Gibbs and Walther Nernst. It moreover led to a mathematical construction of the concept of entropy by Clausius and to the starter of radiant energy laws by Jožef Stefan. The energy conservation is a consequence of the fact that the laws of physics do not change over time, according to Noether's theorem [19].

2.2. Forms of energy

The whole energy of a system can be divided in different ways. For instance, classical mechanics differentiates between kinetic energy, which is decided by an object's motion through space, and potential energy, that is a function of the site of an object inside a field (**Figure 2**). It may be too suitable to discriminate gravitational energy, thermal energy, numerous kinds of nuclear-powered energy (which use capacities from the nuclear force and weak force), electric energy (from the electric field) and magnetic energy (from the magnetic field) between others. Several of these taxonomies overlap; for example, thermal energy ordinarily involves partly of kinetic and partly of potential energy (**Figure 3**).

Figure 2. Energy is converted into the same amount of energy in other forms, mostly light energy and thermal energy.

Potential energies are frequently measured as positive or negative depending on whether they are greater or less than the energy of a specified base state or configuration such as two interacting bodies being infinitely far apart. Some example of different kind of energy with description is shown in **Table 1** and **Figure 4**.

2.3. Types of energy

Energy is the power we use for transportation, for heat and light in our homes and for the manufacture of all kinds of products. There are two sources of energy: renewable and nonrenewable energy [20] **Figure 5**.

2.3.1. Nonrenewable sources of energy

We use the most types of energy which originates from fossil fuels, for instance, natural gas, coal and petroleum. Uranium is considered as nonrenewable source, but it is not a fossil fuel. It is changed to a fuel and undergoes the nuclear power plants. As soon as these normal

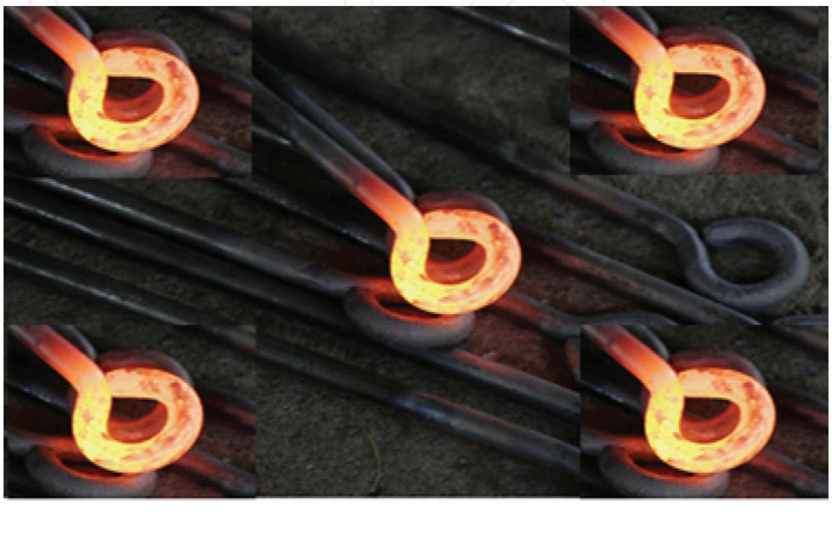

Figure 3. Thermal energy is energy of microscopy constituents of matter, which may include both kinetic and potential energy.

Forms of energy	
Type of energy	**Description**
Kinetic	(-o), that of the motion of a body
Potential	A category comprising many forms in this list
Mechanical	The sum of (usually macroscopic) kinetic and potential energies)
Mechanical wave	(-o), a form of mechanical energy propagated by a material s oscillations
Chemical	That contained in molecules
Electric	That from electric fields
Magnetic	That from magnetic fields
Radiant	(-o), that of electromagnetic radiation including light
Nuclear	That of binding nucleons to form the atomic nucleus
Ionization	That binding an electron to its atom or molecule
Elastic	That of de formation of material (or its container) exhibiting a restorative force
Gravitational	That from gravitational field
Rest	(-o) that equivalent to an objects rest mass

Table 1. Some examples of different kinds of energy.

resources are used up, they are gone forever. The process of meeting these fuels can be dangerous to the biomes from which they originate. Fossil fuels are set through a process named burning for create energy. Burning liberates pollution, such as sulfur dioxide and carbon monoxide which can result in acid rain and global warming.

2.3.2. Renewable sources of energy

Renewable energy resources can be used over and over again. Renewable resources contain wind, geothermal energy, solar energy, hydropower and biomass. That resource generates much less pollution, both in gathering and production, than nonrenewable sources.

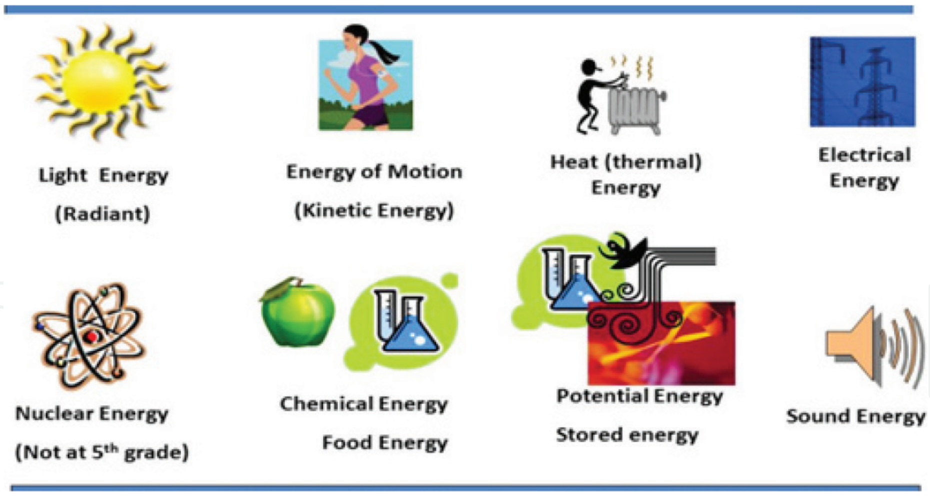

Figure 4. Forms of energy.

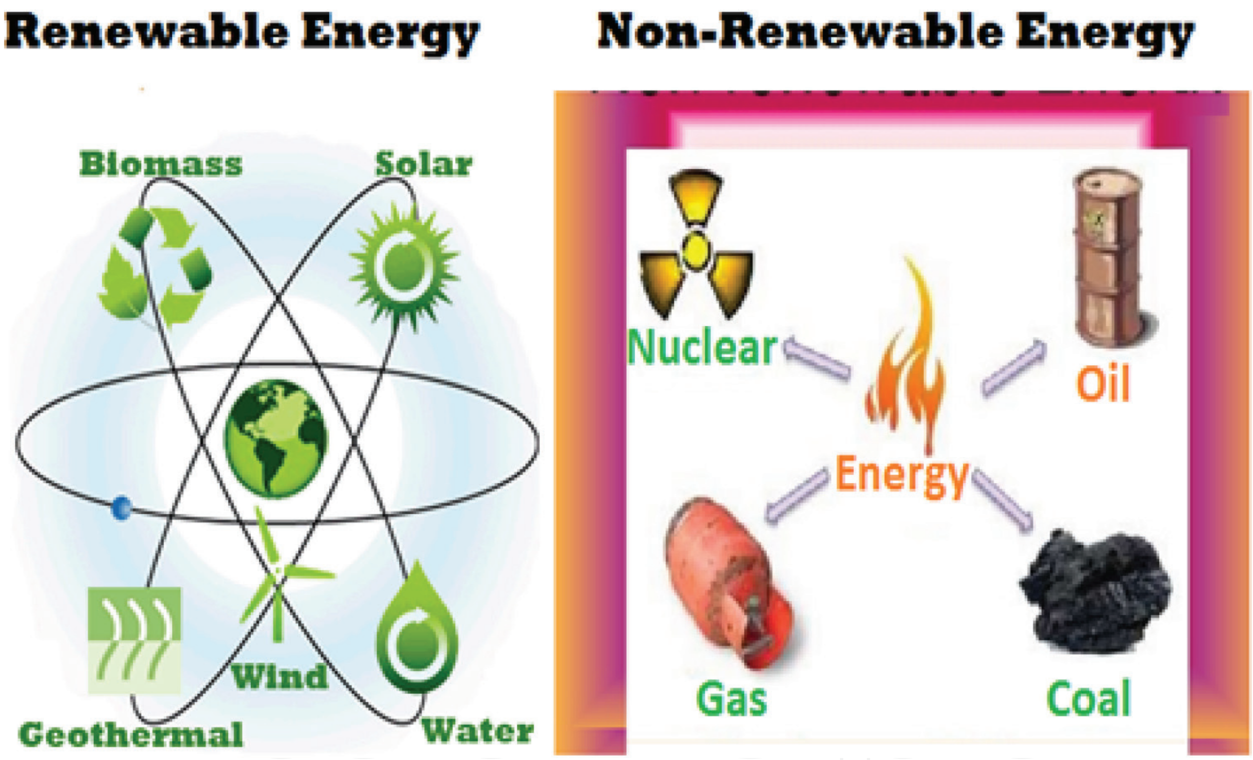

Figure 5. Types of energy.

- The sun produces the solar energy. Some people use solar panels on their homes to convert sunlight into electricity.
- Wind turbines generate electricity. Turbines look like giant windmills
- Earth's crust produces the geothermal energy. Engineers extract steam or very hot water from the Earth's crust and use the steam to generate electricity.
- Dams and rivers generate hydropower. When water flows through a dam it activates a turbine, which runs an electric generator. Biomass includes natural products such as wood, manure, corn and algal biomass of living organisms which used as energy source.

3. Biomass production

Biomass, a renewable energy source, is organic matter resulting from living, or newly living organisms. It can be used as a source of energy and it most ultimately pointed to plant-based materials which are not used for feed, and are specially named lignocellulosic biomass. Biomass can either be used in a straight line throughout burning to create heat such as forest residues and municipal solid waste, or indirectly after converting it to various types of biofuel. Conversion of biomass to biofuel can be summarized by different methods which are generally classified into: thermal, chemical and biochemical methods [11].

3.1. Biomass sources

Biomass is considered the simply source of fuel for domestic use in several developing countries even today. Biomass is entire biologically created matter based in hydrogen, carbon and oxygen. The assessed biomass yield in the world is 104.9 petagrams (104.9×10^{15} g–about 105 billion metric tons) of carbon/year, approximately half on land and half in the ocean [21].

Even today, wood remains the largest biomass energy source [22]; examples include forest residues (such as dead trees). Wood energy is derived by using lignocellulosic biomass (second-generation biofuels) as fuel. Depending on the biomass source, biofuels are divided generally into two main groups. First-generation biofuels are resulting from origin such as corn starch and sugarcane. Sugars existing in the biomass are fermented to yield bioethanol, which can be used immediately in a fuel to yield electricity or act as a flavor to gasoline [23]. Second-generation biofuels use non-food-based biomass sources, for instance, municipal waste and agriculture. These biofuels are often composed of lignocellulosic biomass, which is not edible and is a low-charge waste for several industries. Although being the favored substitute, except the second-generation biofuel neither yields an inexpensive production nor achieved by technological issues. These issues appear essentially due to chemical slowness and building inflexibility of lignocellulosic biomass [24].

Energy derived from biomass is projected to be the largest non-hydroelectric renewable resource of electricity in the US between 2000 and 2020 by Energy Information Administration [25]. There is research involving algae as non-food source can be yielded at rates of 5:10 times those of other kinds of land-based agriculture, for example, soy and corn. As soon as gathered, it can be fermented to yield biofuels, for example, ethanol and methane, in addition to hydrogen and biodiesel [26].

3.2. Biomass types

Researchers characterize the various types of biomass in different ways but one simple method is to define four main types, namely woody plants, herbaceous, plants/grasses, aquatic plants and manures.

Resources of biomass include primary, secondary and tertiary. The first one (primary biomass resources) consisted directly by photosynthesis process and are income directly from the land. They contain permanent short-rotation woody crops and herbaceous crops, the seeds of oil crops and remains produced from the collecting of forest trees and agricultural

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crops. Secondary biomass resources result from the processing of primary biomass resources such as agricultural by-product (field crop residues) and water vegetation (algae, seaweeds, etc.). Tertiary biomass resources are post-consumer residue streams including animal fats and greases, used vegetable oils, packaging wastes and construction and demolition debris [27] as shown in **Table 2**. Algae used as third generation of biofuels production. This generation of biofuels is advanced and is based on biological. Many species of algae naturally produce low levels of long-chain fatty acids, when they are stressed, this algae species can be screened and/or modified to increase the production yields of long-chain fatty acids.

3.3. Algae

Microalgae are prokaryotic or eukaryotic photosynthetic organisms. Indeed, they can grow quickly in fresh or salt water due to their unicellular or simple multi-cellular building structure. Because of their simple cellular structure, they are very capable converters of solar energy. Microalgae are oxygen-producing microorganisms containing chlorophyll “a”, mostly autotrophs, using atmospheric CO_2 as primary carbon source [28]. As the cells of microalgae grow in aqueous suspension, they have efficient access of water, CO_2 and other nutrients [29]. Microalgae are one of the oldest living organisms in our planet and have more than 300,000 species. Several species of them have oil content up to 80% of their dry body weight. **Table 3** shows oil contents of different microalgal species [30].

BIOMASS CLASSIFICATION

Category	Source	Raw material
Primary biomass: It is available “in the field” and needs to be collected to be available.	Woody biomass	• Forest arisings • Wood process residues • Recovered woodfuels from land clearance or municipal green waste
Secondary biomass: It is produced after biomass processing.	Agricultural biomass	• Energy crops (short rotation and annuals) • Water vegetation (algae, seaweeds, etc.) • Agricultural by-products (field crop residues) • Animal by-products (cattle, pigs, horses, poultry, humans) • Agro-industrial by products (bagasse, rice husks, etc.)
Tertiary biomass: It is available after a biomass-derived commodity has been used (waste streams).	Industrial and municipal bio-degradable wastes	• Organic fraction of Municipal Solid Waste (MSW) • Sludges • Waste and demolition wood • Landfill gas

Table 2. Biomass classification.

Microalga	Oil content (% dry wt)
Botryococcus braunii Kützing 1849	25-75
Chlorella sp. Beyerinck [Beijerinck] 1890	28-32
Crypthecodinium cohnii (Seligo) Javornicky 1962	20
Cylindrotheca sp. (Ehrenberg) Reimann & J.C.Lewin 1964	16-37
Dunaliella primolecta Butcher 1959	23
Isochrysis sp. Parke 1949	25-33
*Nannochloropsis sp.*D.J.Hibberd, 1981	31-68
Nannochloris oculata Droop 1955	20-35
Nannochloris sp. Naumann 1919	35-54
Nitzschia sp. Hustedt 1954	45-47
Phaeodactylum tricornutum Bohlin 1898	20-30
Schizochytrium sp. Goldstein & Belsky, 1964	50-77
Tetraselmis suecica (Kylin) Butcher 1959	15-23

Table 3. Oil content of different microalgal species.

Microalgae can grow in wastewater, thus giving it the ability to address treatment, utilization and disposal concerns [9]. Also, it can be grown in arid and semi-arid regions with poor soil quality, with a per hectare yield estimated to be many times greater than that of even tropical oil seeds [9].

3.4. Advantages of using algae as renewable energy source

Microalgae can be considered as a sustainable energy source of next generation biofuels [31]. Microalgae are able to create oil along the year. Microalgae produce oil is more compared to conventional crops. Microalgae oil content is in the range of 20 to 50% which is better than other challengers. Microalgae yield 15–300 times greater oil for biodiesel production than traditional crops. Biodiesel yield from algal lipid is distinguished with a high biodegradable and non-toxic. Microalgae can cultivate in high amounts arrived to 50 times greater than that of switchgrass, which is the more growing terrestrial crop. Microalgae can complete the whole growth cycle in limited days by way of photosynthesis process that alters sun energy into chemical energy. They grow in fresh water, seawater, wastewater or non-arable lands [5]. Therefore, they have minimal environmental effect such as deforestation. So, microalgae are an alternative fuel feedstock that could avoid fuel versus food conflict [6]. The cultivation of microalgae needs less water than other energy oil crops. **Table 4** shows comparison of different sources of biodiesel [32].

Production of biodiesel from microalgae can fix CO_2. Roughly 1 kg of algae biodiesel fixes 1.83 kg of CO_2. Microalgae cultivation has a higher CO_2 mitigation rate between 50.1 ± 6.5% on cloudy days and 82.3 ± 12.5% on sunny days for different algal species [33]. Microalgae cultivation can use phosphorus and nitrogen as nutrients from wastewater resources. Therefore, microalgae can provide the additional advantage for wastewater bioremediation. Furthermore, microalgal biodiesel can decrease the liberation of NO_x. Microalgae yield significant by-products for instance H_2, ethanol, biopolymers, carbohydrates, proteins, beautifying products, animal feed, enricher, biomass remains, etc. [34]. Improvement of microalgae does not need stimulant for growth. The warming value of microalgal biodiesel is greater than that of the other terrestrial plants. The great heating value of biodiesel resulting from soybean or rapeseed is 37 MJ/kg, while biodiesel resulting from algae is 41 MJ/kg [35].

3.5. Algal biomass

Algal biomass is a renewable resource that has the potential to supply a limited portion of international energy needs [36].

3.5.1. Selecting algae species

Preference toward microalgae is due largely to its less complex structure, fast growth rate and high-oil content (for some species) This characteristics of the strain should be taken into consideration. There are greater than 100,000 types of algae, with varying ratios of three main types of molecule: protein, oils and carbohydrates. Types of algae great in carbohydrates in addition to oils create starches that can be liberated then fermented into ethanol; the residual proteins can be converted into animal grains [1]. Research into algae for the mass-production of oil is mainly focused on microalgae organisms capable of photosynthesis that are less than 0.4 mm in diameter, including the diatoms and cyanobacteria; as opposed to macroalgae.

3.5.2. Isolation

In the end of eighteenth century, Robert Koch was one of the first scientists focused on the isolation of microorganisms in pure culture, followed by Sergei Winogradsky who initiate the field of microbiology and he was responsible for the first isolation of microorganism. Unialgal

CROP	OIL YIELD (L/ha)
CORN	172
SOYBEAN	446
CANOLA	1190
JATROPHA	**1892**
OIL PALM	5950
COCONUT	**2689**
MICROALGAE-a	**1,36,900**
MICROALGAE-b	**58,700**

-a 70% oil (by wt) in biomass
-b 80% oil (by wt) in biomass

Table 4. Comparison of different sources of bio diesel.

culture means it contains only one kind of alga, usually a clonal population, or cultures may be “axenic,” meaning that they contain only one alga. There are four main techniques for obtaining unialgal isolates: spraying, streaking, serial dilution and single-cell isolations [37].

Spraying and streaking are useful for single-celled, colonial or filamentous algae that will grow on an agar surface; cultures of some flagellates may also be founded by these methods. A lot of flagellates, and in addition to other forms of algae, must be separated by single-organism isolations or serial-dilution procedures. Spraying procedure, a stream of air is utilized to diffuse algal cells from a mixture onto the surface of a petri plate having solidified medium with agar for growth.

Single-cell/filament/colony separation: the first stage in this process is to prepare a count of “micropipettes” (very fine-tipped) from glass Pasteur pipettes. Hold a pipette in both hands; the tip end is caught with a forceps so that the glass near the tip is within the flame of a Bunsen burner (gas flame). The pipette is held in the flame only until the glass becomes marginally soft. This is determined by testing for flexibility by moving the tip with the forceps. Then the pipette is removed from the flame and pulled out straight or at an angle so that there is a bend.

You can differ the diameter of the fine pulled tip by altering the speed of pulling. You would need a fine diameter tip if you are trying to separate very small algae, but a bigger diameter tip is necessary for large cells.

Addition of antibiotics to the growth medium is necessary to prevent growth of cyanobacteria and other bacteria, while addition of germanium dioxide will inhibit diatoms growth. Treatment of culture, isolated algae, by an extensive washing procedure via one or more antibiotics is called axenic culture. Resistant stages such as zygotes or akinetes can be treated with bleach to kill epiphytes, and then planted on agar for germination.

3.5.3. Cultivation

Two basic alternatives for microalgae cultivation exist and their relative merits are the basis of ongoing debate.

3.5.3.1. System used in cultivation

Microalgae cultivation using sunlight energy can be carried out in open ponds, covered ponds or closed photobioreactors, based on tubular, flat plate or other designs [38]. Algae houses are utilizing numerous variance methods to grow the algae, involving covered ponds, open ponds, bioreactors and raceways. Algae grow normally in brackish, fresh or salt water centered on the algae species. An algal biofuels house must assess the cost and accessibility of water at the site of the production capacity. Water evaporation is the main problem, may be depending on the climate or whether of the system that used for growth of the algae open or closed. **Table 5** presents a short comparison of open pond systems and closed photobioreactors. Each system has benefits and drawbacks with respect to optimal growth conditions.

Figure 6 shows fixation of carbone dioxide in photobioreactors, utilizing microalgae to convert carbon dioxide and solar energy into algal biomass through photosynthesis process. The microalgae transferred to isolated photobioreactor for hydrogen creation, where the algae will transform solar energy into hydrogen gas using a biophotolytic procedure under sulfur deficiency.

Parameter	Open pond	Photobioreactor
Building	Very simple	More complicated—varies by design
Charge	Inexpensive to construct, operate	More expensive construction, operation
Growth rates (g/m2-day)	Low: 10–25	Movable: 1–500
Water losses	High	Low
Biomass concentration	Low: 0.1–0.2 g/L	High: 2–8 g/L
Temperature control	Difficult	Easily controlled
Species control	Difficult	Simple
Contamination	Great risk	Low risk
Light utilization	Poor	Very high
CO_2 liberation to atmosphere	Great	Almost none
Area requirements	Large	Small
Depth/diameter of water	0.3 m	0.1 m
Surface: volume ratio (m^2/m^3)	~6	60–400

Table 5. Advantages and disadvantages of open pond and closed systems which are used for algal growth.

After the hydrogen yields stage, the algal biomass will be gathered and used for various purposes: the algae can be utilized immediately as a food for human or as animal feed or in aquaculture. After nutrient control, algal biomass can hold big quantities of important biomolecules,

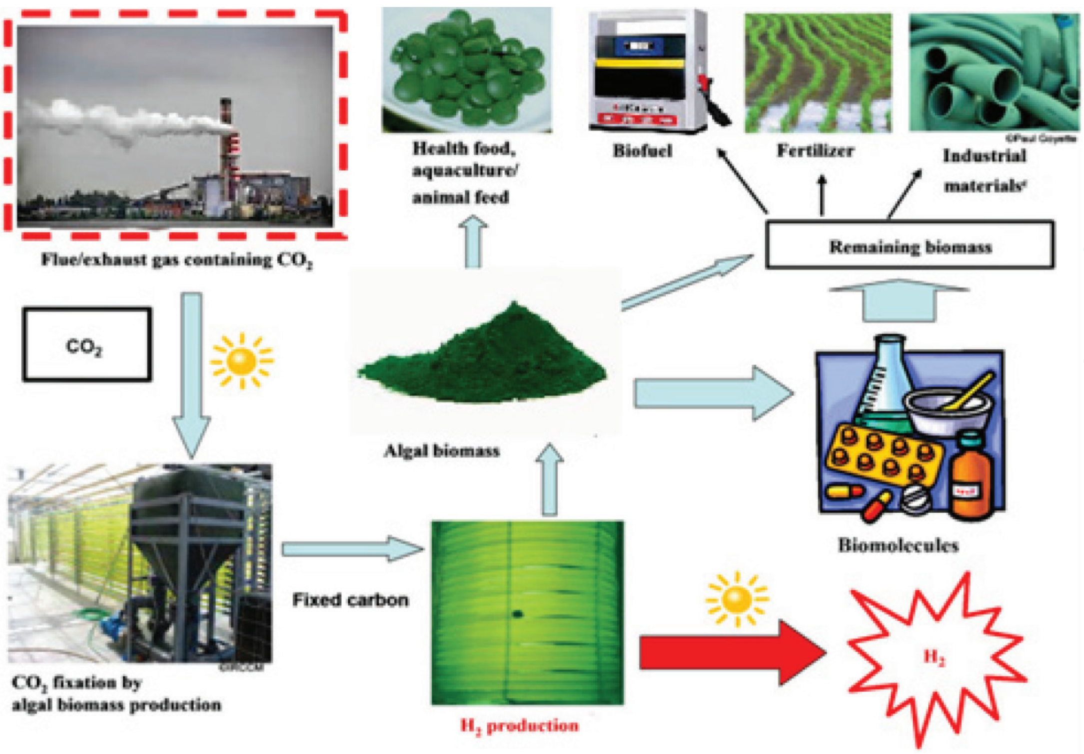

Figure 6. Fixation of carbone dioxide in photobioreactors, utilizing microalgae to convert carbon dioxide and solar energy into algal biomass through photosynthesis process.

which will be removed for industrial trade. However, these substances generally contain few percent of the biomass, leaving the common of the fixed carbone dioxide in the residual biomass. The remaining algal biomass from different method steps can be utilized either as a fertilizer for agriculture in which case the fixed carbon will be retained for some years, or for storing of the fixed carbone dioxide by industrial uses like manufacture of plastics. Remaining biomass can also be utilized as an energy transporter by removal of biodiesel through the direct conversion of the biomass to other energy transporters by biological or thermochemical procedures [39].

3.5.3.1.1. Photobioreactors

Photobioreactors, the closed systems are much more expensive than ponds. Indeed, most companies pursuing algae as a source of biofuel are pumping nutrient-laden water through plastic tubes (called "bioreactors") that are exposed to sunlight (and so-called photobioreactor or PBR). PBR can have different sizes and shapes: plastic bags, flat panels, tubes, fermenter like and others, as shown in **Figure 7**. Vertical tubes are the most popular system due to their relatively easy maintenance, high surface to volume ratio and low cost [40]. Between the advantages of utilizing photobioreactors are resistance to infection with uninhabited algae types and the possibility of simply controlling different factors, including temperature, light intensity and pH. The PBR can be located outdoors or indoors using artificial light or sunlight or a mixture of both. A recent study showed that different wavelengths may have a significant influence on biomass and lipid productivity, as well as on the lipid profile [41]. Recent researches aimed at improving the efficiency of photobioreactors [42] and have shown that the key to greater yields of up to 100 g dry mass m^{-2} h^{-1} is a pronounced heightening of algal flux tolerance.

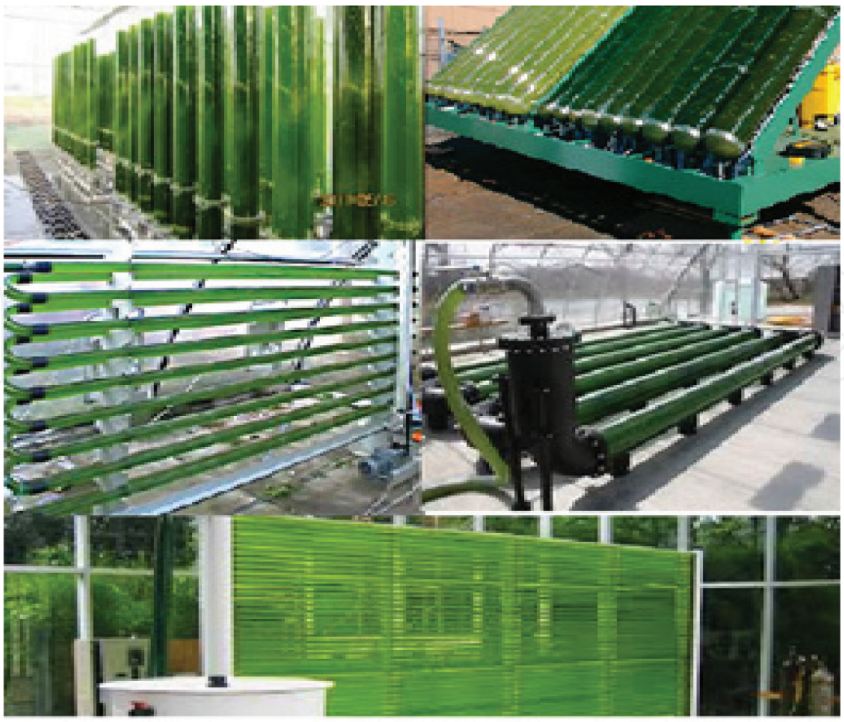

Figure 7. Different shapes of closed system.

3.5.3.1.2. Open ponds

Open ponds can be considered a cheap and easy to build, as extended as the area is relatively flat. Cultivation can be prepared immediately above the soil and some simple surface covering for reducing water loss due to seepage, and the other enhancements can be prepared to increase solar energy capture, and reduce the contamination process. The most common types are raceway (**Figure 8**), circular, inclined and unmixed. Open-pond systems for the most part have been given up for the cultivation of algae with high-oil content [43]. Open systems using a monoculture are vulnerable to viral infection. However, such open ponds also suffer from various limitations, including more rapid (than closed systems) biological invasions by other algae, algae grazers, fungi, amoeba, etc., and temperature limitations in colder or hot humid climates and water decrease by evaporation process. It became a main problem, limiting its latter problem is offered. Wastewaters and marine waters can be used as environment and considered a good match for this system due to the water sustainability issues that would prevent large open-pond cultivation from using potable water and the cost of this operation is relatively low. Therefore, this system is able to generate the biomass with a good price [44]. In general, open ponds constitute the cheapest method of producing algae in large quantities [45].

3.5.4. Requirements for cultivation

3.5.4.1. Nutrients

Nutrients such as phosphorus (P), potassium (K) and nitrogen (N) are vital for microalgae growth and are necessary quantities of fertilizer. Iron and silica, in addition to many trace elements, which considered essential marine nutrients, the lack of one can limit the growth of microorganism. A suitable nutrient source for algae is from the sewage wastewater treatment, agricultural, flood plain run-off, all presently major pollutants. However, this wastewater cannot feed algae immediately, but the first process through anaerobic digestion by bacteria. If wastewater is not processed before it reaches the algae, it will possibly kill much of the desired algae strain. Anaerobic digestion of wastewater produces a mixture of methane, carbon dioxide and organic fertilizer. Since the organic fertilizer that comes out of a digester is liquid, and approximately suitable for algae growth, it must first be cleaned and sterilized [1].

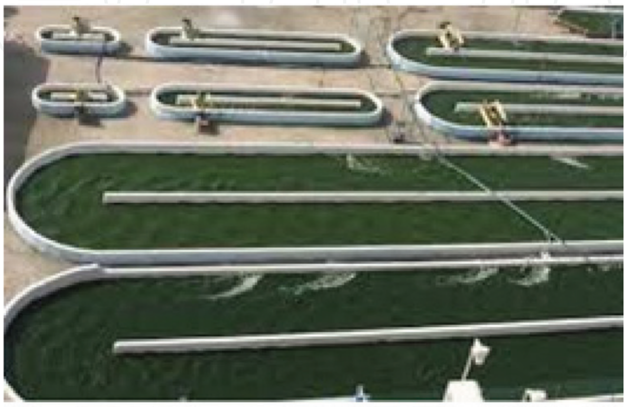

Figure 8. Open system (raceway pond).

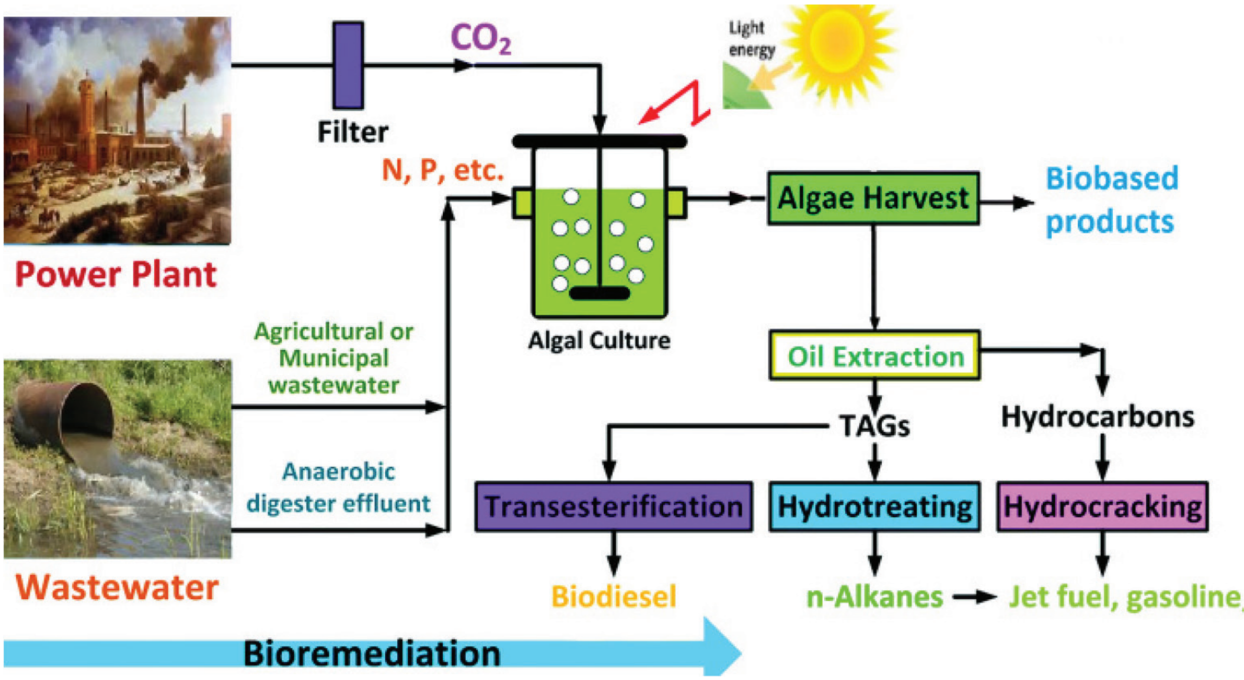

Figure 9. Using of CO_2 (industrial produced) in enrichment of algal biomass production.

3.5.4.2. CO_2 enrichment

One method to increase productivity is to increase the concentration of carbon dioxide [44, 46]. Indeed, the enzyme responsible for CO_2 fixation (ribulose-1,5-bisphosphate carboxylase oxygenase), has a little affinity for CO_2 and also functions as an oxidase of 1,5-bisphosphate, act with oxygen. So, oxygen is a competitive inhibitor with CO_2 and subsequently the atmospheric concentration of CO_2 is amount lower than that of oxygen, which can has a major effect. Assessment of this problem has been achieved by the improvement of carbon concentration mechanisms, where the cell locally induces the CO_2 concentration around the Rubisco enzyme to confirm its function in CO_2 fixation [47]. So this mechanism is common between the algae and demonstrates the benefits of increasing of the CO_2 concentration in mass cultures. Actually, dispersing CO_2 into the culture medium is known to raise its cellular density and two different methods are often reported, the use of CO_2 to adjust pH and CO_2 enrichment as a way to moderate flue gas [48]. Of course any feedstock used in large-scale production will play an important role on the price and CO_2 is not an exception. Thus, this type production should optimally be coupled to a bioremediation process, as shown in **Figure 9**.

4. Production of energy from algal biomass

4.1. Harvesting of algal biomass

In common logic, production of biodiesel from microalgae is actual like to the production of first-generation biodiesel. The biomass created is then cropped. The lipids are removed and

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then treated via transesterification into fatty acid methyl ester, generally named biodiesel. Though, dissimilar oil seed plants, cropping microalgal cells can demonstrate to be relatively challenging. The small cells moving in water cannot be accessed as simply as microscopic organism, and subsequently oil extraction becomes more complex than the traditional process used for oil seeds in development centuries. Many standard techniques have been evaluated for use in mass algal cultivation and their limitations are reviewed in detail elsewhere [49]. Thus, harvesting can be done at once or divided into different steps, each one varying depending upon the desired final total solids concentration. Of course, selection of crop process will differ according to the critical use of the biomass. Nutraceutical yields may need physical procedures for cropping, thus preventing chemical contamination and sustaining the product's natural features. In this situation, the high value of the product will contribute in the high cost and energy power of the method.

Harvesting methods are one of the major problem in developing a possible biodiesel from microalgae production process is how to successfully harvest the biomass in a cost-effective way [50]. A variety of approaches are possibly available, including flocculation, centrifugation, filtration, sedimentation and mat creation, a number of recent studies provide some hope for the near-term development of a cost-effective harvesting technology.

4.1.1. Centrifugation

Centrifugation has been the technique of choice in small scale studies since it is extremely effective and capable of harvesting all species. However, it has been said that this technique is also energy severe for request to what is fundamentally a little value yields anywhere there is a need to preserve as high net energy ratio as possible. This is indeed real if great levels of removal are required [51].

4.1.2. Flocculation

Flocculation is a procedure used to eliminate algae and other suspended particles from water during its treatment to harvest potable water. In this method, we added external compound that causes flocs to suspended algae. Actually, floc creation is a physico-chemical procedure and the resulting particle size is a function of mixing speed [52]. Because of the negative charge of microalgae cell wall, they tend to remain distributed in solution. Flocculation factor can neutralize this charge, yield the cells to cumulative and settle which facilitates the harvest procedure. Chemical flocculation procedures and the factors that can be used in microalgal cultures have been methodically examined [53]. A desirable flocculant should be inexpensive, non-toxic, recyclable and efficient at low concentrations. Different chemical flocculants can be applied, alum or alkali are traditionally used, but cannot be considered for application in harvesting microalgae for biofuels production because, in addition to cost attentions, their toxic nature precludes further use of the algal biomass. This process might be adapted to make a cost-effective harvesting technology for biofuels production from microalgae if the correct compound could be found. Some algal strains have a natural ability to auto-flocculate under some specific conditions, while others can be flocculated by the addition of a bacterial culture [54].

4.1.3. Filtration

Filtration can be right actual method of crop if the species is large abundant or propagates in filaments. Yet, again this proposes that the favorite species be sustained as closely similar monoculture. Most microalgae are also minor to be successfully collected this way, since their small size and extracellular material quickly clog on filters that have been tested.

4.1.4. Sedimentation/flotation

Several microalgal types have the odd properties of either floating or depositing in the non-existence of adequate mixing. While this propriety might be utilized as advantage in a minimum at first dewatering process, as soon as again the applicability of this process would need a full level of species control through crop growing. Furthermore, these properties lead to low cropping cost, may too negatively impact mixing requests hence it could be highly difficult to sustain these strains as consistently dispersed cells through cultivation.

4.1.5. Biofilm formation

Microalgal types that willingly consist of biofilms have been low focused for biofuels yield hence it is clearly hard to conserve them as a homogenous suspension in the crop growing medium. Though, many modern studies, with two diverse systems, have revealed that this type of growth way can propose the ease and the simple of mechanical harvesting, resulting slurries with a dry weight content of 9–16%. In some event, microalgal were developed or grown on a rotating drum, that was else an open-pond system and simple harvesting process was done by simply unspooling and scratching the cotton fiber that was used [55]. In alternative method, the algae were grown on a regular surface which was drip-watered. In the last growth phase, the algae were improved by simple mechanical scratching [56]. Most harvesting process was greatly simplified in addition to succeeded high rates of biomass production at suitable light conversion efficiencies.

4.2. Technologies for converting biomass into liquid fuels

Scientific hard work has shown that it is possible to produce a variety of liquid biofuels from cellulosic biomass (next generation' feedstock); however its cost is not competitive with petro fuels, even with recent price hikes. Multiple steps are required for conversion into a liquid fuel. Recent studies have indicated that 6:10% of energy in biomass is utilized in feedstock preparation [57]. The two primary conversion pathways are thermochemical and biochemical process, as shown in **Figure 10**.

4.2.1. Thermochemical conversion

These technologies typically use high temperatures and pressure to depolymerize lignocelluloses into small molecular weight organic and inorganic compounds which can be transformed into hydrocarbons, alcohols, aromatics and other organics [57].

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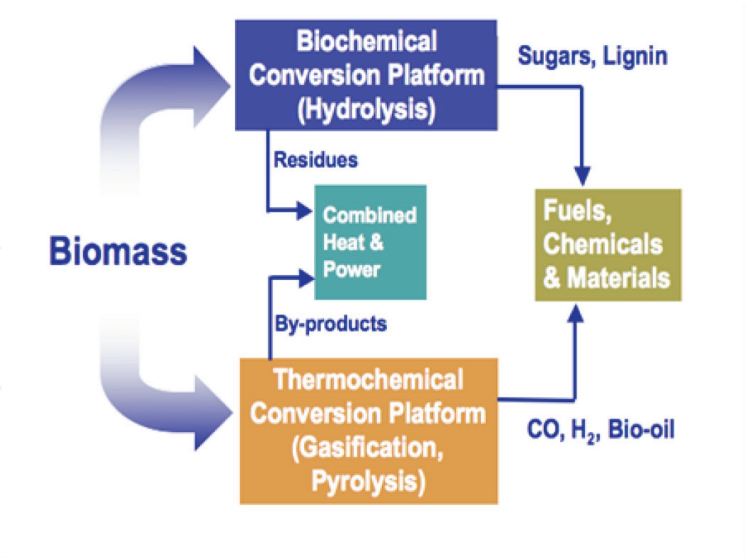

Figure 10. Methods of biomass conversion.

4.2.1.1. Gasification

The two major thermochemical pathways for converting biomass to gaseous and liquid fuels are gasification and pyrolysis. Gasification is the thermochemical partial oxidation of hydrocarbons in the biomass at high temperature (800–1000°C) to a combustible gas mixture (typically containing H_2, CH_4, CO_2 and C_2H_4) [58] (**Figure 11**).

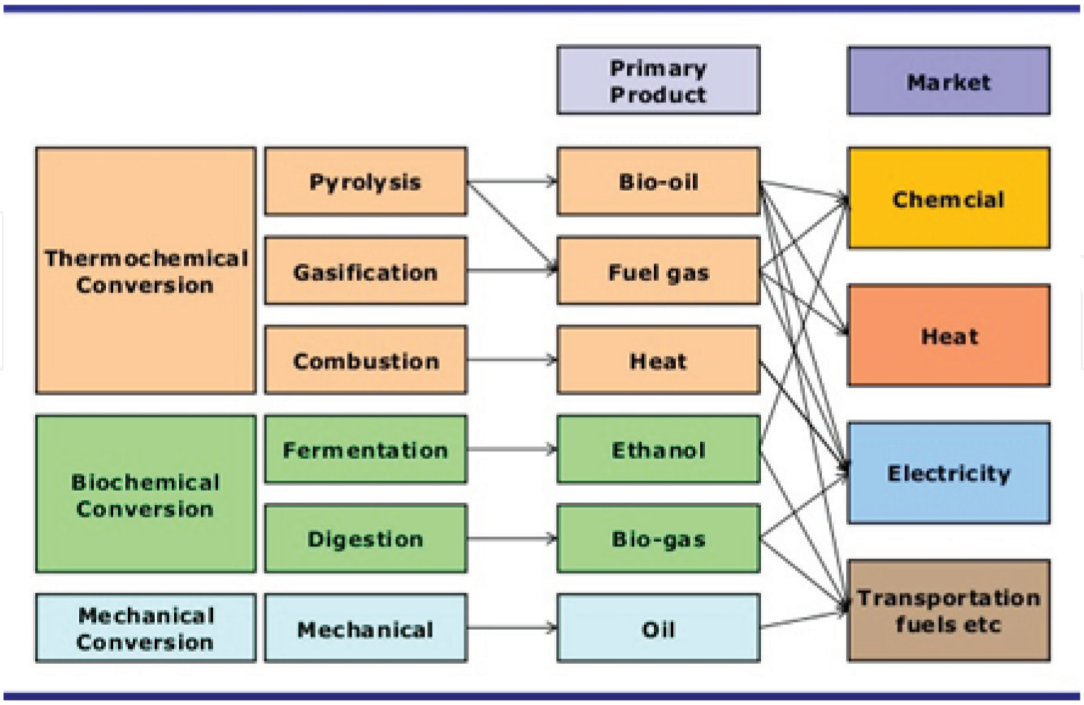

Figure 11. Biomass conversion processes and product.

In gasification procedure, the biomass is thermally decayed at great temperature in O_2 hungry environment to avoid the explosive gas from combustion. This synthesis gas (a mixture of CO_2, CO, CH_4 and H_2) is transformed to a liquid fuel such as synthetic diesel using Fischer-Tropsch technology.

4.2.1.2. Pyrolysis

Pyrolysis method depends on using high temperature in the non-existence of O_2 to transform the biomass into bio-oil. Pyrolysis can be classified as fast, conventional or flash according to the heating rate, particle size, operating condition of temperature and solid seat time. For instance, if bio-oil yield is to be maximized fast, this is required that biomass is heated to 500°C for around 10 second. Pyrolysis temperatures are approximately 475C, where gasification is ready at temperatures fluctuating from 600 to 1100°C.

4.2.2. Biochemical conversion

This process is described as enzymatic hydrolysis in addition to microbial digestion. It includes decomposition of the biomass into hemicellulose, cellulose and lignin and transforming the hemicellulose and cellulose into fermentable sugars, subsequently the use of yeast and specific bacteria to transform the sugar to ethanol. This method needs a pre-treatment stage (steam, ammonia and acid) to decomposition of the biomass into fluid slurry. Use of acid to destroy lignocellulosic fibers can be used also to destroy much of the hemicellulose sugar earlier then can be fermented into ethanol, causing low incomes [59]. Nowadays there are researcher variations and combinations of thermochemical and biochemical pathways for converting biomass into useful energy products.

4.2.2.1. Anaerobic digestion

The natural process is called anaerobic digestion and is the micro-biological conversion of organic matter to CH_4 in the deficiency of O_2. The biochemical transformation of biomass is finished throughout alcoholic fermentation to yield liquid fuels, while fermentation with anaerobic digestion produce biogas (H_2, NH_4, CO_2 and CH_4) generally by four stages that includes hydrolysis, acidogensis, acetogensis and methanogensis). The decomposition is caused by natural bacterial action in different stages and occurs in a variety of natural anaerobic environments including water sediment, waterlogged soils, natural hot springs, ocean thermal vents and the stomachs of various animals.

4.2.2.2. Fermentation and hydrolysis

Some methods permit biomass to be converted into gaseous fuel, for instance, CH_4 or H_2 [60]. One genetic-modified procedure uses bacteria and algae to yield H_2 immediately instead of the usual biotic energy carriers. The second way uses agricultural remains in fermentation for produce biogas. This method is documented and used for waste treatment in a wide range. Lastly, high temperature in gasification supplies a crude gas for the production of hydrogen by a second reaction step. Also in biogas, there is also the opportunity of using the compact by-product as a biofuel. Traditional fermentation plants producing biogas are in routine use, ranging from farms to large municipal plants.

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4.2.2.3. Transesterification

Transesterification is a chemical combination of bio-oil with an alcohol (methanol or ethanol) [61]. The resulting biodiesel is an alkyl ester of fatty acid, which contains an alcohol group attached to a single hydrocarbon chain comparable in length to that of diesel (C10H22–C15H32). The transesterification method means biodiesel production [62] in which glycerin is extracted from the fat or vegetable oil [63]. Plants late two products are methyl esters and glycerin that is used in soaps and other products. Transesterification of triglycerides can be improved by using catalysts which are divided in to alkali, acid and enzyme. Alkali-catalyzed transesterification is the best and faster than acid-catalyzed transesterification, so it used commercially [64, 65].

4.3. Challenges and opportunities

Challenges for production of biofuel from microalgae are summarized in these points: (1) microalgae require a large amount of nutrients and CO_2.(2) Low lipid yield high growth or in reverse a high lipid yield with low growth rate.(3)High cost of closed systems and difficult of maintenance of open pond cultivation. (4) Presence of several numbers of steps and high cost methods involved in the oil production in addition an imbalance in an energy cost. (5) Small market-high value co-products. (6) Presence of few commercial cultivating farms, so there is a lack of data on large-scale of cultivation [66].

Opportunities are brief in these topics: (1) heterotrophic and mixotrophic cultivation. (2) Using of super strain and applied of genetic modification. Use of wastewater in algal cultivation and practical biorefineries [66].

4.4. Current status of energy production from algal biomass in Egypt

Egypt depends on a mixture of energy resources; a lot of them are produced from fossil fuel with proportion approximately 98% and depends on other renewable energy sources to cover its needs with percent about 2%. The electricity sector exhausts around 30% from its yield of fossil fuels while industrial needing in Egypt exhausts around 40% from its production. Egypt yield large quantity of fossil fuel represented in natural gas and oil, however, Egypt exhaust the energy severely according to US Energy Information administration, the exhaustion rates of crude oil in Egypt through 2000–2011 are in permanent increasing above the production rates **Figure 12**, but the production rates of natural gas are sufficient or go above its consumption which leads to spread some of its production out of the country [67].

The energy catastrophe in Egypt is liberated from the gap between the accessible energy sources and the exhaustion levels, as the natural gas can not only enough to the growing request of energy in the continuous individuals rise.

So there are two methods to solve the problem of energy in Egypt and succeed the sustainable development which becomes the alarm worldwide:

First: Rationalization of current consumption of energy and improving the efficiency of its use: Industrial Modernization Centre made a study aiming to decrease the energy exhaustion to 20% in 2022 dispersed on several sectors as: 9.4% in industrial division, 5.4% in

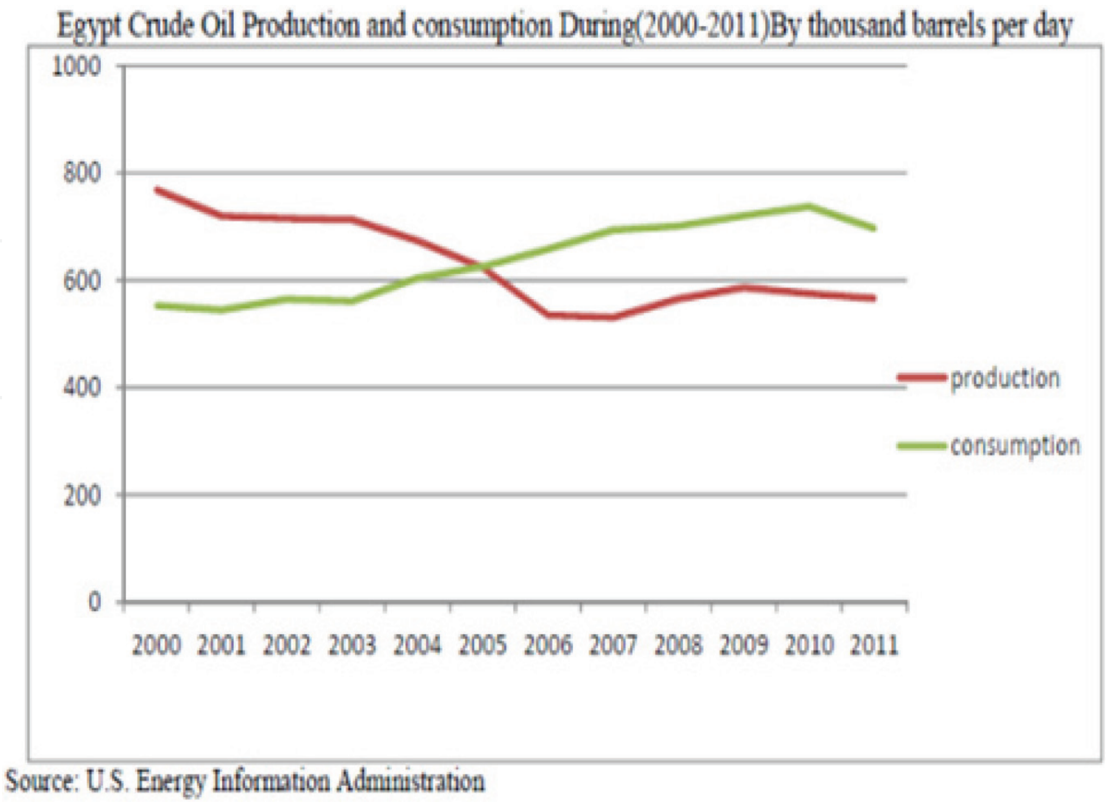

Figure 12. Represent the production and consumption of oil in Egypt during the period (2000–2011).

transportation section, 3% in trade and housing section, 0.45% in governmental and public building, 0.05% in irrigation and agricultural section as well as 2.5% in the natural gas yield.

Second: depending on renewable energy resources: Egypt has a several renewable sources such as solar, wind power and biomass. For this reasons, nowadays, the Egyptian government encourages renewable energy including biomass energy. And there are many attempts for the creation of biofuel from algal biomass. Some researchers in Faculty of Agriculture, Cairo University; Faculty of Science, Alexandria University; Agriculture Research Center; Institute of Petroleum Research and National Research Centre started in production of biodiesel on laboratory scale. Also, there are some projects on production of biodiesel from microalgae in selected Mediterranean Countries" Med-algae project (http://www.med-algae.eu) was done during 2013–2014. It is a new technology project which can contribute to the goals of the European Union (EU) strategy on "Climate change and energy. The project supported by the programme European Neighborhood and Partnership Instrument (ENPI) - Mediterranean Sea Basin Joint Operational Programme. The group consist of 12 organizations: research organizations, academic institutions, energy agencies, private organizations from 6 countries: Italy, Cyprus, Malta, Greece, Lebanon and Egypt represented by the Faculty of Science, Alexandria University and National Research Centre. Final conclusion of the project refers to biodiesel production by *Nannochloropsis* sp. is not practical at the economical level if the alga is employed for just biodiesel production. In order to enhance biodiesel fuel quality, the alga must be subjected to genetic engineering for up-regulation of fatty acid biosynthesis and/or by down-regulation of β-oxidation. However, supplementation of biodiesel with other short-chain fatty acid esters may be a good choice. Economically, the algal biomass must be processed for bio-refinery to maximize its utilization for different applications [68].

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5. Conclusion

Microalgae are one of the most effective sources of renewable energy production. Microalgae are contain up to 50:70% protein, 30% lipids, over 40% glycerol, up to 14% carotene and a fairly high concentration of vitamins B1, B2, B3, B6, B12, E, K, D, etc., compared with other plants or animals. Algal industry techniques is integrated process to CO_2 capture, contribute to solve global warming problem and produce valuable byproducts such as lipids (oils), carbohydrates, proteins and various feedstocks that can be converted into biofuels and other useful materials. Microalgae are probable to be an essential raw material for amino acid, vitamin and yields of valuable by-products. The production of microalgae is known to be the more gainful business in the biotechnological process. It is a waste less and environmentally safe. Microalgae are capable of producing oil all year long. Oil productivity of microalgae is greater compared to conventional crops. The oil content of microalgae is in the range of 20–50% which is greater than other competitors. Biodiesel production from algal lipid is non-toxic and highly biodegradable. Microalgae can grow at high rates which can be 50 times more than that of switchgrass, which is the fastest growing terrestrial crop. Microalgae have higher photon conversion efficiency; it is approximately 3–8% against 0.5% for terrestrial plants. Microalgae are an alternative fuel feedstock that could avoid fuel versus food conflict and it can be cultivated in wastewater as a source of nutrients. The costs of algal cultivation and harvest for biofuel production are covered by the wastewater treatment function.

Recommendations

Wide transfer of the algae industry techniques to achieve the greatest benefit from the process of algal cultivation (opened and closed photobioreactor) to produce the economic and required valuable materials (biofuel).

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