Journal of Clean Technology

REVIEW ARTICLE

Bioethanol Production as Renewable Energy from Macroalgae *Eucheuma cottonii*: A Mini Review

Rahimsyah Ijas Nur Rasyid[1]*, Muhammad Fadhlan Dzikri[1], Hayya Laudza Adani[1], Evelyna Anindya Davina[1]

[1)]*Department of Chemical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Indonesia*

(*Corresponding author's e-mail: rahimsyahijasnr@students.unnes.ac.id)

Received: 14 July 2024, Revised: 03 August 2024, Accepted: 13 August 2024, Published: 20 August 2024

Abstract

Energy demand has increased from several years ago due to economic growth and population increase. Meanwhile, non-renewable energy reserves from fossil fuels are dwindling. Bioethanol is one alternative energy resource to substitute fossil fuels and their derivatives. T The fast expansion and environmental friendliness of *Eucheuma cottonii* macroalgae's growth make it a promising contender for use as a sustainable renewable energy source. Because of its abundant carbohydrate content, it can be utilized in generating bioethanol. This analysis delves into the potential of macroalgae in bioethanol production by concentrating on hydrolysis and fermentation. The *Eucheuma cottonii* process involved hydrolyzing it into reducing sugars using an optimal dilute acid hydrolysis pretreatment. This hydrolysate is converted into bioethanol by *Saccharomyces cerevisiae* through fermentation. Process the bioethanol obtained is distilled to reach the maximum concentration. The process of producing bioethanol, which is a renewable energy source, is expected to have an important impact on dealing with the energy crisis and advancing environmental sustainability.

Keywords: Bioethanol, Fermentation, *Eucheuma cottonii*, Renewable Energy, Yeast

1. Introduction

Fossil energy plays a crucial role in meeting human energy needs. The use of fossil energy has increased rapidly in line with the expanding global population, leading to a greater demand for fuel oil overall (Figure 1). Indonesia's dependence on fossil fuels is very high, but the depletion of non-renewable resources results in resource scarcity in future generations [1] [2]. Indonesia's dependence on fossil energy reaches 93.3%, leading to energy insecurity [3]. Not only that, Indonesia has recorded the most severe decline in fossil fuel supply in the Asia-Pacific region over the past 12 years [4]. Therefore, a solution is needed to address this issue of fossil energy demand. As an alternative to petroleum-derived fuels, converting carbohydrates into sugars is a key step in producing high concentrations of ethanol from biomass [5]. Interest in utilizing biomass as a substitute raw material has been revived because of its affordability, reliability, and supply challenges, with bio-derived ethanol being the foremost biotechnological commodity [6].

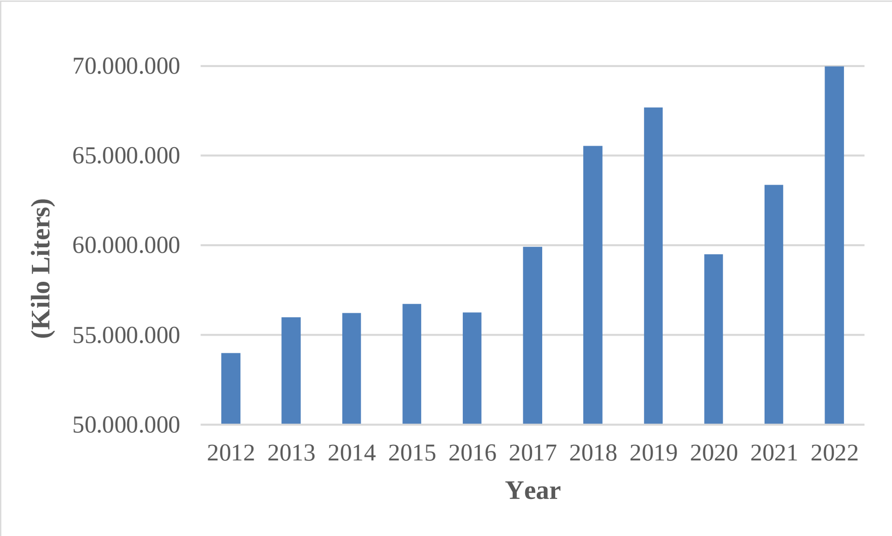

Figure 1. Total oil fuel consumption in Indonesia (2012-2022) [7]

Bioethanol is a renewable and eco-friendly type of biofuel that offers a sustainable alternative to traditional fuel sources [8]. This type of fuel is derived from biological raw materials, making it a renewable resource C_2H_5OH, the compound used in bioethanol, is produced through the fermentation of glucose derived from vegetable raw materials using microorganisms. By using bioethanol as a renewable fuel source, CO_2 emissions can be reduced directly [9]. It's important to remember that macroalgae, found in large quantities in the Earth's oceans that span 70% of the planet's surface, can be efficiently transformed into bioethanol [10].

Marine macroalgae presents a promising and sustainable option for producing bioethanol. Among the various species of macroalgae, *Eucheuma Cottonii* shows particular potential for bioethanol production. Specifically, from 1 kilogram of *Eucheuma Cottonii* macroalgae, 0.3934 kilograms of galactose can be extracted. This translates to an annual yield of 1.18 kilograms per square meter of cultivation area [11]. *Eucheuma Cottonii* is rich in carbohydrates, and its unique chemical composition makes it a versatile feedstock for bioenergy [12]. For example, carrageenan, a carbohydrate macroalgae contains a compound that can be utilized to produce ethanol, and *Eucheuma Cottonii* contains up to 65.75% carrageenan extract. The properties mentioned above greatly increase the possibilities for new uses of macroalgae in the bioenergy field [13].

Eucheuma Cottonii, a type of macroalgae, possesses a remarkable carbohydrate content that can be transformed into bioethanol through a process of hydrolysis followed by fermentation using microorganisms [14]. The hydrolysis procedure disintegrates the polysaccharide framework of the macroalgae cell wall, thereby releasing intracellular compounds like cellulose into simple sugars [15]. The acid hydrolysis method, which deploys H_2SO_4 or HCl, is a commonly used methodology that yields more ethanol and is faster than enzymatic hydrolysis [16] [17]. The fermentation process is essential in bioethanol production as it converts the reducing sugars produced by hydrolysis into bioethanol using microorganisms like yeast, fungi, and bacteria [9]. Microorganisms like *Saccharomyces cerevisiae* are highly efficient in fermenting glucose into ethanol at a pH ranging from 3.5-6.0 and a temperature of 28˚C-35˚C [16].

Based on available research, it appears that there has been a significant exploration of the use of *Eucheuma Cottonii* in bioethanol production. Based on research, employed a hydrolysis technique and added EM4 liquid to facilitate biological fermentation over 25 days [18]. Their findings indicate that 45 kg of *E. cottonii* raw material yielded 719 mL of ethanol, with peak fermentation achieved on day 21, producing 130 mL of ethanol. After undergoing distillation, 477 mL of pure ethanol was obtained [18]. Meanwhile, in other research results conducted a separate study using a 3% sulfuric acid hydrolysis method on the remaining carrageenan extract from *Eucheuma Cottonii* [18]. They found that fermentation with *Saccharomyces cerevisiae* microorganisms resulted in a 2.57% ethanol concentration with a yield of 32.64% over 6 days. Reducing sugar levels were found to be at 0.60% [19].

The goal of this review endeavor is to attain the utmost quantity of reducing sugars during the hydrolysis process. This is due to the direct correlation between the amount of sugar acquired from hydrolysis and the resulting ethanol content from fermentation [14]. To accomplish this, the process utilized a chemical hydrolysis method that involved a dilute acid catalyst, specifically 3% sulfuric acid. The process of hydrolysis took place at a temperature of 150˚C for 50 minutes to attain the optimal levels of reducing sugar and bioethanol content.

2. Materials

Table 1. Bioethanol Concentration of Macroalgae

Macroalgae Type	Bioethanol Concentration (%)	Reff
Eucheumma Cottonii	87,64	[20]
Sargassum Sp	24,67	[21]
Laminaria Japonica	32,61	[22]
Undaria Pinnatifida	9,74	[22]
Gracilaria Verucossa	7,30	[22]

Based on the comparison in the table above, E cottoni has high bioethanol content results reaching 87.64% which can be optimized as bioethanol. *Eucheuma cottonii* is a type of macroalgae known for its ability to synthesize carrageenan and other polysaccharides [23]. Carrageenan is a hydrocolloid that consists of potassium, sodium, magnesium, and potassium sulfate esters combined with galactose copolymer 3,6-anhydrogalactose [23]. Carrageenan is a high molecular weight sulfated polysaccharide commonly found in the cell walls of macroalgae. It has the ability to interact with various bioactive molecules, including proteins, lipids, pigments, and other polysaccharides [23]. *Eucheuma cottonii* is one of the macroalgae that produces high carrageenan extract where the carrageenan content in E.cottonii is 65.75% [24].

Table 2. Nutritional Label of Eucheuma cottonii

Nutrition	P.australis	E.cottoni	Reff
Water	87,25 $\pm$ 0,86	76,15 $\pm$ 0,23	[25]
Ash	2,34$\pm$0,16	5,62$\pm$0,12	[25]
Proteins	1,05$\pm$0,09	2,32 $\pm$ 0,05	[25]
Fat	0,58$\pm$0,01	0,11$\pm$0,02	[25]
Carbohydrate	8,78$\pm$ 0,80	15,8$\pm$0,70	[25]

3. Methodes

2.1 Pre-treatment

Macroalgae E. cottonii is harvested from the coast of Wini, TTU-NTT Regency. The E. cottonii is meticulously cleaned to remove impurities such as sand, then dried for a day. Subsequently, the dry sample is oven-dried at 105°C for 15 minutes to eliminate air content and blended until smooth. Sulfuric acid (H_2SO_4) is among the chemicals used as catalysts [14].

2.2 Hydrolysis of Substrates by H_2SO_4

Hydrolysis begins by preparing *Eucheuma cottonii* powder, which is ground and dried. 10g of the powder is suspended in a 2% H_2SO_4 solution and heated in a microwave at 120°C for 30 minutes [26] [10]. The process of hydrolyzing with H_2SO_4 significantly increases the bioethanol yield from microalgae for biodiesel production [27]. The process of conversion entails the breakdown of cellulose from the substrate into simple sugars, like glucose, which can then undergo fermentation to produce bioethanol [28].

Table 3. Bioethanol production from *Eucheuma cottonii* through hydrolysis using a chemical catalyst.

Enzyme Type	Concentration (%)	Condition	Results (%)	Reff
Aspergillus Niger	3	40 min, 45 C	31,91	[29]
Trichoderma Longibrachiatum	3	40 min, 45 C	31,91	[29]
K karagenase	2,5	2 h, 40 C	40 – 45	[24]
Sacharomyces Cerevisiae	1	144 h, 30 C	32,64	[19]

Table 4. Bioethanol production from *Eucheuma cottonii* through hydrolysis using a chemical catalyst.

Chemical material	Concentration (%)	Condition	Results (%)	Reff
Solid acids	8–20	140 °C, 150 min	47.4	[30]
Sulfuric acid	1	120 °C, 60 min	23.7	[31]
Amberlyst (TM)-15	2–5	130 °C, 150 min	65	[32]
H_2SO_4	2	80°C,120 min	87.53	[20]

2.3 Fermentative Production of Bioethanol

The hydrolysis solution's pH was adjusted to 6.0 [28]. A total of 300 mL of the solution was used, and nutrients were added. This comprised 10 g of glucose, 0.1306 g of KH_2PO_4, 1.2021 g of $(NH_4)_2SO_4$, and 0.1502 g of MgSO [14]. These components expedited the fermentation process of *Eucheuma cottonii* seaweed waste, resulting in a 4.4% per day increase in bioethanol production and yielding 14.0% ethanol [33]. The solution was then sterilized at 121°C for 15 minutes using an autoclave [14]. After sterilization, 30 g of instant yeast was added [34]. And the solution was then incubated for an optimal fermentation period of 6 days [19].

Fermentation is a commonly used natural metabolic process for converting lignocellulosic biomass into bioethanol. In this process, an organism transforms complex carbohydrates into simple sugars, which are then further metabolized into alcohol or acids [35]. In the production of ethanol, fermentation can be achieved through two primary methods: Simultaneous Saccharification and Fermentation (SSF) and Separate Hydrolysis and Fermentation (SHF) [36]. The production of bioethanol from the macroalga *Eucheuma Cottonii* involves using the Simultaneous Saccharification and Fermentation (SSF) method. SSF is highly favored for bioethanol production due to its capability of combining both hydrolysis and fermentation reactions within a single reactor. This approach ensures immediate consumption of all generated glucose by yeast, thereby preventing enzyme inhibition from sugar accumulation and minimizing bacterial contamination [37]. The benefits of the SSF method include reduced processing time, heightened productivity, accelerated hydrolysis process with sugar conversion, decreased enzyme requirements, and elevated product yields [38]. Therefore, bioethanol production utilizes the Simultaneous Saccharification and Fermentation (SSF) method, in which both hydrolysis and fermentation reactions occur in a single reactor [37]. The process for bioethanol production from the macroalga *Eucheuma Cottonii* using the Simultaneous Saccharification and Fermentation (SSF) method is detailed in Table 5.

Table 5. Bioethanol production from *Eucheuma Cottonii* using the SSF Method

Microbes	Fermentation Time (h)	Results (%)	Reff
Clostridium acetobutylicum	96	2,4	[28]
Saccharomyces cerevicae	120	4.0	[39]
Saccharomyces cerevicae	96	2.49	[40]
Saccharomyces cereviceae	6	45	[41]

Based on previous research findings, it has been established that using the SSF method for fermentation with Saccharomyces cereviceae yeast over a 6-hour period yields the highest bioethanol percentage of 45%. Saccharomyces cerevisiae is a yeast strain with close ties to industrial production and the human ecosystem, commonly present in various habitats and diverse environments impacted by human activities [42]. Saccharomyces cerevisiae is widely utilized in ethanol production due to its ability to tolerate a broad pH range, rendering the production process less vulnerable to contamination [43].

2.4 Distillation of the Produced Bioethanol

In this study, we employed the multilevel distillation method. Initially, ethanol obtained from the fermentation process undergoes purification through a multistage distillation process. The primary objective is to separate ethanol from other remaining substances in the fermentation process, including water, yeast sediment, and acid catalyst [14]

Distillation is a method used to separate liquid substances from a mixture by exploiting differences in boiling points or the substances' ability to evaporate. The mixture is heated to vaporize the liquid, which then passes into a condenser where it cools and turns back into a liquid [44]. The aim of distillation is to obtain pure liquid from liquid that has been contaminated with dissolved substances, or mixed with other liquids with different boiling points [45]. The following is some previous research regarding the *Eucheuma Cottonii* distillation method which is shown in table 6.

Tabel 6. Method of Distillation of *Eucheuma Cottonii*

Method	Results (%)	Reference
Simple distillation	5,65	[44]
Multilevel distillation	6,1	[44]
Modified rectification distillation	90	[44]
Electric distillation	39	[44]

According to prior research on distillation methods, it was found that the modified rectification distillation process with a 90% ethanol content yields the highest ethanol concentration. This distillation is a distillation method using a rectification distillation device with a sieve tray type which has several important components such as a reboiler or steam, a bottom column to heat the bioethanol to be distilled, a tray column as an ethanol purifier, condenser, temperature control, heat exchanger, and distillate storage tank. Heat exchangers and temperature controls are useful in the process of heating bioethanol which will be purified so that it is more effective, there is no mixing between hot steam from the steam boiler and the ingredients, the temperature at the bottom and distillation tower is stable so that the results obtained are better [46].

2.5 Application Bioethanol in Indonesia

Macroalgae represents one of the most abundant sources of biomass in Indonesia. With its significant potential, Indonesia is poised to emerge as a leading producer of bioethanol derived from macroalgae, playing a pivotal role in meeting the nation's renewable energy requirements. After conducting thorough data analysis and careful consideration, it has been concluded that the production of bioethanol from macroalgae through the hydrolysis fermentation method shows significant promise.

Several factors contribute to this promising outlook, including minimal operational expenses, ample availability of production materials, and relatively short production cycles. These factors combine to enhance productivity and efficiency in the manufacturing and distribution processes, thus bolstering the sustainable advancement of renewable energy in Indonesia.

4. Conclusion

Based on the review, the most efficient technique for producing bioethanol from *Eucheuma Cottonii* involves acid hydrolysis using H_2SO_4. This method is preferred for its shorter processing time, reduced costs, and high yields. The fermentation process with Saccharomyces cerevisiae yeast lasted for 6 hours, followed by modified rectification distillation. Utilizing *Eucheuma Cottonii* for bioethanol production holds great potential in addressing the current energy crisis and promoting a sustainable environment.

References

[1] Rahman A, Dargusch P, Wadley D. The political economy of oil supply in Indonesia and the implications for renewable energy development. Renewable and Sustainable Energy Reviews 2021;144:111027.

[2] Martins F, Felgueiras C, Smitkova M, Caetano N. Analysis of fossil fuel energy consumption and environmental impacts in European countries. Energies (Basel) 2019;12:964.

[3] Hadi SP, Prabawani B, Purnaweni H. Environmental and social issues on energy policy in indonesia. E3S Web of Conferences, vol. 73, EDP Sciences; 2018, p. 02002.

[4] Bahlawan ZAS, Megawati, Damayanti A, Putri RDA, Permadhini AN, Sulwa K, Feliciata FP, and Septiamurti A "Immobilization of Saccharomyces cerevisiae in Jackfruit (Artocarpus heterophyllus) Seed Fiber for Bioethanol Production," *ASEAN Journal of Chemical Engineering*, vol. 22, no. 1, pp. 156–167, 2022.

[5] Damayanti A, Bahlawan ZAS, and Kumoro AC "Modeling of bioethanol production through glucose fermentation using Saccharomyces cerevisiae immobilized on sodium alginate beads" Cogent Engineering, 9: 2049438. 2022.

[6] Yanto H, Rofiah A, and Bahlawan ZAS, "Environmental Performance and Carbon Emission Disclosures: A case of Indonesian Manufacturing Companies" Journal of Physics: Conference Series", 1387, 012005, 2019.

[7] ESDM. Handbook of Energy and Economic Statistics of Indonesia 2022.

[8] Awaliyah A, Yani S, Sabara Z. Pembuatan Bioetanol Dari Limbah Industri Agar-Agar. Journal of Technology Process 2022;2:32–7.

[9] Pangaribuan RN, Tambunan GA, Martgrita MM, Manurung A. Kajian Pustaka: Potensi Kulit Buah Untuk Menghasilkan Bioetanol Dengan Mengkaji Kondisi, Substrat, Dan Metode Fermentasi. Journal of Applied Technology and Informatics Indonesia 2021;1.

[10] Kolo SMD, Presson J, Amfotis P. Produksi Bioetanol sebagai Energi Terbarukan dari Rumput Laut Ulva reticulata Asal Pulau Timor. Alchemy Jurnal Penelitian Kimia 2021;17:159.

[11] Fakhrudin J, Setyaningsih D, Rahayuningsih M. Bioethanol production from seaweed Eucheuma cottonii by neutralization and detoxification of acidic catalyzed hydrolysate. International Journal of Environmental Science and Development 2014;5:455.

[12] Zelvi M, Suryani A, Setyaningsih D. Hidrolisis eucheuma cottonii dengan enzim k-karagenase dalam menghasilkan gula reduksi untuk produksi bioetanol. Jurnal Teknologi Industri Pertanian 2017;27.

[13] Loupatty VD. Analysis Of Seaweed Carbohydrate Eucheuma Cottonii And Effect On The Hydrolysis Process And Fermentation Time In Producing Bioetanol. Pattimura Proceeding: Conference of Science and Technology, 2017, p. 95–100.

[14] Bria PM, Kolo SMD. Sintesis Bioetanol dari Rumput Laut Coklat (Sargassum sp) Asal Pulau Timor Sebagai Energi Terbarukan. Eksergi 2023;20:162–7.

[15] Hasan B, Azis A. Optimization Of Sonication Temperature and Time fot the Pretreatment of seaweed as raw material for Bioethanol Production. Prosiding 4 SNP2N Politeknik Negeri Ujung Pandang 978-602-60766-9 2020;4.

[16] Kurniati Y, Khasanah IE, Firdaus K. Kajian pembuatan bioetanol dari limbah kulit nanas (Ananas comosus. L). Jurnal Teknik Kimia USU 2021;10:95–101.

[17] Hermawan R, Supriyatna D. Energi Terbarukan Dari Biofuel Rumput Laut: Menggali Potensi Hijau Di Lautan. Kohesi: Jurnal Sains Dan Teknologi 2024;3:91–100.
[18] Adharani N, Wardhana MG. Formulasi Bioetanol Dari Eucheuma Cottonii Upaya Energi Terbaru Nelayan Sumberkencono Banyuwangi. Jurnal Lemuru 2023;5:144–50.
[19] Yuliani N, Sutamiharja RTM, Prihantara A. Utilization of residual carrageenan extract from Eucheuma cottonii seaweed into bioethanol. Indonesian Journal of Applied Research (IJAR) 2020;1:25–31.
[20] Tan IS, Lam MK, Lee KT. Hydrolysis of macroalgae using heterogeneous catalyst for bioethanol production. Carbohydr Polym 2013;94:561–6.
[21] Wardani AK, Herrani R. Bioethanol from sargassum sp using acid hydrolysis and fermentation method using microbial association. J Phys Conf Ser, vol. 1241, IOP Publishing; 2019, p. 012008.
[22] Ra CH, Kim S-K. Marine Bioenergy: Trend and Development of Bioethanol Production from Macroalgae. Red n.d.;22:41–6.
[23] Fakhrudin J, Setyaningsih D, Rahayuningsih M. Desalination Technique on Seaweeds Hydrolysate Eucheuma Cottonii for Bioethanol Production. International Journal of Engineering, Science and Information Technology 2021;1:114–20.
[24] Zelvi M, Suryani A, Setyaningsih D. Hidrolisis eucheuma cottonii dengan enzim k-karagenase dalam menghasilkan gula reduksi untuk produksi bioetanol. Jurnal Teknologi Industri Pertanian 2017;27.
[25] Maharany F, Nurjanah N, Suwandi R, Anwar E, Hidayat T. Bioactive Compounds of Seaweed Padina australis and Eucheuma cottonii as Sunscreen Raw Materials. J Pengolah Has Perikan Indones 2017;20:10.
[26] Miranda JR, Passarinho PC, Gouveia L. Pre-treatment optimization of Scenedesmus obliquus microalga for bioethanol production. Bioresour Technol 2012;104:342–8.
[27] Seon G, Kim HS, Cho JM, Kim M, Park W-K, Chang YK. Effect of post-treatment process of microalgal hydrolysate on bioethanol production. Sci Rep 2020;10:16698.
[28] Wadi A, Ahmad A, Tompo M, Hasyim H, Tuwo A, Nakajima M, et al. Production of bioethanol from seaweed, Gracilaria verrucosa and Eucheuma cottonii, by simultaneous saccharification and fermentation methods. J Phys Conf Ser, vol. 1341, IOP Publishing; 2019, p. 032031.
[29] Padil P, Syamsiah S, Hidayat M, Kasiamdari RS. Kinerja enzim ganda pada pretreatment mikroalga untuk produksi bioetanol. Jurnal Bahan Alam Terbarukan 2017;5:92–100.
[30] Tan IS, Lee KT. Comparison of different process strategies for bioethanol production from Eucheuma cottonii: An economic study. Bioresour Technol 2016;199:336–46.
[31] Hernowo P, Setyaningsih D, TIP BSBU. Proses Hidrolisis Asam Dan Enzim Pada Polisakarida Euchema Cottonii Untuk Bahan Baku Bioetanol. Jurnal Teknologi Industri Pertanian 2015;25.
[32] Ainuri M, Gusvita R. Design Process of Hydrolysis and Fermentation Bioethanol Production from Seaweed Eucheuma cottonii to Renewable Energy Sovereignity. KnE Life Sciences 2016:107–13.
[33] Putra INW, Kusuma I, Winaya INS. Proses treatment dengan menggunakan NaOCl dan H2SO4 untuk mempercepat pembuatan bioetanol dari limbah rumput laut E. cottonii. Journal Ilmiah Teknik Mesin 2011;5:64–8.
[34] Ainuri M, Gusvita R. Design Process of Hydrolysis and Fermentation Bioethanol Production from Seaweed Eucheuma cottonii to Renewable Energy Sovereignity. KnE Life Sciences 2016:107–13.
[35] Hossain N, Zaini JH, Mahlia TMI. A review of bioethanol production from plant-based waste biomass by yeast fermentation. International Journal of Technology 2017.
[36] Saragih HTM, Sembiring JH, Ginting E. Conversion Of Pineapple Peel Glucose Into Bioethanol Using Simultaneous Saccharification And Fermentation (Ssf) Method And Separate Hydrolysis And Fermentation (Shf) Method. Jurnal Kimia Riset 2023;8.
[37] Mendieta CM, Kruyeniski J, Felissia FE, Area MC. Modelling of the simultaneous saccharification and fermentation for a pine sawdust biorefinery. Fermentation 2022;8:130.
[38] Rahayuningsih M, Febrianti F, Syamsu K. Enhancement of bioethanol production from tofu waste by engineered simultaneous saccharification and fermentation (SSF) using co-culture of mold and yeast. IOP Conf Ser Earth Environ Sci, vol. 1063, IOP Publishing; 2022, p. 012004.
[39] Candra KP. Study on bioethanol production using red seaweed Eucheuma cottonii from Bontang sea water. Journal of Coastal Development 2011;15:45–50.
[40] Fakhrudin J, Setyaningsih D, Rahayuningsih M. Bioethanol production from seaweed Eucheuma cottonii by neutralization and detoxification of acidic catalyzed hydrolysate. International Journal of Environmental Science and Development 2014;5:455.
[41] Tan IS, Lee KT. Enzymatic hydrolysis and fermentation of seaweed solid wastes for bioethanol production: An optimization study. Energy 2014;78:53–62.

[42] Zhang H, Zhang P, Wu T, Ruan H. Bioethanol Production Based on Saccharomyces cerevisiae: Opportunities and Challenges. Fermentation 2023;9:709.
[43] Azhar SHM, Abdulla R, Jambo SA, Marbawi H, Gansau JA, Faik AAM, et al. Yeasts in sustainable bioethanol production: A review. Biochem Biophys Rep 2017;10:52–61.
[44] Kuni N, Ah Sulhan F. Optimation of Fermentation Time for Bioethanol Production from Young Coconut Fiber with Distilation Refluks. Jurnal Pendidikan Teknik Mesin Undiksha 2021;9:124–33.
[45] Khotimah H, Anggraeni EW, Setianingsih A. Karakterisasi Hasil Pengolahan Air Menggunakan Alat Destilasi. Jurnal Chemurgy 2018;1:34–8.
[46] Susmiati Y, Nuruddin M, Nursalim A. Pemurnian Bioetanol dengan Distilasi Rektifikasi Tipe Sieve Tray untuk Menghasilkan FGE (Fuel Grade Etanol). Jurnal Ilmiah Inovasi 2017;17.