



Evaluation and Advantages of Algae as an Energy Source

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Abstract: Primary energy consumption is increasing gradually together with population growth, urbanization and industrialization in the world. It is known that most of the energy used throughout the world is obtained from fossil fuels called primary energy sources such as coal, petroleum and natural gas. Within this context, the more the humanity continue to search for sustainable development and better living conditions, the more the renewable energy production will be a priority in whole world. As a result of all these, renewable energy sources used in the world today are classified as solar, wind, wave and geothermal, hydroelectric, biomass and hydrogen energies. Biomass energy, depending upon agriculture within the context of alternative energy politics, has found a wide range of application field in all over the world with its properties which target development and provide eco-friendly, sustainable energy production and environmental management. However, biofuel production that increases along with agricultural potential and technological levels of the countries brings about some crucial debates with itself. In this case, scientists express that algal biomasses, defined as third generation fuel, might be an alternative energy source; and that they have a lot of advantages. In recent years, algae have started to be seen as a promising energy source as a result of biomass energy researches accelerated due to increasing oil prices. The studies, in which biofuels such as biodiesel, renewable aviation fuel/biojet fuel, biogasoline/green gasoline, biobutanol, bioethanol, and methane are obtained from algal biomass, have enhanced widely. Algae are potentially best-yielding product that can be produced in large quantities of biofuels. This microscopic plant can be produced in dirty water, saltwater, deserts and in environments unsuitable for any other plant. Because they connect the carbon dioxide in the environment, it is produced especially around the power plants, thus reducing the damage caused by the carbon dioxide from the plants. One of the most important advantages of algae is that the amount of oil obtained is very high. Moreover, it is one of the other advantages that they are not affected by changing climate conditions and can be produced in high quantities in a short period of time.

Keywords: Energy sources, biofuels, algae, biodiesel, biogasoline

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INTRODUCTION

Most countries in the world meet great deal of their energy need from fuels of fossil origin. Climate change, caused by fossil fuels, and environmental problems it brings together and rural development policies applied by

countries lead to the usage of renewable energy sources. For countries, such as Turkey, that export great majority of their energy of fossil origin, it is a very critical issue to obtain energy out of alternative energy sources, which can be produced from domestic sources. It is essential that alternative fuel sources be

sustainable for economic development and obtainable from domestic sources for a cleaner environment, and people oriented, renewable, applicable and easily attainable. The fact that biofuels, which are gradually gaining significance throughout the world among the alternative energy sources, and that they can be used as alternative to fossil origin fuels attracts all attentions to this point in energy issue (1).

Biofuels, becoming more and more common these days, provide contribution to the energy supply of the countries; and especially in rural areas, they provide alternative income and employment for producers who conduct biofuel raw material production. The decreasing amount of agricultural crop supply in relation with drought being lived across the world and the increasing food prices because agricultural crops are used in biofuel production have increased the debates on production and use of biomasses for food and energy. Because of the reasons mentioned above, a need to develop an alternative source against the usage of agricultural crops as biofuels has come into existence.

On the other hand, the usage of biofuels in energy technology by producing equivalent alternative solid, liquid and gas biofuel equal to present fuels is provided by means of direct burning or physical and chemical processes (2). Among biomass sources whose use is rising every passing day worldwide, especially algae, which are environmentally friendly energy sources, are studied comprehensively since we use these fuel sources without interfering in other available sources which may lead to increases in food prices; and without utilizing the agricultural areas. More than to come to the agenda as an alternative energy source, algae have been produced and evaluated as food additives in animal breeding for years (3). In recent years, as a result of biomass energy researches having accelerated

due to increasing oil prices, algae have started to be seen as promising energy sources. The idea to make use of algae as fuel is not a new issue. The studies were carried out at the beginning of 1950s after methane was produced out of them. Energy crisis in 1970s caused more researches not only on methane production from algae but also obtaining hydrogen from algae. The researches which were carried out in 1980s headed for oil production from algae; and today, in research and development of the oil produced from algae called biofuel, a significant progress has been made. Scientists are interested in algae biofuel seriously since they are edible, and they can be grown relatively easily in bio reactors, and they are likely to take place of fossil fuels (4). It is expected that algae will be the most important biofuel source in the near future (5). As an alternative and renewable energy source, algal biomass has been a promising source recently owing to its high lipid content. Today, algal oil production is basically intended for biofuel production (6). With their relatively high lipid, carbohydrate and food content and rapid growth potential, algal biomasses attract great attention in today's energy scenario. All these properties are thought to be excellent properties for biodiesel, bioethanol and biomethane (7).

Through the studies carried out today, it is seen that biofuels such as biodiesel, renewable aviation turbine fuel/biojet fuel, biogasoline/green gasoline, biobutanol, bioethanol, and methane are obtained from algal biomass. Table 1 shows the lipid contents, lipid efficiencies; volumetric and spatial efficiencies of biomass of some types of algae used in production of bio fuel. The most widely used algal types in biodiesel production are *Chlorella*, *Dunaliella*, *Isochrysis*, *Nannochloris*, *Nannochloropsis Oculata*, *Neochloris*, *Nitzschia*, *Phaeodactylum* and *Porphyridium* sp. The oil content of these algal ranges from 20% wt to 50% wt.

Table 1. Lipid contents and efficiencies of some algal types used in biofuel production (8).

Type of Algae	Lipid content (Dry Weight %)	Lipid efficiency (mg/L/day)	Volumetric efficiency of biomass (mg/L/day)	Areal efficiency of bio mass (mg/m ² /day)
<i>Ankistrodesmus</i> sp.	24-31	-	-	11.5-17.4
<i>Chlorella emersonii</i>	25-63	10.3-50	0.036-0.041	0.91-0.97
<i>Chlorella vulgaris</i>	5-58	11.2-40	0.02-0.20	0.57-0.95
<i>Chlorella</i> sp.	10-48	42.1	0.02-2.5	1.61-16.4
<i>Chlorella pyrenoidosa</i>	2	-	2.90-3.64	72.5-130
<i>Chlorella</i>	18-57	18.7	-	3.5-13.9

Type of Algae	Lipid content (Dry Weight %)	Lipid efficiency (mg/L/day)	Volumetric efficiency of biomass (mg/L/day)	Areal efficiency of bio mass (mg/m ² /day)
<i>Dunaliella salina</i>	6-25	116	0.22-0.34	1.6-3.5/20-38
<i>Dunaliella primolecta</i>	23.1	-	0.09	14
<i>Haematococcus pluvialis</i>	25	-	0.05-0.06	10.2-36.4
<i>Nannochloropsis</i> sp.	12-53	37.6-90	0.17-1.43	1.9-5.3
<i>Porphyridium cruentum</i>	9-18.8	34.8	0.36-1.50	25
<i>Scenedesmus</i> sp.	19.6-21.1	40.8-53.9	0.03-0.26	2.43-13.52
<i>Spirulina platensis</i>	4-16.6	-	0.06-4.3	1.5-14.5/24-51
<i>Spirulina maxima</i>	4-9	-	0.21-0.25	25
<i>Tetraselmis suecica</i>	8.5-23	27-36.4	0.12-0.32	19

As can be seen from the table, it is observed that algal types such as *Chlorella emersonii*, *Chlorella vulgaris*, *Chlorella*, *Nannochloropsis* sp. have considerably high lipid contents, whereas they have low volumetric efficiencies (mg/L/day). In the initial studies, *Nannochloropsis* sp., a cold sea algal type, which is tolerant to salty water and has an inclination to absorb CO₂, was used for biofuel production. *Nannochloropsis* sp. has also high triglyceride rate and a relatively high growth rate. Thus, it was established that *Nannochloropsis* sp. algae type was appropriate for biofuel production, yet with the studies going on, it was found out that there are more appropriate algal types (9). In the studies carried out, it was determined that *Schizochytrium* sp. (50–77% wt), *Botryococcus braunii* (25–75% wt), *Nitzschia* sp. (45–47% wt), *Cylindrotheca* sp. (16–37% wt) and *Chlorella* sp. (28–32% wt) are the algae which have the highest amount of oil content (10). The fact that agricultural fields are not used when algae are grown, and that they can rapidly proliferate even in small areas, and that there is no need for soil for their growth, and that they can adapt desert conditions, and they can be grown in nylon sacks and tanks around energy plants emitting carbon dioxide to the environment are the most important advantages of algae. Due to the fact that some algae types contain more oil compared to field crops, and that their growth process is easier, and that they are not affected from changing seasons and climatic conditions, and that they can be produced in large amounts in a short time, they are advantageous. In Figure 1, the processes of obtaining fuel gases, ethanol, gasoline, jet fuels, diesel, heavy oils, and some chemical raw material products by using different

production methods from algae biomass are given.

In general, though it changes according to the species, algae may contain approximately between 15-77% oil. The fact that algae have high oil rate and growth efficiency compared to other plants grown for oil; this makes it attractive for production of biofuels. The fact that these fuels are produced from algae makes them possess a potential to meet increasing global energy crisis and to contribute to prevent global warming by, though partly, converting excessive carbon dioxide into efficient products via photosynthesis. One of the advantages of algae use as raw material for biofuels is that it is possible to produce different types of fuels. The properties of algae meet the need of biofuels such as biodiesel and biogas ethanol, bio jet fuel, bio gasoline or other fuels (12).

Biodiesel

Biodiesel is an alternative diesel fuel which is produced from plant oils or animal fats (liquid or solid oil/fat). Studies show that some algae types contain more than 80% oil than their total dry weight. Since most of the algae cells are grown with water, CO₂ and dissolved nutrient in aqueous suspension environment, they possess great scale biomass production capacities. The oil produced from algae can then be converted into biodiesel to be used in engines as fuel (13). Because of the cost of biodiesel production, especially the high forage cost of vegetable oils, they still set a significant obstacle for large scale of use in trade. Another important issue is that first and second generation biodiesel raw materials are inefficient and unsustainable. Despite this, the third generation biodiesel raw materials obtained from algae appeared to be one of the

most promising alternative lipid energy sources due to their high growth speed and productivity and with their high photosynthetic efficiency. In addition to their rapid production, they can be grown more easily, and more oil can be obtained from them for biodiesel production than a number of plant types (14). Soladiesel BDR company was able to use 100% biodiesel produced from algae with standard diesel engines without making any changes in the machine. Also, this biodiesel is completely appropriate for ASTM D 6751 (ASTM D6751 (ASTM=American Society for Testing and Materials) specifications for Fatty Acid Methyl Ester based fuel (FAME), which meets ASTM D 975; and it is considered that it has significant superiority to diesel fuel due to total hydrocarbon (THC) volume, very low carbon monoxide and particle substance and ultra low sulphur content. Soladiesel BDR also stated that this biodiesel has better cold

flow properties than any kind of biodiesel available in trade (15).

With algal oil use as raw material in biodiesel production, not only biodiesel unit price will be able to be pulled down to the levels to be able to compete with petroleum based diesel fuel but also it will make it possible for the countries to diversify their energy sources; and to be able to save the country from dependence on foreign sources in energy. In the studies carried out, it is stated that like vegetable and animal oils and fats, biodiesel fuel obtained from renewable energy sources can be used as alternative to petroleum diesel and thus, that it may decrease petroleum dependency, and that it can be taken into consideration as a promising alternative fuel to reduce pollution stemming from exhaust emissions and petroleum dependency (16).

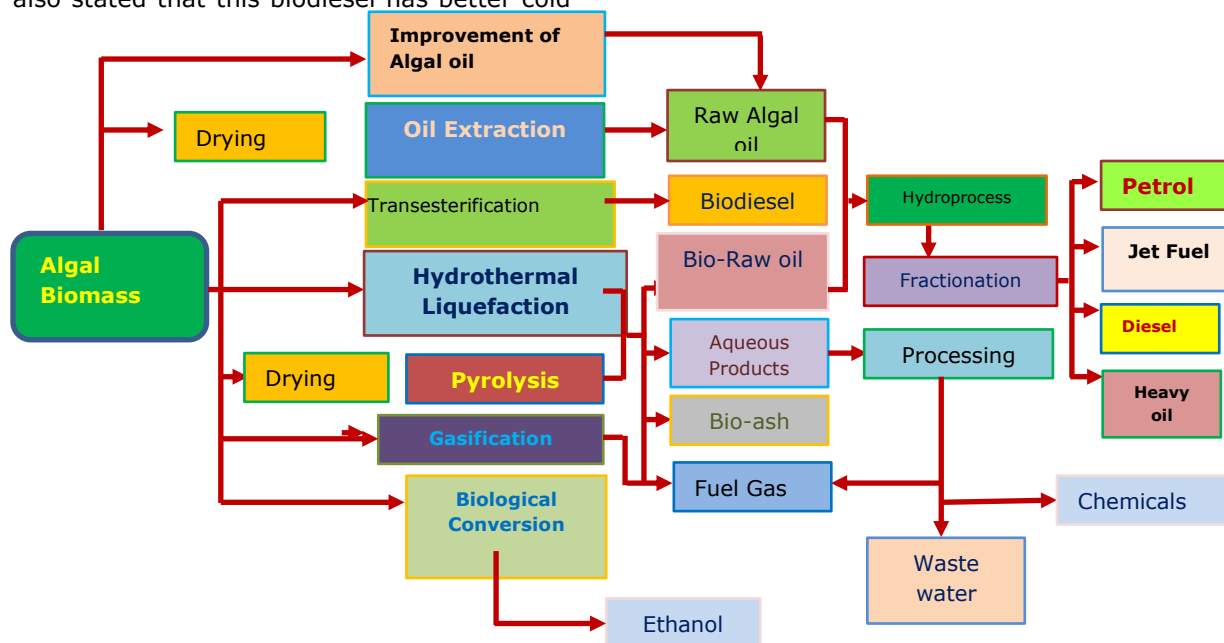


Figure 1: Production processes of bio fuels obtained from algae biomass (11).

Renewable aviation fuel/Biojet fuel

Algae-based fuels are not only limited to automobile and truck fuel in countries in general. While increasing jet fuel costs affect many airway companies economically, this has made an incentive for many companies and researchers to produce biojet fuel out of algae. For instance, it was expressed that member companies of International Aviation Transportation Association (IATA), which provides research, development and widespread use of these products, could be supported until 2017 so that they can use 10% alternative bio jet fuels. Biojet fuel is increasingly produced from raw materials such as algae, and used in flight tests. Continental Airlines flew between Houston and Chicago by using 40% algae-based biojet fuel and the US

Navy carried out a flight by utilizing 50% algal bio-jet fuel in a helicopter (17). Solazyme Company, California gave the USA Navy 1500 gallon 100% algae-based jet fuel for test and certification. The USA Navy previously explained its target that it would operate at least 50% of its fleet by means of clean, renewable fuel until 2020. Solazyme produced the world's first 100% algae based jet fuel via officially patented fermentation process by cooperating with UOP Company of Honeywell in renewable jet fuel process technology (18). The fact that petroleum sources are rapidly running out, and that the aviation sector is developing every other day, and as a result, there is an increase in petroleum based aviation fuel, and fluctuations in crude oil prices, and increase in greenhouse gas

emissions and the need for energy security all promote the development of an alternative jet fuel. Biojet fuel should be technically and economically possible, eco-friendly, greener than jet fuel, locally producible, and should have a lower price than low gallon fuel for per BTU. Bio-jet fuel can be produced by blending petroleum based jet fuel with algae oil biodiesel (19).

Bio-jet fuel can be obtained from sustainable sources such as vegetable oils, sweets and animal fats and even waste biomasses; and it can be used in jet engines available now without making any changes in them. Renewable aviation fuels are different from conventional fuels because this fuel is not of a petroleum origin; it however has the same structure. One of the most important advantages of bio-jet fuels is that they provide a low emissive option for fuel in commercial and military planes. Other advantage of these fuels is that they have similar chemical properties with commercial jet fuels. As a result, these fuels are completely compatible with present engines and distribution systems, so there is no need to make any changes with these parts. Also, these fuels meet the same performance criteria with conventional fuels (12).

Biogasoline/Green gasoline

Bio gasoline is a kind of fuel which is produced from biomass of algae and contains C₆-C₁₂ carbon atoms like commercial gasoline and can be used in internal combustion engines. During the use of this fuel, no changes are applied to the engine because this fuel also has the same chemical properties with commercial gasoline. As a result, bio-gasoline can be used in any kind of gasoline operating engine and at any blend (10). In the literature, there are studies in which premium gasoline is obtained from algae and vegetable oils via catalytic conversion, and accompanied with selector zeolite catalyst (20).

Biobutanol

Biobutanol can be produced from algae and diatoms utilizing a solar energy bio refinery. This fuel has 10% less energy density compared to commercial gasoline, while it can be produced more than ethanol or methanol. In addition to this, biobutanol can be used in gasoline powered engines without applying any changes. In numerous test studies, it was determined that biobutanol has similar consumption amount with gasoline; and that when compared to gasoline, biobutanol provides better performance; and that it has a higher corrosion resistance compared to E85 (8). In recent times, biobutanol obtained from algae biomass, due to its high capacity of starch content and polymeric carbohydrate

accumulating ability, has been thought as fermentable raw material convenient for biobutanol production (21). Biobutanol produced out of algal biomass is a biofuel possessing similar properties with gasoline (22).

Bioethanol

Most of the studies carried out in recent years have been about fermentation of algae and bioethanol production. Algal biomasses supply protein and carbohydrate in the form of glucose, starch and other polysaccharides, and this protein and carbohydrate may be used as carbon sources for fermentation of bacteria, yeast and fungus. For example *Chlorella vulgaris* is accepted as a potential raw material for bioethanol production since it has high starch accumulation. *Chlorococum sp.* have been used as a fermentable substance for bioethanol production under different fermentation conditions. Although there seems to be limited number of studies about fermentation of algae, it has been known that there are a lot of advantages of bioethanol production from algae by means of fermentation. Fermentation process has lower energy consumption due to the fact that it has a simpler system compared to biodiesel production. In addition, CO₂, a side product obtained in fermentation process, can be recycled as carbon source for algae. Thus, greenhouse gas emissions will be reduced and the effect of global warming will decrease (12).

Algae, third generation raw material for biofuels, are alternative to first and second generation raw materials because of its productivity and because they can be easily grown and they have appropriate harvest time. Algae, due to their high lipid contents, cellulosic structure and high amount of carbohydrate content, are considered to be quite an important source for bioethanol production (23). Some kinds of algae have high carbohydrate content in terms of starch and cellulose; besides, they are excellent sources for bioethanol production. The use of algae biomass rich in carbohydrate for bioethanol production is advantageous because algae grow faster and they fix CO₂ at higher rates than land plants (24).

Methane

Methane, one of the basic components of natural gas, can be produced from algae via methods such as gasification, pyrolysis, and anaerobic decomposition. Methane is obtained under high temperature and pressure via gasification and pyrolysis methods. Anaerobic decomposition, also known as the decomposition process of organic substances in airless environment, is a method, in which

after the solid particles are disposed to algae, the fatty acids are converted by utilizing acidic bacteria; and in which algae are separated into simple components with addition of methanogenic bacteria into the environment for the spread of a gas mixture. It has been proved with a number of successful studies that algae biomass can be converted into biogas as a result of anaerobic decomposition. Therefore, it is recommended to grow algae so that general energy balance and electric production can be bettered by means of energy regain from waste biomass via methane anaerobic decomposition (12).

Advantages of Utilizing Algal Oil as Energy Source

The oil obtained from algae can be directly used in diesel engines like other vegetable oils and can be converted into biofuel after refined.

Since algae are fed with more CO₂ and organic substances, it has been observed that the oil they produce has increased 40% in laboratory environment. Especially, algal oil utilized in biodiesel production can be used as an organic origin and environmentally friendly fuel. While algae produce oil in their structure, they utilize sunlight and CO₂ more effectively compared to oil plants; and their division potential and growth rate are quite high. Some kinds of algae contain up to 60% oil of their total weight and when the optimum conditions are provided, they can produce approximately 55,000-60,000 liters of oil annually per hectare. For all these reasons, it is possible to produce algae in small areas in large amounts and with low costs when compared to oil-based plants whose plantation is carried out in large areas. The advantages of the use of algal oil as energy source are given below (Figure 2).

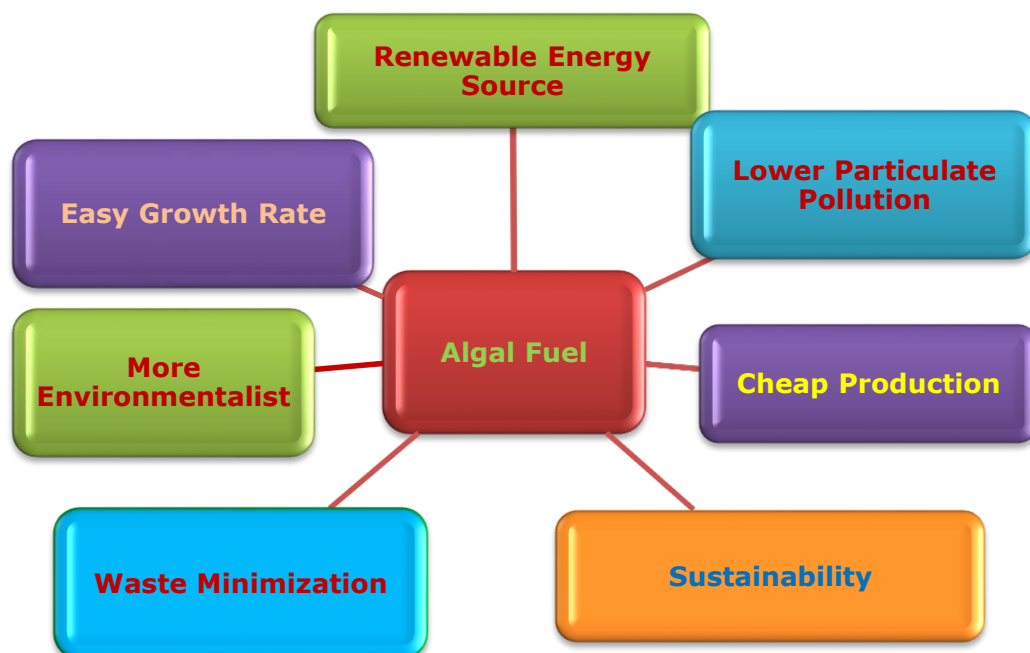


Figure 2. Advantages of algal fuel (25).

- The fact that CO₂ in industrial exhaust gases is attached to algae with bio-attachment, and the algae, which are grown and thus their oil is converted into biodiesel, decrease the effect of greenhouse gases in the atmosphere (26).
- Since they are able to be grown photosynthetically, they do not need any carbon source, and they use up carbon dioxide as energy source which is the product of previous consumptions, so, they provide carbon dioxide neutralization (27).
- The lipids, which algae accumulate, are generally in the form of triacylglycerol (>80%), they contain fatty acids rich in

- C₁₆-C₁₈ carbon atoms, the ratio of which is clearly seen in oil-acid distribution of algae oil we use. Although the lipid content of algal cells changes in average between 1% and 70%, when optimum conditions are provided, algae can accumulate 90% lipid.
- When compared with agricultural products and other aqueous plants, algae are known to have very fast growth rate.
- When compared to the other agricultural raw materials used for biodiesel production, smaller areas are needed for their growth. Consequently, it is stated that thanks to use of algae as raw material in biodiesel production, arable areas reserved

- for growing raw materials for biodiesel production will decrease.
- It is expressed that biodiesel produced from algae either contains very little or no sulfur, and that though CO, hydrocarbon and SO_x emissions are little, NO_x emission is more in some engine types (8).
 - It is known that some algae types have very high lipid content and that in optimum conditions, these photosynthetic microorganisms can produce 100 times more lipid than plant system grown in the same field.
 - In the studies carried out, some scientists have found algae as matchless energy alternative, and at the same time, they

emphasized their contribution to gas emission volumes (28).

- The algae grow two fold in a day by utilizing very little water and only day light. Even, some algae complete this growth within only a few hours. Therefore, as biofuel raw materials, algae are among the most popular choices.
- Algae are great CO₂ absorbents.
- They have the properties to be grown everywhere since they do not have region selection.

Oil content, oil efficiency, field of use and biodiesel efficiencies of algal oil and different vegetable oils are given in Table 2 [29].

Table 2. Comparison of algae oil and other vegetable origin oils (30).

Raw Materials of oils	Oil Content (%)	Oil Efficiency * (L oil/ha.year)	Field of use ** (m ² /year.L Biodiesel)	Biodiesel Efficiency *** (L Biodiesel/ha.year)
Algal (with low oil cont.)	30	58,700	0.2	61,091
Algal (With medium oil cont.)	50	97,800	0.1	101,782
Algal (With high oil cont.)	70	136,900	0.1	142,475
Corn	44	172	56	179
Hemp	33	363	26	378
Soya	18	636	15	661
Jatropha	28	741	13	772
Camelina	42	915	10	952
Canola	41	974	10	1,014
Sun flower	40	1,070	9	1,113
Castor	48	1,307	8	1,360
Palm	36	5,366	2	5,585

* : L oil / ha.year: Amount of oil in litres per hectare per year

** : m² /year.L Biodiesel: The amount of biodiesel obtained from m² per year

*** : L Biodiesel / ha.year: Amount of biodiesel per liter per year

Table 2 demonstrates that biodiesel efficiencies of algae are a lot higher than the other bio-oil raw materials especially in terms of annual oil efficiencies when low, medium and high content algal types are compared to other agricultural origin oil raw materials. In addition, when areas used for growing raw materials are examined, it can be easily seen that there is no need to use great amount of areas for algae production.

CONCLUSION

While about 9% of total renewable energy consumed in global scale is met from energy sources which are called conventional biomass and which are used for cooking and heating purposes, 10.3% of it is obtained from modern renewable energy sources. Within the context of alternative energy policies, agriculture based biomass energy, which is environment friendly and provides sustainable energy production and environment management and has properties targeting development, has found a vast application area throughout the world. However, increasing biofuel production,

which countries have, at agricultural and technological levels has brought along a lot of important debates as well. In this case, scientists have started to mention that algal biomasses, defined as third generation, could be alternative energy source and that they have many advantages. Due to increasing petroleum prices in recent years, algae have started to be seen as promising energy source as a result of researches on biomass energy. The studies, through which biofuels such as biodiesel, renewable aviation fuel/bio-jet fuel, biogasoline/green gasoline, biobutanol, bioethanol and methane are obtained out of algal biomass, have been widely developed. The fact that the agricultural areas are not utilized during algae growth, and that they reproduce very rapidly even in small areas, and that there is no need for fertile lands for their growth, and that some algae types contain more oil than field crops, and that their growing process is easier, and they are not affected by changing seasons and climatic conditions, and that they can be produced in vast amounts in a very short time make them advantageous.

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