Future production of bioethanol from microalgae as a renewable source of energy

Wusnah1,2, M. D. Supardan1, S. Haryani3 and Yunardi3,*

1Doctoral Program, School of Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia
2Department of Chemical Engineering, Malikussaleh University, Lhokseumawe, 24351, Indonesia
3Department of Chemical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia
4Department of Agricultural Engineering, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, Indonesia

*Email: yunardi@unsyiah.ac.id

Abstract. Fossil fuels that mainly supply the current increasing world's energy demand originated from non-renewable resources. In addition to the depletion of their resources within the next short time, the combustion of fossil fuels to power industries and transportation also negatively impacts humans and the environment due to the release of various gaseous pollutants. To increase the share of renewables in the primary energy mix, the Government of Indonesia is currently struggling to meet a target of 23% by 2025. Therefore, more significant efforts to search for potential renewable energy sources are the only way to overcome this issue. Bioethanol is an eco-friendly renewable energy source since its combustion emits a low concentration of pollutants. Microalgae have gained significant interest in bioethanol production because of rapid biomass growth and relatively easy pretreatment steps. It is renewable, carbon-neutral, sustainable and can be grown in wastewater coupling as wastewater treatment. This paper reviews bioethanol production, providing knowledge on the characteristics of microalgae potential for producing biomass to be converted into bioethanol, introducing process for bioethanol production, and presenting the potential challenges of bioethanol as a future renewable energy.

1. Introduction

Global warming and climate change have become extensive issues being discussed worldwide in recent years. One of the causes of the problems is air pollution due to smoke released from vehicles and industry. At present, the increase in the number of land vehicles such as cars and motorcycles operated with fossil fuels has significantly contributed to air pollution. With significant population growth, reducing the number of vehicles to reduce air pollution would be challenging, as people require mobility. In addition to pollution, the growing population and industry result in a significant increase in energy consumption. With the massive use of fossil fuels to fulfill the need of the global population at present, many issues such as depletion of reserves, price fluctuations, negative impacts on the environment and climate change are observed [1, 3, 4]. The world's energy supply is currently made up of 80% fossil fuels, 10% biofuels, 5% nuclear power, and 5% renewable energy sources such as hydro, wind, solar, and geothermal power [5]. Indonesia's energy supply profile is also similar to
that of the rest of the world, with over 90% coming from fossil fuels (gas, oil, and coal) and the rest from renewables. Despite Indonesia being rich in non-renewable and renewable energy sources, fuel oil consumption much outnumbers domestic supply. For example, domestic oil and condensate productions in 2018 were 772.3 thousand barrels per day (bpd), while domestic oil consumption is 1.3 million bpd. As a result, to meet domestic needs, Indonesia has to import oil around 500-600 thousand bpd [6]. As a result, the world's primary task today is to identify new renewable energy resources that will help to mitigate this problem and ensure the long-term development of energy.

At the current stage of renewable energy development, biofuels derived from microalgae are the third generation of bioenergy, which are considered more profitable than first and second-generation biofuels as alternative energy sources for fossil fuels. [7] Because microalgae do not contain lignin like other biomass (such as wood, straw, and grass), lignin removal is unnecessary [8]. The first-generation biofuels generally come from plants, such as soybean, corn, corn, sugar beet, and sugar cane; Palm oil; rapeseed oil; and animal fat [9]. The detrimental impact of biofuels derived from these resources on food security, global food markets, water scarcity, and deforestation has sparked much debate [10,11]. Second-generation biofuels, primarily obtained from vegetable oils (Jatropha curcas, Pongamia pinnata, Simarouba glauca, and others), lignocellulosic biomass, and forest leftovers, necessitate a vast amount of land for cultivation, preventing these areas from being used for food production. Currently, there is no efficient method for commercial-scale exploitation of multiple raw material sources in the manufacturing of second-generation biofuels [12]. Microalgal biofuels could be a viable alternative energy source to replace or supplement fossil fuels, based on the shortcomings outlined above for first and second-generation biofuels. Microalgae is one of the environmentally benign alternative energy resources, providing optimism in human attempts to replace the depletion of fossil fuel reserves. Although various biofuels can be made from microalgae biomass, this paper focuses more on the prospect of producing bioethanol from microalgae as a renewable energy source.

2. Microalgae Biomass as Bioethanol Feedstock
Microalgae are single-celled plants, reproduce very quickly with a relatively short life cycle. They can grow significantly faster as they don't need as much growth media. Microalgae multiply once every 24 hours on average, but in the exponential phase, they breed once every 3.5 hours [13]. For industrial use, the microalgae biomass must meet the requirement as presented in Table 1.

| Industrial use       | Chemical characteristics |
|----------------------|--------------------------|
| Food and feed        | Protein 20-50%           |
| Bio-diesel           | Lipid 8-50%              |
| Bioethanol           | Carbohydrate 20-50%      |

Microalgae biomass with a carbohydrate content of 20 to 50% can be used as a source of raw materials for bioethanol production. The productivity of third-generation bioethanol (in litres per hectare per year) is higher than that of first and second-generation bioethanol, as demonstrated in Table 2.
Table 2. Bioethanol productivity from different feedstocks [15]

| Feedstocks                  | Bioethanol productivity [L/(ha year)] |
|-----------------------------|---------------------------------------|
| Wheat                       | 2590                                  |
| Cassava                     | 3310                                  |
| Sweet sorghum               | 3050–4070                             |
| Maize                       | 3460–4020                             |
| Beet                        | 5010–6680                             |
| Sugarcane                   | 6190–7500                             |
| *Panicum virgatum* (switch grass) | 10,760                               |
| Microalgae                  | 46,760–140,290                        |

Microalgae have piqued the interest of researchers from India, the United States, South Korea, China, and Malaysia. They are investigating its potential as a source of raw materials for ethanol production. To build a dependable production technique, the process of converting microalgae into ethanol on a commercial scale, which is ultimately meant as a fuel, necessitates an in-depth study with reviews from multiple perspectives. Each microalga has specific characteristics that distinguish it from other microalgae. Certain types of microalgae may survive in a variety of environments. The right conditions are significant for the growth of microalgae, especially when faced with other nuisance organisms. Microalgae require CO₂ as a carbon source to grow and need sunlight as a source of energy for photosynthesis. Nutrients, especially nitrogen, phosphorus, and iron, are required for their growth [16], which might be derived from effluent with high levels of the first two nutrients. Although it varies depending on the microalga type, algae grow best in water temperatures ranging from 20 to 35 °C [7, 16, 17]. The palm oil industry in Indonesia has been recognised as one of the significant contributors to CO₂ emissions, which can be exploited as a carbon source for microalgae development. Microalgae has the potential to be used to treat palm oil industrial waste since they can grow well in the wastewater [19].

Several studies have found that restricting the quantity of nitrogen in the culture is a crucial component in microalgae carbohydrate accumulation [16]. Carbon flow will shift to carbohydrate synthesis in nitrogen-deficient growth conditions, reducing protein production [20]. As a result, efforts to boost the yield of biofuels produced by microalgae are still being undertaken, including optimising light technologies to modify carbon sequestration pathways to increase biomass accumulation or particular components like carbohydrates and lipids [21]. Microalgae with this potential for bioethanol production were chosen primarily based on their ability to collect carbohydrates, influenced by environmental and nutritional factors. Environmental parameters include light intensity, pH, salinity, and temperature, while nutritional factors comprise nitrogen, carbon, phosphorus, sulfur, and iron [17,18].

Species of *Scenedesmus*, *Chlorella*, *Chlorococcum*, and *Tetraselmis* from the divisions of *Chlorophyta* and *Synechococcus* have been studied extensively as potential raw materials to produce bioethanol. In general, microalgae cultivation at high light intensity ranges from 150 to 450 mol/(m²s) and at a temperature range of 20-30 °C was able to produce microalgae biomass containing carbohydrates up to 50%, if the nutrient concentration was controlled. However, the carbohydrate content can vary greatly depending on the cell growth as well. In general, the microalgae strains that accumulated the higher carbohydrate content did not accumulate lipid under the same growth conditions [18]. The microalgae production, harvesting, and conversion process of biomass into biofuel are essential aspects to be explored concerning the usage of microalgae as the raw material for bioethanol. [24]. *Prymnesium parvum* [25], *Chlorococum* sp. [8], *Tetraselmis suecia*, *Anthrospira* sp.
[26], and *Chlorella* sp. are microalgae species that have the potential to be used as raw materials for bioethanol.[27]. The carbohydrate content of several species of microalgae is presented in Table 3.

| Microalgal species                  | Carbohydrate content (% dry weight) | Reference |
|------------------------------------|-------------------------------------|-----------|
| *Chlamydomonas reinhardtii*         | 17                                  | [28]      |
| *Chlorella pyrenoidosa*             | 26                                  | [28]      |
| *Chlorella sp.*                     | 19                                  | [29]      |
| *Chlorella vulgaris*                | 12-17                               | [28]      |
| *Chlorococcum sp.*                  | 32.5                                | [30]      |
| *Dunaliella salina*                 | 32                                  | [28]      |
| *Mycronastes afer*                  | 28.4                                | [31]      |
| *Porphyridium cruentum*             | 40-57                               | [32]      |
| *Prymnesium parvum*                 | 25-33                               | [28]      |
| *Scenedesmus abundans*              | 41                                  | [31]      |
| *Scenedesmus dimorphus*             | 21-55                               | [28]      |
| *Scenedesmus obliquus*              | 15-51.8                             | [22]      |
| *Spirogyra* sp.*                    | 33-64                               | [28]      |
| *Tetraselmis sp.*                   | 24                                  | [33]      |
| *Tetraselmis suecica*               | 15-50                               | [34]      |
| *Chlamydomonas reinhardtii UTEX90*  | 60                                  | [35]      |

3. Bioethanol Production from Microalgae

In recent years, microalgae have gotten a lot of attention as a source of biomass for bioethanol production. Microalgae cultivation is the most critical step in the development of bioethanol from microalgae biomass. Microalgae produce 5-10 times more biomass than plants due to their superior photosynthetic efficiency [36]. Microalgae, unlike plant biomass, do not contain lignin, a component that can obstruct the enzymatic hydrolysis process. The features of microalgae containing lignin make pretreatment and enzymatic hydrolysis for the ethanol production process much more accessible [37]. Figure 1 presents a block diagram illustrating the bioethanol production process from microalgae biomass.

3.1 Dehydration of microalgal biomass

Microalgae must be dried first after harvesting since they still have a water content of about 90%. The drying stage is expected to produce microalgae biomass with a moisture content of 50% or less, allowing easier handling at further processing stages. The dehydration process can be carried out by various methods to dry the microalgae biomass. Usually, it uses low-pressure rack drying, including sun drying, sprig drying, freeze-drying and fluidised bed drying [38-40]. Because each drying process has its benefits and drawbacks, it must be tailored to the appropriate circumstances and requirements. Solar drying of biomass, for example, is relatively inexpensive; but it has several downsides, including an extended drying time, a vast drying area, and the possibility of losing some of the biomass's contents [41]. Sprig drying is commonly used to extract high-value compounds, although it is costly.
and reduces microalgae pigment [39]. Similarly, freeze-drying is an effective dehydration method since it removes the oil, but it is also expensive and difficult to use in large operations.

![Diagram of bioethanol production process from microalgae](image)

**Figure 1. Procedure for bioethanol production from microalgae [15]**

### 3.2 Extraction of Bioethanol
Bioethanol is produced from microalgae biomass using the fermentation process. Fermentation converts the biomass's sugar, starch, or cellulose into ethanol [39]. The biomass must first be crushed, and the starch transformed into sugar, then mixed with yeast and water in a heated container known as a fermenter [42]. Yeast breaks down sugar and converts it into bioethanol [39]. The resulting low-concentration alcohol mixture (10–15 percent ethanol) is purified in a distillation stage to remove water and other impurities. Further purification is required to achieve a 99 percent ethanol content for usage as a supplement or alternative for gasoline in automobiles [43].

### 4. Potential Challenges Bioethanol as Renewable Energy
The global market for bioethanol produced from microalgae biomass is expected to grow. Leading bioethanol producing countries, such as Brazil, the United States and European Union, can no longer rely solely on sugar cane and soybeans as raw materials to achieve their goal for biofuel demands. As a result, some barriers in the manufacturing of microalgae-based bioethanol must be addressed for it to be commercialised into a large scale. In addition, various other parameters such as high carbohydrate content, low sensitivity to contamination, temperature tolerance, and appropriate salinity must also be addressed to build a productive and effective bioethanol production process from microalgae. From an engineering standpoint, photobioreactors for microalgae cultivation are substantially more expensive than open pond systems.

The use of optimal equipment capacity and proper construction material selection are expected to minimise processing costs [44]. The water demand, CO₂, and nutrient sources impact profitability because they account for up to 30% of the overall cost of manufacturing biofuel from microalgae. [36,45,46]. Nutrients such as nitrogen and phosphorus from wastewater and CO₂ from industrial exhaust gas can support microalgae biomass production. As a result, microalgae cultivation utilising nutrients and CO₂ from industrial wastes produces biomass and reduces processing costs and protects the environment by reducing waste pollutants [47]. At the same time, wastewater treatment expenses can be lowered, and energy savings can be realised [48].

When food crops are used to make bioethanol, as with the first-generation biofuels, there has been debate about competing land use for food and rising grain costs. Fermentation of non-food sources such as straw and wood, dubbed "second generation" biofuels, has been marketed as a possible alternative. Still, it comes with its own set of drawbacks, including the requirement for huge facilities
and complex treatment methods. On the other hand, the use of biofuels is aimed at, among others, improving air quality, reducing greenhouse gases, saving the environment, and ensuring food security. Bioethanol is an excellent future biofuel because it is less toxic and biodegradable and releases fewer toxins into the air. Bioethanol’s development and usage as a fossil fuel substitute still require more innovation, particularly in process engineering, to simplify and lower the production cost to enable bioethanol to be utilised as a sustainable energy source in the future.

5. Conclusions
Microalgae biomass as a raw material for bioethanol production is a renewable energy source that is both sustainable and environmentally benign. Microalgae development utilising wastewater as a source of nutrition for its biomass growth can be used for environmentally friendly wastewater treatment management. Microalgae based bioethanol production can be developed in a sustainable manner in modern civilisation to address the issues of energy scarcity and pollution. Microalgae development for commercial purposes is a viable industry and should be developed sustainably and friendly toward the environment and biodiversity by improving the cultivation and production process.

References
[1] Jambo S A, Abdulla R, Azhar S H M, Marbawi H, Gansau J A and Ravindra P 2016 Renew Sustai energy Rev. 65, 756–769
[2] Suali E and Sarbatly R 2012 Renew Sustain Energy Rev. 16 4316–4342
[3] Adenle A A, Haslam G E and Lee L 2013 Energy Policy. 61 182–195
[4] Maity J P, Hou C P, Majumder D, Buneschuh J and Kulp T R 2014 Energy. 78 94–103
[5] Thomas W and Haigh M 2017 Shell. World Energy Model
[6] Migas S K K 2018 Annual Report
[7] Alam F, Mobin S and Chowdhury H 2015 Procedia Eng. 105 763–768
[8] Harun R, Danquah M K and Forde G M 2010 J Chem Technol Biotechnol. 85, 199–203
[9] Brennan L and Owende P 2010 Renew Sustain energy Rev. 14 557–577
[10] Eide A 2008 FAO Rome, Italy
[11] Goldemberg J 2007 Science. 315 808–810
[12] Tabatabaei M, Tohidfar M, Jouzani G S, Safarnejad M and Pazouki M 2011 Renew Sustain Energy Rev. 15 1918–1927
[13] Chist Y Biotechnol Adv 25 294–306
[14] Ben-Amotz A 2008 in The 11th International Conference on Applied Phycolgy
[15] Mussatto S I, Dragone G and Guimaraes P M R 2010 Biotechnol Adv. 28 817–830
[16] Dragone G, Fernandes B D, Abreu A P, Vicente A A and Teixeira J A 2011 Appl Energy. 88 3331–3335
[17] Aslani A, Mohammadi M, Gonzalez M J I, Sobczuk T M, Nazari M and Bakhtiar A 2018 Bioresour Techno Reports. 1 24–30
[18] Rizza L S, Smachetti M E S, Nascimento M D O, Salerno G L and Curatti L 2017 Algal Res. 22 140–147
[19] Tao G, Yaakob Z and Sobri M 2015 Int J Hydrogen Energy. 41 4888–4895
[20] Behrens P W, Bingham S E, Hoeksema S D, Cohoon D L and Cox J C 1989 J Appl Phycol. 1 123–130
[21] De Farias Silva C E and Bertucco A 2016 Process Biochem. 511833–1842
[22] Ho S H, Chen C Y and Chang J S 2012 Bioresour Technol. 113 244–252
[23] Markou G, Angelidaki I, Nerantzis E and Georgakakis D 2013 Energies. 6 3937–3950
[24] Gouveia L 2011 Springer. 1–69.
[25] Assadad L, Utomo B S B and Sari R N 2010 Squalen. 5 51–58
[26] Ragauskas A J, Williams C K, Davison B H, Britovsek G, Cairney J and Eckert C A 2006 Science. 311 484
Acknowledgement

The authors would like to express their gratitude for the financial support of this research through Doctoral Dissertation Research Scheme from the Directorate of Research and Community Services, Ministry of Education, Culture, Research and Technology under Contract No:34/UN11.2.1/PT.01.03/DRPM/2021.