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Possible Opportunities for the Use of Microalgae in Renewable Energy Production

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Abstract: The importance of energy increases day by day, and the use of second-generation biomass fuel energy sources, such as corn, sorghum, rapeseed, soybean and sunflower plants, biogas energy, biodiesel and ethanol production, continues. Algae, defined as third generation, are thought to be a solution for the protection of the environment. In this context, especially in countries with suitable climatic conditions such as the USA, promising practices for energy conservation and a renewable product is earned.
In this study, algae, which provide positive results in laboratory studies, are discussed as an energy resource that can reduce the energy deficit and environmental pollution in our country.

INTRODUCTION

As conventional energy reserves are being depleted, energy has become one of the most expensive production inputs, along with being a source of environmental pollution. Because of these and additional similar reasons, as in all developed and developing countries, our country sought to take advantage of the most promising new and renewable energy sources. In our country, alternative energy laws have begun to encourage the production of alternative energy. In this context, to find a global solution for climate change, governments, industry associations, non-governmental organizations and agricultural associations are encouraged to give priority to the use of renewable energy sources (Yilmaz and Atalay, 2004).

In recent years, the energy sector in Turkey has grown very rapidly. Although energy consumption is low compared to the European Union countries, increasing population and industrialization are expected to increase primary energy consumption by an average of 4% by 2020. Turkey's total primary energy consumption in 2008 was 106,3 million tons of oil equivalents (TOE), while energy production was 29,2 million TOE. This shows that energy production is very low relative to consumption. The majority of the consumed energy is met through imports. Natural gas constitutes the largest imported energy source at 32%, followed by 29,9% for oil, 29,5% for coal and 8,6% for renewable of imported energy sources (EB, 2011).

According to the Greenhouse Gas Inventory Reports submitted to the United Nations, Turkey's greenhouse gas emissions increased by 118,8% between 1990 and 2007 (Atamer, 2010). The United Nations Framework Convention on Climate Change was signed in 1997 and became active in 2005, and as of August 2009, Turkey is a part of the Kyoto Protocol. Due to the rapid increase of emissions, it will be very difficult to meet the obligations that will be put into effect after 2010 by the protocol (PPD, 2009).

Biomass Energy

The use of fossil fuels emits carbon into the atmosphere, leading to global climate change. Biomass energy provides the capability to rebuild the global carbon balance by trapping the released carbon in the biomass. This is a more environmentally-friendly option than other renewable energy sources and therefore shows significant development each year (Ladanai and Vinterback, 2009).

The first generation of biomass energy resources, such as corn, sorghum, rapeseed, soybean and sunflower plants, have been used to produce energy alternatives to traditional fossil fuels, including biogas energy, biodiesel and ethanol. The production of ethanol from cellulosic biomass, which is second-generation biomass energy, is still far from being a feasible alternative energy source (Say et al., 2010).

Biomass Energy in Turkey

Because industrialization and urbanization, together with energy demand, increase day by day, Turkey has one of the fastest growing energy markets in the world. Turkey's foreign trade data in the last 10 years shows that the import value for crude oil, coal and natural gas was $154 billion and that the foreign trade deficit during this period was $377 billion. A total of 41% of the foreign trade deficit is due to the need for energy. These data show that Turkey is a major importer of energy and has an energy supply security problem that requires an assessment of the impact of export dependencies on national security (Geka, 2011).

Turkey is a country that maintains its position as a rapidly increasing emitter of carbon dioxide. According to the global competitiveness index, Turkey is in 61th order and although many developments exist in energy production, the lack of planning, incentive mechanisms, legal infrastructure, investments in technological research and development of renewable energy are among the inadequacies that prevent a solution for these problems (Geka, 2011).

In addition to the energy production deficit, environmental pollution and the Kyoto Protocol, the total greenhouse gas emission in Turkey in 1990 was 170 million metric tons of CO_2 equivalents, while in 2007 it was 372 million metric tons of CO_2 equivalents. Looking at areas of greenhouse gas sinks, in 1990, 44 million metric tons of CO_2 equivalents greenhouse gas emissions were engulfed, and this value increased to approximately 77 million metric tons of CO_2 equivalents in 2007 (Figure 1). In Turkey, greenhouse gas emissions are equal to 5,3 metric tons of CO_2 equivalents per person in 2007. The OECD average is 15 metric tons of CO_2 equivalents per person, and the European Union average is 10,2 metric tons of CO_2 equivalents in 27 countries in the same period (Atamer, 2010).

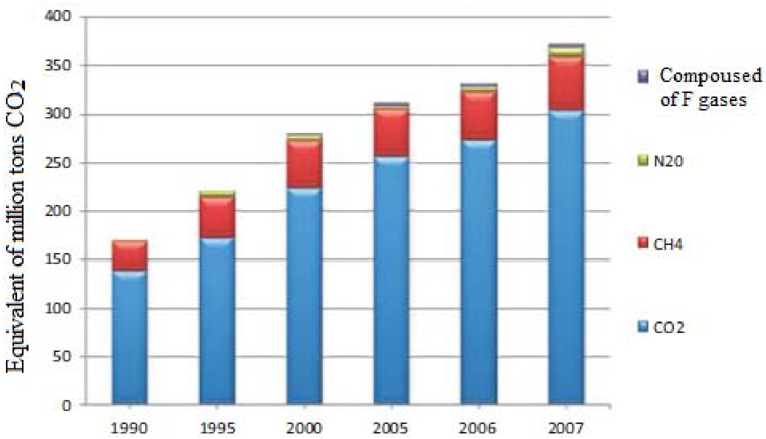

Figure 1. Greenhouse gas emissions and components in Turkey between the years 1990-2007

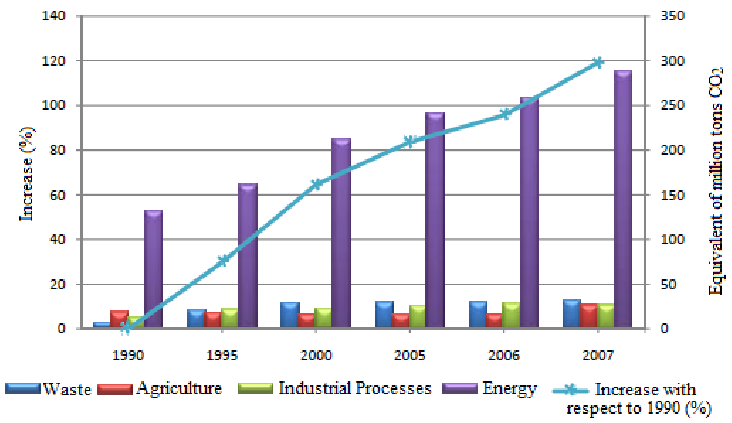

Figure 2. Amount of increase according to sources of greenhouse gas emissions

Figure 2 shows the amount of CO_2 produced according to energy usage between 1990-2007. In this period, the largest share was from the energy sector between four different sources. This rate increased with increasing energy demand.

Biodiesel is a type of fuel produced from animal fats or vegetable oils, including extracted seed oils such as rapeseed, sunflower, soybean and safflower. Household frying oils and animal fats can be used as the raw material for biodiesel. Biodiesel does not contain petroleum and can be used in pure form or can be mixed with petroleum-based diesel fuel at any ratio. Because biodiesel is produced from crops, which capture CO_2 through photosynthesis, it does not produce a net increase of greenhouse gas emissions. In our country, biodiesel can be be used in all areas except in very cold regions. Biodiesel is used instead of diesel fuel in the transportation sector, and it can also be used in place of fuel oil in residential and industrial sectors.

Bioethanol is the alternative fuel obtained through the fermentation of agricultural crops, such as sugar beet, corn, wheat and other woody plants that contain sugar, starch or cellulose. It can be used in unaltered modern gasoline engines by mixing with up to 20% gasoline (Alibaş and Çıtıroğlu, 1991). The use of pure bioethanol for motor fuel requires motors specifically designed for the use of alcohol. In South American countries, especially Brazil, alcohol is widely used in motors. Bioethanol is mixed with gasoline in the transportation sector, as well as being used for small household appliances and in the chemical products sector. Bioethanol increases the oxygen level of the fuel and makes the fuel burn more efficiently, thereby reducing emissions of harmful gases in exhaust.

In our country, fuel consumption totals 22 million metric tons, 3 million metric tons of which is gasoline, whereas current bioethanol capacity is 160000 tonnes. The most criticized aspect of biofuel farming is that it uses areas that are suitable for food agriculture and thereby creates a potential risk to global food security.

Biogas is the gas composed primarily of methane and carbon dioxide gas, which are produced as a result of the biological degradation of organic matter (animal waste, vegetable waste, urban and industrial wastes) under oxygen-free conditions. In biogas technology, energy is obtained from organic-based waste and materials that can also be used as fertilizer. The animal waste produced in Turkey corresponds to an estimated potential biogas production of 1,5 to 2 million TOE.

Biomass sources include livestock, agricultural-based products and residues, forestry products and residues, and urban organic wastes. The potential energy that can be produced from waste is about 8,6 million TOE, 6 million TOE of which is used for heating. In 2008, the total amount of energy derived from biomass sources was 66 thousand TOE (EB, 2011).

Biomass Energy in World

Global climate change remains a global concern and is not only "an environmental catastrophe" but also become a phenomenon that brings together many different disciplines. The fight against climate change should be conducted while maintaining economic growth using "clean development" models. In 2009, the USA allocated $5.4 billion of the budget to green energy products and passed new laws, which created tens of thousands jobs in the energy sector. Approximately 40% of a $586 billion incentive package in China funds green projects. Also in China, one of every ten homes uses a solar thermal water heater. At the same time, China has the largest wind farm portfolio in Asia and the 4th largest in the world. In Germany, in 10 years, the energy sector will become one of the leading sectors, providing more employment opportunities than the automotive industry. Denmark has had a stable policy supporting renewable energy and has not increased its fossil energy use for 50 years (Geka, 2011).

What is microalgae?

Prior to their use as an alternative energy source, algae have been produced for nutrient purposes in animal farming for many years. In recent years, as a result of rising oil prices, biomass energy research studies have accelerated, and algae are now regarded as a promising source of energy. Third generation biofuels technology use algae as an energy source. Although successful laboratory studies have been conducted that use the algae found in nature, larger pilot and small-scale experiments could not achieve the desired yields.

Microalgae are microorganisms that contain carbohydrates, proteins, lipids and vitamins. In general, microalgae contain approximately 15-77% oil (Xu et al., 2006; Chisti, 2007). When compared to other oil crops, they have a high oil content and growth yield, and this makes them attractive for biodiesel and biogas production. Production of these fuels from microalgae may provide a response to increasing global energy demand and, by converting excess carbon dioxide in the atmosphere into the product through photosynthesis, has the potential to contribute to the prevention of global warming.

Algae also do not constitute as great a danger to drinking water sources as terrestrial energy crops and provide the advantage of removing pollutants such as nitrogen and phosphorus.

Biofuels such as biodiesel and ethanol have been proposed as possible alternative fuels. Current biofuel production methods require increasing amounts of arable land, competing with terrestrial food crops and heightening concerns over food affordability. An algae-based approach offers a unique alternative because it does not compete with agricultural food production. This is due to the ability of microalgae to generate a much higher oil content of up to 80% of the total dry (Harun et al., 2011).

Table 1. Comparison of biofuel sources on annual basis (Chisti, 2007)

Oil Source	Oil Production (l/ha)
Soybean	446
Rapeseed	1190
Palm oil	5950
Microalgae (30% oil content)	58700
Microalgae (70% oil content)	136900

As shown in Table 1, microalgae with high oil content appear to be the only source of biodiesel that has the potential to completely displace fossil diesel (Chisti, 2007). In this table, the production of oil in a year as a liter per ha is given for soybean, palm and microalgae. For example in Turkey, for 1000000 m^3/year biodiesel production, 2,8 million ha arable land is required for soybean while 1 million ha is required for rapeseed.

At this production rate, microalgae containing 30% and 70% oil require 0,0102 and 0,0044 million ha arable land, respectively. According to these values, even microalgae with 15% oil provide better results than soybean, rapeseed and palm. As a result, in the near future, biofuels that are produced from high fat content microalgae may replace petroleum-based biofuels for use in transport.

Algae, both in the natural environment and under laboratory conditions, are of great importance to the economy because the use of algae can be applied to a wide variety of areas. Algae production is the most effective and most economical way to convert solar energy to biomass. Microalgae adjust the pH of their environment by removing CO_2 and help control water quality by removing excess nutrients in the environment. In addition, they are used in the manufacture of some chemical substances and the production of methane gas by fermentation. Microalgae are extremely rich in carbohydrates, protein and fatty acids. Algae, having a high nutritional value, are the most important source in vitamins and trace elements for aquatic organisms. At the same time, they provide pigments for color development for fish and other aquatic organisms. Excessive amounts hunting in marine and inland waters have led to increased environmental pollution and a decrease in the amount of living organisms. For this reason, the culturing of algae has accelerated. Larvae feeding in aquaculture facilities are the most important step of algal culture units.

Microalgae in the World

The use of microalgae as an alternative energy source has been suggested for years by many researchers (Thomsen, 2010). For many years, microalgae were produced as food for use in animal farming. More recently, they have been viewed as a promising source of energy as a result of the impact of rising oil prices. Microalgae are the third generation of biofuels technology, but studies are currently limited to laboratory, pilot and small scale trials, and difficulties in the process have prevented full-scale development.

Tilman et al. (2006) see microalgae as the most promising alternative energy source and also emphasize the contribution of gas emissions in the results. With very little water, microalgae can double in size in a day using only the light of day. Some microalgae even complete this growth in just a few hours.

Therefore, microalgae represent the highest yield biofuel crop, having the capability to produce millions of liters of biodiesel per ha per year. This contrasts with palm oil crops, which can produce only 5950 l/ha. Not all algal oils are satisfactory for biodiesel production, but suitable oils are commonly produced (Ahmad et al., 2011).

Many publications describing research on microalgae have been published. Several researchers have focused on the *Chlorella* genus, which appears to be a good option for biodiesel production because these algae are readily available and easily cultured in the laboratory (Ahmad et al., 2011). Converti et al. attempted to increase the lipid content in microalgae by varying the temperature and nitrogen concentration during the culture and concluded that variation of these growth conditions strongly influenced the lipid content of the microalgae.

For each ton of algae produced, 1,8 tons of CO_2 are consumed. In this respect, algae are a major CO_2 absorber. They can be grown in any location without regional selectivity (Oilgae, 2010).

Microalgae in Turkey

In Turkey, microalgae-related scientific studies are largely conducted at fisheries facilities and are usually focused on larvae feed production and monitoring of eutrophication in marine and surface waters. The Bioengineering Department at Ege University has conducted photobioreactor design studies related to the production of active ingredients in food products. As a result of this work, microalgal biomass production research has begun at some universities, primarily at Ege University, but little of this work has been focused on the production of energy. Energy-focused studies have been attempted in İzmir, Ankara and Gebze. These studies have been laboratory-based, and despite the success under laboratory conditions, application-oriented studies have not yet been conducted.

One of the studies on the production of algae in our country, which started in April 2010 and was supported by TÜBİTAK, Gebze High Technology Institute, was a project titled: "Innovative Approaches to the Production of Biomass Microalgal." In this project, microalgae-based biodiesel production cost solutions were presented. Additionally, CO_2 emissions, which are the largest cause of global warming, are reduced with algae, and the risk of eutrophication is also reduced by the removal of nitrogen and phosphorus. The algae were collected from the discharge water at the Ömerli Domestic Waste Water Treatment Plant at regular intervals and cultured. Nutrient usage rates and CO_2 absorption capacities were measured in laboratory-based experiments. The results of this project are expected to significantly reduce the cost of biodiesel production from algae.

In Turkey, the annual total sunshine duration is 2640 h/year, from which an average energy of 3,6 kWh/m^2 can be obtained, as reported by General Directorate of EIE. In this case, the necessary energy for the production of microalgae, which are extremely rich in terms of solar energy for our country, will be the focus of the scientific studies in this area (Say et al., 2010).

Microalgae usage areas

The main application areas of microalgae are presented in Table 2. As shown in the table, different products may be obtained by applying different processes.

Table 2. Processes that use microalgae

Final Product	Production Process
Biodiesel	Oil extraction and transesterification
Ethanol	Fermentation
Methane (biogas)	Anaerobic fermentation of algae residual
Heat and electricity	Direct combustion of algae residual or gasification of biomass

Microalgae production and its use as a fuel

Production methods

Microorganisms contain a certain amount of protein called the single-cell protein (SCP). Microorganisms obtain their protein groups from non-pathogenic and nontoxic substances. These proteins are added to human and animal food as a protein source. The microorganisms used in SCP production are algae, bacteria, yeasts, molds and fungi.

However, microalgae are the most commonly used for manufacturing SCP and find a wide range of applications in human and animal feed products.

One of the reasons microalgae are preferred is their use of photosynthesis. In other words, they transform water and carbon dioxide in water into organic matter (sugar) using light energy.

Light is required for algae manufacturing, and 12-20% of this light is converted to energy in chemical form. For algae production, the carbon dioxide in the air is not sufficient. The carbon dioxide in the air is only 0,03%, and supplemental carbon dioxide needs to be added to the environment for algae growth. Lakes are used for the production of SCP because the amount of calcium carbonate is high. The most widely used type of algae for global SCP production is *Spirulina maxima*. Microalgae do not need organic carbon compounds to reproduce and require only a source of carbon (carbon dioxide, bicarbonate) and a nitrogen source (ammonium salts, urea). For algal development, phosphate, sodium, magnesium, copper, chloride and sulfate ions are required. This provides the advantage of low cost production. Algae reproduce very easily and quickly. Algae also contain many carotenoids. Carotenoids exist in many plants and in bacteria capable of photosynthesis and are a class of fat-soluble natural pigments. One of the advantages of the use of algae is removal of food waste. Currently, industrial algae production is conducted in 20-30 cm deep, open-top, concrete ponds equipped with a mixer and centrifuge that are filled with domestic fresh water and sewage water. Algal cultures developed in a different environment are added to prepared ponds. The water in the ponds is rich in nitrogen and phosphorus, providing the source materials for the development of algae, while organic matter present in the water is converted into the small molecular building blocks that algae may use. This approach allows for the easy reproduction of algae. In these types of ponds, industrial and agricultural waste products can also be used instead of sewage. Thus, these waste materials are converted into protein and environmental pollution would be eliminated.

Microalgae are also important in products for their nutritional value. Algal cells contain up to 60% crude protein and 16-55% carbohydrates (cellulose and starch), as well as fat and vitamins.

In addition to these advantages, the use of algae protein is been applied to animal and human nutrition for digestive difficulties, but has been avoided primarily due to taste and flavor rather than the high cost of the final product. In addition, the development of many microorganisms to limit the growth of algae is seen as a disadvantage

Harvesting of microalgae

The ease of harvesting microalgae primarily depends on the size of organisms. According to its size, it can be filtered or precipitated easily. The main methods of harvesting of microalgae are as follows:

- Precipitation and sedimentation
- Mechanical filtration and the use of membranes
- The use of chemical substances and biological harvesting
- Centrifugation techniques

Biodiesel production from microalgae

In the process of producing oil in their structures, microalgae use sunlight and CO_2 more effectively than other oil plants. Their division potential and growth rates are very high. During rapid growth, the doubling time of microalgae is 3,5 hours. For these reasons, it is possible to produce microalgae in large quantities with a small amount of arable lands at a lower cost than oil plants. The algae cycle is shown in Figure 3.

Microalgae production can provide a high yield at the industrial scale inside open ponds or in photobioreactors in greenhouses in regions with a temperate climate (Borowitzka, 1999; Yilmaz, 2008; Chisti, 2007).

Biogas production from microalgae

If biochemical conversion is conducted under anaerobic conditions, the end product is methane. Chemical conversion involves the extraction of lipids accumulated in cells and a transesterification reaction that converts these lipids to biodiesel. Thermochemical conversion, gasification, pyrolysis and liquefaction processes may also be used. Thermochemical conversion is one of the most efficial conversion transactions. The conversion of algae to methane is shown in Figure 4.

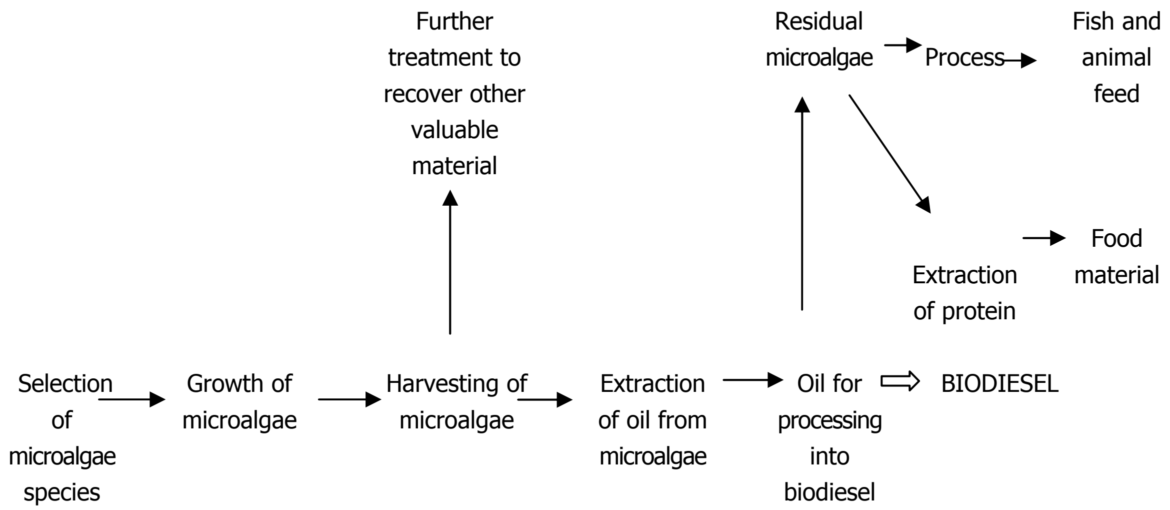

Figure 3. Algae recycle (Oilgae, 2010)

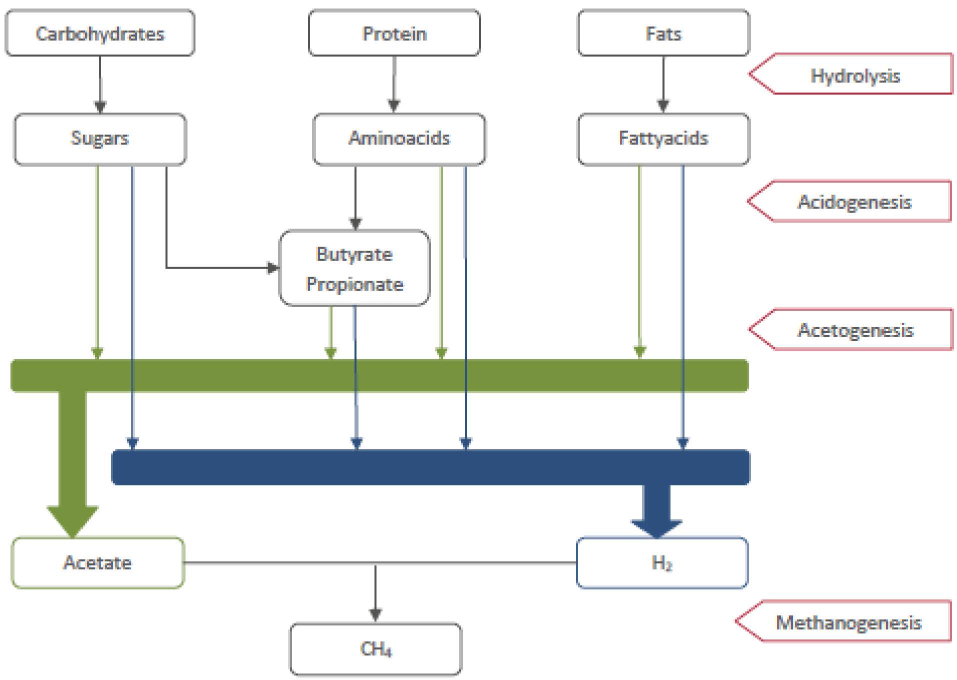

Figure 4. Biogas production phases of microalgae (Oilgae, 2010)

CONCLUSION

Algae are seen as a raw material for alternative energy sources. The climatic and nutrient requirements, particularly CO_2, are readily available in our country, making it economically suitable for the production of algae.

When only natural gas-powered thermal plants are considered, there is a great potential source of CO_2, which is the main food source of microalgae. Approximately 48% of the 198,418 GWh of electricity produced in Turkey in 2008 was from natural gas. This amount corresponds to approximately 95,240 GWh of electricity production. When 1 MWh of natural gas is combusted, 0,6 tons of CO_2 is released into the atmosphere. According to these data, the amount of CO_2 released into the atmosphere is about 57144000 tons per year from natural gas-powered thermal plants. This amount constitutes approximately 20% of Turkey's CO_2 emissions.

In Bursa in 2006, 91,16% of the installed electricity production capacity was provided by natural gas. Bursa's total thermal power (including coal) is 2398,2 MW. If thermal exchanges are established and a 71% loading rate is considered, the amount of energy produced in thermal power stations in 2008 can be calculated as 14915844 MWh / year in Bursa. During this production, 8949506 tons/year CO_2 was released.

The Ovaakça thermal power plant, which has the installed capacity of 1400 MW, produces 8584800 MWh/year of electricity, resulting in the production of 5150880 tons/year of CO_2. With this power plant alone, 2884493 tons of dry microalgae may be grown (0,56 tons of dry microalgae may be produced from one ton of CO_2 (Say et al., 2010)). Considering a microalgae production capacity of 200 tons/ha, 14400 ha would be required to produce this amount of microalgae.

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