Waste of rice straw as renewable energy: An overview of the potential availability, content, and production process

A Ana*, I Khoerunnisa, M Muktiarni, V Dwiyanti and A Maosul
Faculty of Technology and Vocational Education, Universitas Pendidikan Indonesia, Jl Dr. Setiabudhi No 229, Bandung, Jawa Barat, Indonesia

*ana@upi.edu

Abstract. Indonesia’s crude oil balance has been in deficit during the last decade. The increase in domestic crude oil consumption is inversely proportional to its production. New crude oil reserves are needed to anticipate a prolonged energy crisis. This study examines the potential of agricultural waste as a renewable energy source that can be produced in terms of availability, content, and production process. A systematic literature review was chosen as the method of this study. The biomass content in agricultural was can be used as bioenergy raw material, one of which is lignocellulose. Rice waste is an agricultural waste that is available in large quantities and contains high lignocellulose. Through biochemical processes, lignocellulose is broken down into lignin in the pre-treatment process. Cellulose is converted into glucose using acids in the process of hydrolysis. The conversion of glucose into ethanol is carried out in the fermentation process. Bioethanol is purified by a distillation process to increase the ethanol content. The high content of lignocellulose in rice waste and high annual production in various regions in Indonesia is a major potential. A comparison of the availability of agricultural waste as raw material for bioethanol is discussed.

1. Introduction
Total energy consumption in Indonesia in 2018 has reached 114 MTOE, consisting of the transportation sector 40%, industry 36%, household 16%, commercial 6% and other sectors 2% [1]. Increased from 2017, which has reached 110.5 MTOE where the transportation sector is still the largest user [2]. The most dominant types of energy used are fuel oils including avtur, avgas, gasoline, kerosene, and diesel oil [3]. On the demand side, fuel needs reached 465.7 million barrels/year which were met from domestic refinery production with an average of around 278.1 million barrels, and imports on average 165.4 million barrels [1]. Fulfilling fuel needs with imports have continued to increase since 2016 [2]. This condition occurs because between consumption and production is not balanced. Besides, an increase in the population [4], also increases the need for transportation and industrial activities which increases fuel demand.

Energy sources that are still the main choice for meeting national energy demand are fossil fuels such as coal, gas, and oil [1]. This energy source has limitations because it is not renewable energy so it will run out if it continues to be consumed [5]. Energy diversification as an alternative in reducing dependence on fossil energy is the solution. Government efforts to increase the target of biodiesel use by 30% and bioethanol use by 20% by 2025 need attention [2].
One form of renewable energy that is environmentally friendly is bioethanol [6]. Bioethanol is a biochemical liquid from the fermentation process of carbohydrates using microorganisms [7]. Bioethanol is cellulose biomass, which is a natural resource with abundant availability and has the potential as a raw material for the fuel industry. One of the cellulose biomass can be obtained from agricultural waste [8]. Bioethanol production in Indonesia is very potential, considering the number of plants that have high carbohydrate content, such as sugar cane, latex, sorghum, cassava, sweet potatoes, sago, corn, corn cobs, wood, and straw.

Agricultural waste in Indonesia that has not been used optimally when abundant is straw. Straw is part of the rice plants that have been taken seeds, so the remaining stems and leaves [9]. The availability of abundant straw can be seen from the agricultural potential of Indonesia as one of the highest rice-producing countries in Asia. The ratio of straw from each harvest is 1.4 calculated from the dry weight of the mass [10]. Every 1 kg of harvest can produce 1-1.5 kg of rice straw [10]. Lignocellulose content in straw has the potential to be treated as an environmentally friendly renewable alternative energy because it can reduce carbon dioxide emissions [11]. This article discusses the potential of straw as the largest agricultural waste in Indonesia as a raw material for renewable energy sources namely bioethanol in terms of availability, content, and production processes.

2. Methods
The method used in this article is a systematic literature review. This method was chosen because it can identify, evaluate, and interpret research data and results following predetermined research questions [12]. Besides, a systematic literature review can be used to minimize interpretation, distribute the literature search framework, and allow for comprehensive analysis [13]. This research is intended to explore the extent of the potential of straw as the main ingredient of bioethanol from the availability, content, and technology of the production process.

A systematic literature review consists of three stages: searching and filtering literature, analyzing the literature, and writing the results of the analysis in the form of scientific arguments. Literary sources come from several online sources. Some library databases used are Google Scholar, Scopus, and Thomson. The publishers used are direct science, Springer, Taylor and Francis, IOP, DOAJ, and nature. Keywords used for literature search are rice straw, agricultural waste, renewable energy, bioethanol, biomass, and national defense. In addition to keywords, there are specific criteria for filtering literature searches, including articles published in the last five years, journals, and research articles. Each article was evaluated by researchers for three main focuses of the potential of straw as the main ingredient in bioethanol from the availability, content, and technology of the production process.

3. Results and discussion
Bioethanol is an alcohol compound obtained through the process of biomass fermentation with the help of microorganisms [14]. While ethanol is an organic compound consisting of carbon, hydrogen, and oxygen, which can be seen as a deviation from the hydrocarbon compound which has a hydroxyl group with the formula C₂H₅O₂ [14]. Bioethanol can reduce CO₂ emissions by 18% [15]. In addition to being environmentally friendly, the use of bioethanol is more efficient, the combustion process is simpler, and the manufacturing process can be done on a household scale [16].

3.1. The potential of straw as a raw material for bioethanol from the perspective of its availability
Straw production in Indonesia as agricultural waste from rice plants reached 70,831 million tons from 13,793,000 hectares harvested in 2014. This waste does not have economic value, because so far the use of rice straw as animal feed has only reached 31-39%, for industrial use around 7-16%, while the rest is used as fertilizer or burned. 1 kg of harvest can produce 1-1.5 kg of straw. When converted to kg, the amount of straw produced in 2014 amounted to 70,831 million kg. From 1 kg of straw can produce 0.28 liters of bioethanol. When converted to the amount of straw produced during one year, 19,832.68 million liters are obtained. Compared to other biomass, the availability of straw is higher so that it has the potential to be used as raw material for bioethanol [17]. Besides, the production of sustainable rice plants
regarding the pattern of food consumption of Indonesian people who still make rice as a staple food becomes an opportunity that rice production is still sustainable.

The potential of straw as a raw material for making bioethanol is supported by its abundant availability in Indonesia and the current condition of straw that does not yet have a high selling value is an opportunity as one of the renewable alternative energy sources. In addition to helping the government reduce the country's high foreign exchange decline due to fuel imports, the use of straw as a source of raw materials to make bioethanol can also increase the economic value of organic waste.

3.2. The potential of straw as a raw material for bioethanol from the perspective of it contains

The prospect of straw as a raw material for making bioethanol is very possible. High carbohydrate content in straw has the potential as a source of renewable energy because straw is one of the ingredients that have lignocellulose [18]. The main component in lignocellulose is polysaccharides wrapped in lignin with strong enough bonds [19]. When these polysaccharides are hydrolyzed into monosaccharides such as sugar, sucrose, xylose, and arabinose, it will be easier to convert straw biomass into ethanol. Cellulose biomass is formed from three main components namely cellulose, hemicellulose and lignin [20]. Cellulose is the main component contained in plant cell walls and dominates up to 50% of the dry weight of plants. Rice straw is known to have high cellulose content reaching 34.2% dry weight, hemicellulose content 24.5% and lignin up to 23.4%. The structure of cellulotic biomass is complex so that cellulotic biomass is included in materials that are more difficult to degrade and convert than starch-based biomass.

Like other grass plants, straw contains higher moisture content than woody biomass but has a lower value of heat, density, and a melting point of ash. The content of ash, chlorine, potassium, and sulfur is higher. Reduction of potassium and chlorine can be done by washing at moderate temperatures in the range of 50-60°C, but this causes the straw's water content to increase so that initial treatment is needed to reduce its water content.

Among the properties of cellulose as one of the main components of straw is when fully hydrolyzed in an acidic atmosphere it will produce glucose [21]. But if the hydrolysis process is not perfect, it will produce maltose. While hemicellulose including polysaccharides that are present together with cellulose, if hydrolyzed with dilute acid will form pentose and hexose. While lignin, its structure can change if treated at high temperatures and under acidic conditions. Lignin will be agglomerated into smaller particles and will separate from cellulose at 200°C. The three main components contained in straw as cellulosic biomass can be utilized as raw material for making bioethanol because it can be converted.

3.3. The potential of straw as a raw material for bioethanol from the perspective of its production process

Application of technology in the production of bioethanol from cellulosic biomass namely straw involves several main stages namely pre-treatment, hydrolysis, fermentation and distillation. The technology of making bioethanol continues to develop. Currently, the technology to produce ethanol from sugars and starches has been widely applied. However, the development of bioethanol from cellulose has not been widely applied. The diagram of the process of making bioethanol from straw is in Figure 1. The first stage of making bioethanol from straw is pre-treatment. Pre-treatment aims to open the structure of lignocellulose so that cellulose is more easily accessed by compounds that will break down polysaccharide polymers into glucose [22]. Schematically the purpose of pre-treatment of lignocellulose biomass is shown in Figure 2. This pre-treatment stage is important because lignin can inhibit acid penetration before hydrolysis takes place and inhibits the growth of microbes in the fermentation process [22]. The use of NaOH aims to damage the structure of lignin and hemicellulose and cause the development of cellulose structure. This pre-treatment causes a change in color from light brown to dark brown and a decrease in the weight of the resulting straw powder.
The second stage is hydrolysis. Hydrolysis is the process of breaking down polysaccharides in lignocellulose biomass to get glucose [23]. Straw is hydrolyzed using 21% HCl. In the process of hydrolysis, the H⁺ group from HCl will convert the fiber group from straw into a free radical group. Free radical groups of fibers which then bind to the OH group from water and will react to produce glucose. Increasing the concentration of HCl solution causes the formation of more groups of fiber-free radicals, but the addition of HCl concentration causes less water in the composition of the hydrolysis solution [23]. So the need for OH⁻ as a binding of fiber-free radicals is reduced and glucose is produced less. Straw hydrolysis process was carried out using 21% HCl concentration. In the process of hydrolysis, glucose formation is marked with a brown color on the filtrate resulting from hydrolysis which shows complete degradation of hemicellulose and cellulose to glucose.

The third stage is the fermentation. Fermentation aims to convert glucose into ethanol using yeast, *Saccharomyces cerevisiae* which grows at 30°C and pH 4.8 [24]. There are two types of yeast that contain *Saccharomyces cerevisiae*, are yeast tape and bread yeast. The difference is that yeast is made by adding spices and other microorganisms so that not only yeast but there are also several other types of bacteria.

The more yeast is added, the more ethanol will be produced because the bacteria that break down glucose into ethanol increases. This fermentation is done anaerobically or without oxygen. Alcohol
produced from the fermentation process still contains gamma CO$_2$ and aldehydes so it needs to be cleaned. CO$_2$ cleaning is done by filtering CO$_2$ bound ethanol. In addition, the ethanol content produced only reaches 8-10% so that the refining or refining process is carried out.

The final step is distillation. Distillation is done to separate ethanol from beer, mostly water, and ethanol, by heating at a temperature range of 78-90°C, causing ethanol to evaporate. The boiling point of pure ethanol is 78°C while the boiling point of water is 100°C. This distillation process can increase ethanol levels by up to 95%. Distillation time is determined by the fermentation time. The longer the fermentation, the more glucose is broken down so that the amount of ethanol produced is more and more.

4. Conclusion
Straw has the potential as a raw material for making bioethanol because of its high lignocellulose content. The main component in lignocellulose is polysaccharides wrapped in lignin. When hydrolyzed, polysaccharides can produce glucose so that it is easier to convert to bioethanol through fermentation. The technology for making bioethanol from rice straw consists of four stages, namely pre-treatment, hydrolysis, fermentation, and distillation. Pre-treatment is done to break the lignin bond. Hydrolysis is carried out to convert cellulose and hemicellulose into glucose with the help of acids. Fermentation aims to convert the glucose produced from the hydrolysis process into bioethanol. Distillation aims to purify bioethanol produced from the fermentation process so that ethanol levels increase. Straw as the largest agricultural waste in Indonesia to date is abundant, but its utilization is still low. Judging from the availability, materials, and production technology processes, straw provides prospects when used optimally.

References
[1] Nasional D E 2019 Indonesia Energy Outlook 2019 Jakarta: Sekretariat Jenderal Dewan Energi Nasional
[2] Nasional D E 2018 Indonesia Energy Outlook 2019 Jakarta: Sekretariat Jenderal Dewan Energi Nasional
[3] Adi A C, Lasnawatin F, Prananto A B, Suzanti V M, Anutomo I G, Anggreani D and Yuanningrat H 2019 Handbook of Energy and Economic Statistics of Indonesia 2018 Ministry of Energy and Mineral Resources Republic of Indonesia
[4] Central Bureau of Statistics 2019 Statistics Indonesia 2019 (Jakarta: Ministry of National Development Planning)
[5] Kabir, Ehsanul, Pawan Kumar, Sandeep Kumar, Adedeji A. Adelodun, and Ki-Hyun Kim 2018 Solar energy: Potential and future prospects Renewable and Sustainable Energy Reviews 82 894-900
[6] Likhanov V A and Lopatin O P 2017 Use of natural gas, methanol, and ethanol fuel emulsions as environmentally friendly energy carriers for mobile heat power plants Thermal Engineering, 64(12) 935-944
[7] Rastogi M and Shrivastava S 2017 Recent advances in second-generation bioethanol production: an insight to pretreatment, saccharification and fermentation processes Renewable and Sustainable Energy Reviews 80 330-340
[8] Tye Y Y, Lee K T, Abdullah W N W and Leh C P 2016 The world availability of non-wood lignocellulosic biomass for the production of cellulosic ethanol and potential pretreatments for the enhancement of enzymatic saccharification Renewable and Sustainable Energy Reviews 60 155-172
[9] Roselló J, Soriano L, Santamarina M P, Akasaki J L, Monzó J and Payá J 2017 Rice straw ash: A potential pozzolanic supplementary material for cementing systems Industrial Crops and Products, 103 39-50
[10] Bilo F, Pandini S, Sartore L, Depero L E, Gargiulo G, Bonassi A and Bontempi E 2018 A sustainable bioplastic obtained from rice straw Journal of Cleaner Production 200 357-368
[11] Saini J K, Saini R and Tewari L 2015 Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments. *Biotech* 5(4) 337-353

[12] Roehrich J K, Lewis M A and George G 2014 Are public-private partnerships a healthy option? A systematic literature review *Social science & medicine* 113 110-119

[13] Rao J and Ye J 2016 From a virtuous cycle of rural-urban education to urban-oriented rural basic education in China: An explanation of the failure of China’s Rural School Mapping Adjustment policy *Journal of Rural Studies* 47 601-611

[14] Baral N R and Shah A 2014 Microbial inhibitors: formation and effects on acetone-butanol-ethanol fermentation of lignocellulosic biomass *Applied microbiology and biotechnology* 98(22) 9151-9172

[15] Mofijur M G R M, Rasul M G, Hyde J, Azad A K, Mamat R and Bhuiya M M K 2016 The role of biofuel and their binary (diesel–biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engine emission reduction *Renewable and Sustainable Energy Reviews* 53 265-278

[16] da Silva Trindade W R and dos Santos R G 2017 Review the characteristics of butanol, its production, and use as fuel in internal combustion engines *Renewable and Sustainable Energy Reviews* 69 642-651

[17] Bušić A, Mardetko N, Kundas S, Morzak G, Belskaya H, Ivančić Šantek M and Šantek B 2018 Bioethanol production from renewable raw materials and its separation and purification: A review. *Food technology and biotechnology* 56(3) 289-311

[18] Kadam K L, Forrest L H and Jacobson W A 2000 Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects *Biomass and Bioenergy* 18(5) 369-389

[19] Chen H 2014 Chemical composition and structure of natural lignocellulose In *Biotechnology of lignocellulose* (pp. 25-71). Springer, Dordrecht.

[20] Manju S and Chadha B S 2011 Production of hemicellulolytic enzymes for hydrolysis of lignocellulosic biomass. In *Biofuels* (pp. 203-228). Academic Press

[21] Swain M R, Singh A, Sharma A K and Tuli D K 2019 Bioethanol Production From Rice-and Wheat Straw: An Overview. In *Bioethanol Production from Food Crops* (pp. 213-231) Academic Press.

[22] Mosier N, Wyman C, Dale B, Elander R., Lee Y Y, Holtzapple M. and Ladisch M 2005 Features of promising technologies for pretreatment of lignocellulosic biomass. *Bioresource technology*, 96(6) 673-686

[23] Ahmad E and Pant K K 2018 Lignin conversion: a key to the concept of lignocellulosic biomass-based integrated biorefinery In *Waste biorefinery* (pp. 409-444). Elsevier

[24] Walker G M and Stewart G G 2016 Saccharomyces cerevisiae in the production of fermented beverages. *Beverages* 2(4) 30