Evaluation of Potential Bioethanol Production from the Indigenous Microalgae of Iran

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Abstract

Industrial growth and population raising lead to rapid increase in worldwide energy demand. Due to the depletion of fossil fuels and their contribution to the global warming, the world requires alternative sources of energy to meet the global demands of energy. One of the most popular source of energy is bioenergy in form of bioethanol since it is clean, cheap, renewable and compatible to the environmental issue. Iran produced 5% of global total capacity of bioethanol equal to 5.3 billion liters (4.2 billion tons) at 2011. In recent years, bioethanol production from microalgae biomass is getting more attraction due to the shorter cycle of algal growth compared to other plants and its abundance in nature. *Chlorella sp*, *Dunaliella sp*, *Spirulina sp* and *Chlomydomonas sp* are some microalgae strains existing in Iran which have the potential to produce bioethanol. In this paper, the potential source of indigenous microalgae of Iran (including Persian Gulf, Urmia Lake, Maharloo lake and Gavkhoony ...) is presented. In order to introduce suitable species for production of bioethanol, the results on potential amount of obtainable bioethanol from each microalgae (as biorefinery platform) is illustrated.

Keywords: Biorefinery, Microalgae, Bioethanol, Indigenous species

1. Introduction

As the population increases in this century, demands for liquid fuels in the transport sector has been risen. Fossil fuels are beginning to run out, so we should consider a solution for this increasing demand. Using renewable biofuels, especially liquid biofuels because of their easy production, transportation and application, is an appropriate response for this demands. Substituting fossil fuels with biofuels has a lot of advantages such as reducing Green House gases, increasing the energy security of countries, renewability, and making employment opportunities.

Bioethanol as a liquid biofuel needs more attention because of increasing production of it. World ethanol production in 2009 reached 73.9 billion liters which shows more than 400% increase in comparison with that in 2000 (17 billion liters). Although it has been predicted that global ethanol production will continue to increase and in 2017, will double that of 2009 [1].

Ethanol is not toxic, is biodegradable and it's use produce fewer air pollutants such as CO, NO_X, SO_2 than petroleum fuels [2]. Ethanol blended gasoline has the potential to contribute significantly to reduce Green House gas emissions and also can enhance octane number [3].

Bioethanol can be produced from several different biomass feedstock such as (i) sugar or starch crops (as sugar cane, sugar beet, corn and wheat) and (ii) lignocellulosic biomass [2]. Based on the type of feedstock used, bioethanol are generally classified into ''First generation bioethanol" and ''Second generation bioethanol' [4]. Bioethanol from sugar/starch crops through traditional production technologies is included in the group of ''First generation bioethanol", and so bioethanol from lignocellulosic biomass is considered as a ''Second generation bioethanol'' [2].

Firs generation bioethanol have problems such as:

(i) The main problem of using food crops for bioethanol production is that it can impact on food supply and food price. (ii) Also use of food crops as feedstock is not idea because of the high price of raw materials, which accounts for almost 40–75% of total ethanol production cost [5]. (iii) In addition, extensive cultivation of energy crops also raises concerns regarding pollution of agricultural land with fertilizers and pesticides, soil erosion, reduced crop biodiversity, biocontrol ecosystem service losses and Green House gas emissions [2].

Using of second generation bioethanol based on lignocellulosic biomass, including agriculture residual, forest harvesting residual and wood processing wood is a better option for addressing the food and energy security and treatment concerns but their harvesting, purification and various pre-treatment needs made their production quite environmental challenging and not economical [1, 5].

In view of the aforementioned issues, algae are gaining wide attention as an alternative renewable source of biomass for production of bioethanol, which is grouped under ''third generation bioethanol" [5].

2. Algae as a "third generation bioethanol"

2.1. An introduction to algae

Algae strains are simple organisms containing chlorophyll and they use light for photosynthesis [6]. Based on their morphology and size, algae are typically divided into two major categories macroalgae and microalgae. Microalgae, capable of performing photosynthesis, are important for life on earth; they produce approximately half of the atmospheric oxygen and use simultaneously the GHG carbon dioxide to grow photoautotrophically. The three most important classes of microalgae in terms of abundance are the diatoms (Bacillariophyceae), the green algae (Chlorophyceae), and the golden algae (Chrysophyceae) [9].

2.2. Advantages of algae as a source for bioethanol

There is a potential for carbohydrates in the structure of algae which can be utilized for ethanol production .Algae can use as an excellent alternative to food crops for bioethanol production without compromising food supplies, rainforests or arable land. Due to structural differences between algae and terrestrial plants, algae are capable of producing high yields of stored material when compared to most productive land plan [2]. Algae cells can be harvested within a short span of time as compared to other feedstock and hence can meet the increasing demand of feedstock for ethanol production [7]. They have a high photosynthetic efficiency; the average photosynthetic efficiency of aquatic biomass is 6–8%, which is much higher than that of terrestrial biomass (1.8–2.2%) [8]. Algae can be easily grown in different aquatic environments such as fresh water, saline water or municipal waste water [10, 11]. Algae have the advantages of having no lignin and low hemicellulose levels, which result in an increased hydrolysis efficiency and fermentation yields [12, 13].
Plus above-mentioned, as you can see in Table 1 ethanol production yield from algae is more than other feed stocks.

Table 1. Ethanol yield from different feedstock [14]

Feed stock	Ethanol yield (gal/acre)	Ethanol yield (L/ha)
Corn stover	112-150	1,050-1,400
Wheat	277	2,590
Cassava	354	3,310
Sweet sorghum	326-435	3,050-4,070
Corn	370-430	3,460-4,020
Sugar beat	536-714	5,010-6,680
Switch grass	1,150	10,760
Algae	5,000-15,000	46,760-140,290

3. Iran's energy status

3.1. Renewable and non-Renewable energy in Iran

The Islamic Republic of Iran is located in the Middle East in the southern parts of the Caspian Sea, Turkmenistan, Azerbaijan and Armenia and has Pakistan and

Afghanistan on the east, Iraq and Turkey on the west, and Persian Gulf and Oman Gulf in the south. The population of Iran is 73 million and the area of this country is 1,648,195 km2. . Iran is ranked as one of the top countries with many renewable and non-renewable natural resources. After Venezuela, Saudi Arabia and Canada, Iran holds the fourth largest crude oil reserves in the world. Also, statistics show that Iran is the second largest natural gas reserve in the world [15].
Figure 1 shows the energy consumption in Iran in 2008. Oil and natural gas provide About 99 percent of total energy consumption while coal provide only 0.21 percent. Indeed, coal is only used in cement and iron industries and there is no power plant in Iran yet. Renewable energy provide less than 1 percent of total energy demand. Since Iran has plenty of fossil fuel resources, alternative fuel and renewable resources have not been taken into consideration seriously [16].
Electricity demand in Iran has been reported to be 50,000 MW which is around 80% of what has been generated by the fossil fuel consumption. It has been projected that Iran's electricity demand will be 200,000 MW in 2030. Due to infrastructure problems, domestic demands and economic nee to export oil and natural gas, these energy sources cannot fully meet future Iranian energy needs [17, 18].

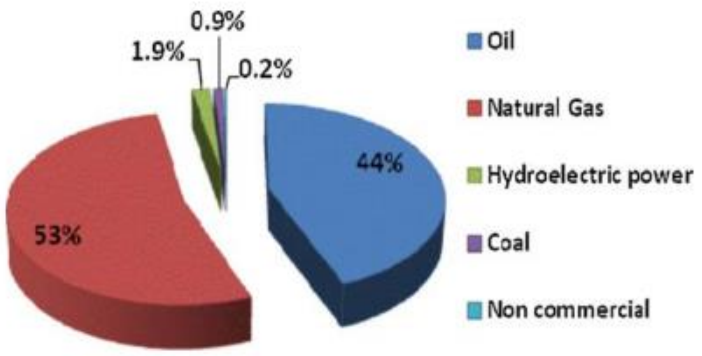

Figure 1. energy consumption in Iran in 2008 [19]

To meet future energy demand and many problems of fossil fuels such as Green House gas emissions, increasing cost and decreasing sources, moving to the use of renewable and sustainable energy resources has been accept by Iranian Government. Renewable Energy Organization has established various research programs for development of bioenergy production from biomass but there is not a comprehensive report on potentially available algae resources in Iran [20].
In the next part, we evaluate the potential of bioethanol from different algae resources and different algae species in Iran.

3.2. Algae as a sustainable source for bioethanol production in Iran

Iran has sufficient land for algae cultivation that does not compete with food production. Geographically, Iran has Caspian Sea in the north and Persian Gulf in the south that has natural advantages for algae culture. Iran has different salt lake that help scientists advance algae-based biofuel technology [18].

Ethanol production from algae is based on fermentation of algal polysaccharides which are starch, sugar and cellulose. For microalgae, their carbohydrate content (mostly starch) can be reached to 70% under specific conditions [21].

Fermentation is a process that fermentable sugars are converted to ethanol by microorganisms. Process consists of conversion of glucose to ethanol and carbon dioxide:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

Bioethanol production yield defines Kg of bioethanol per Kg of glucose. In this process 0.51 kg bioethanol is obtained from per kg of glucose in theory maximum yield.

Fermentation processes generally are carried out with two basic processes as simultaneous scarification and fermentation (SSF) and separate hydrolysis and fermentation (SHF) [40].

There are at least 30,000 known species of microalgae, and they are widely distributed in marine waters, freshwater lakes, and others. As their small size makes subsequent harvesting more complicated, cultivation is the main way to generate biomass from microalgae [5].

The absolute and relative amounts of the bioethanol that can be generated vary markedly between algal species and even between strains of the same species. This is because, algal species and strains vary greatly in terms of growth rate and productivity, nutrient and light requirement, ability to accumulate lipids or other desirable compounds, ability to adapt to adverse conditions, etc. [22].so it is better to select strains and species that capable of accumulating high cellulose/starch which result to producing highest amounts of bioethanol. Microalgae like Chlorella, Chlamydomonas, Dunaliella, Scenedesmus, and spirulina have been shown to accumulate a large amount of carbohydrates (>40% of the dry weight) [2]. Algae species that have high carbohydrate content of more than 30 weight percent, are presented in Table 2. So these microalgae species could be a good substrate for bioethanol production.

Table 2. Algae species with high carbohydrate content

Algae species	% carbohydrate content(g/dry weight) Starch/cellulose /hemicellulose	Reference
Chlamydomonas reinhardtii UTEX 90	60(starch)	[23]
Chlorella vulgaris	55(starch)	[24]
Spirulina fusiformis	37.3–56.1 (starch)	[2]
C. vulgaris FSP-E	51.0(starch)	[25]
Scenedesmus dimorphus	21-52(starch)	[26]
Chlorococum sp.	32.5 (starch)	[27]
S. obliquus *CNW-N*	51.8 (starch)	[28]
Dunaliella tertiolecta	40.5 (starch)	[37]
Chlorococcum infusionum	32.5 (starch)	[29]
Chlorella sp. KR-1	36.0(starch)	[30]
Spirogyra sp.	43.3(starch and cellulose)	[2]
Spirulina platensis	26.8(cellulose and hemicellulose)	[38]

In Table 3, some of the most important microalgae used in the process of bioethanol production, specifying geographical states in Iran has been illustrated. Each of these microalgae has a specific composition in their carbohydrate content which determines the required operation in order to convert to ethanol

For each of the microalgae, pretreatment steps, fermenting organism, fermentation process type and process time has been presented. The bioethanol production yield of each of these microalgae has been estimated. It is noticeable that for each of microalgae, the operation conditions mentioned in the tables, have been optimized and the best obtainable yield is reported. . In order to choose the appropriate type of the microalgae, two parameters have to be considered: abundance of indigenous microalgae and the yield of bioethanol production from these microalgae.

Table 3. Bioethanol production yield from microalgae strain

Microalgae strains	Microalgae resources in Iran	Pretreatment	Fermenting organism/process type and process time	Bioethanol production yield (%)	Reference
Dunaliella tertiolecta	Maharloo salt lake, Uramia Lake, Gavkhuni salt marsh	Enzymes saccharification with 82% yield	-	-	[37]

Chlorococum sp.		Supercritical CO2 lipid extraction	*Saccharomyces bayanus*, SHF, 60 h	38.3	[7]
Chlorococcum infusionum		0.75% (w/v) NaOH pre-treatment in 120°C for 30 min	*Saccharomyces cerevisiae*, SHF, 72 h	26.00	[29]
Spirulina sp	*Caspian Sea, Qeshm Island*	2% H2SO4 with 25 min hydrolysis time	*Saccharomyces cerevisiae, 7 days*	0.99(ethanol percentage)	[39]
Chlamydomonas reinhardtii UTEX 90	*Fars province*	3% H2SO4 pre-treatment in 110°C for 30 min	*Saccharomyces cerevisiae* S288C, SHF, 24 h	29.10	[31]
Chlamydomonas reinhardtii UTEX 90	*Fars province*	a-amylase (90 °C, 30 min) and glucoamylase (55 °C, 30 min) enzymatic hydrolysis	*Saccharomyces cerevisiae S288C*, SSF, 40 h	23.50	[32]
C. vulgaris FSP-E	Caspian Sea	dilute acid hydrolysis (1% H2SO4)	. Z. mobilis, SHF, 12 h	٠,٤٩	[25]
Chlorella vulgaris	*Caspian Sea*	3% H2SO4 pre-treatment in 110 °C, for 105 min	*Escherichia coli* SJL2526, SHF, 24 h	40.00	[33]
Schizochytrium sp		hydrothermal degradation and a-enzymatic hydrolysis	*Escherichia coli KO11*, SSF, 72 h	5.51	[34]
Chlorococcum humicolo		H2SO4 pre-treatment	*Saccharomyces cerevisiae*, SHF, 50 h	48	[35]
Chlamydomonas reinhardtii cw15	*Fars province*	12 N H2SO4 pre-treatment	*Saccharomyces cerevisiae*, SHF, 48 h	44	[36]
Chlorella sp. KR-1	*Persian Gulf*	0.3 N HCl at 121 C for 15 min with 98.2% yield	S. cerevisiae KCTC 7931 (ATCC 20626)	40	[30]

4. Conclusion

This paper shows that there is a considerable potential for bioethanol production from algae carbohydrate in Iran. Spirulina containing about 37.3-56 weight percent of starch, chlamydomonas with about 60 weight percent of starch, chlorella with about 36-55 weight percent of starch and Dunaliella with about 40 weight percent of starch are some microalgae that have high potential for bioethanol production. The abundance of Spirulina in Caspian Sea and Qeshm Island, chlamydomonas in Fars province, Chlorella in Persian Gulf and Caspian Sea, and Dunaliella in Maharloo lake, Uramia salt lake and Gavkhuni salt marsh, create the possibilities to produce bioethanol in these states. The producing process may defer considering this fact that each of these microalgae have a specific composition in their carbohydrate content. Thus, it could result in a different producing yield of ethanol from each of the microalgae. Iran has sufficient lands for culturing these microalgae. It has been estimated that approximately 5000–15,000 gal of ethanol/acre/year (46,760–140,290 L/ha) can be produced from microalgae. Bioethanol production from microalgae could provide Iranian nation with a means to invest in natural renewable resources instead of exporting its capital to purchase fossil fuel products such as gasoline and diesel fuels.

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