The potential of biomass waste feedstock for bioethanol production

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Abstract

Research and needs of bioethanol in Indonesia was grow with increasing of energy needs and also encouraged by government policy in the development of renewable energy from biomass to change fossil fuel. One of the primary benefits of switching to this fuel is that biomass is renewable, and can potentially provide a sustainable fuel supply over the long term. These policy drivers provide a strong rationale for pursuing the expansion of the ethanol fuel sector. Such a sector will be constrained by feedstock availability. Generally, bioethanol converted from edible source is called first generation bioethanol. The drawback of first generation bioethanol stems from the edible feedstock utilized, which is includes corn, cassava, starch and sugarcane. The development of second-generation bioethanol using lignocellulosic feedstock offer great promise to replace fossil fuel because lignocellulosic biomass does not play an intrinsic role in the food chain and thus a fundamental aspect of food security is preserved. To meet the increasing need for bioenergy several material that contain lignocellulosic have to be considered for the bioethanol production. Their composition with regard to cellulose, hemicellulose, lignin, extractives and ash was evaluated, as well as their potential as raw materials for bioethanol. In this paper will discuss the potential biomass waste feedstock for bioethanol such as biomass waste containing lignocellulosic from agricultural waste, oil palm plantations and wood industry waste. Biomass waste from oil palm plantation was the largest source of organic material available in Indonesia. Lignocellulosic biomass from oil palm plantations that potential into bioethanol feedstock are empty fruit bunches, frond, and trunks of oil palm. In 2010 the palm oil plantation areas reach of 8.4 million hectares with potential lignocellulosic waste as much as 60 million tons. The contents of cellulose, and hemicelluloses in common palm oil waste are 30-60 % and 24-35% respectively. Regarding the higher cellulose content in these biomass is possibility as feedstock for bioethanol production.

Keywords: bioethanol; feedstock; lignocellulosic; empty fruit bunch; oil palm.

1. Introduction

Over the past years, lack of energy fossil has become important issue around the world, especially in developing countries such as Indonesia. Energy consumption is increasing from year to year. Fuel oil is still the main consumption countries in the world, although the stock already started thinning. On the other hand, extreme usage of fossil fuels brings another looming disaster to human being and the mother earth, namely global warming [1]. The problems of energy should be resolved by finding other energy alternatives to reduce dependence on fossil fuel use. Renewable energy source is one of the alternative energy solutions. One of them is to develop bio-fuel, such as ethanol, from biomass. Biomass-based ethanol is well-entrenched in policy as a partial substitute for petroleum-based gasoline requirements. One of the primary benefits of switching to this fuel is that biomass is renewable, and can potentially provide a sustainable fuel supply over the long term [2].

The government of Indonesia has planned to increase the share of renewable energy up to 17 percent of the total energy consumption by 2025. Five percent of which come from biofuel including biodiesel, bioethanol and bio-oil [3][4]. These policy drivers provide a strong rationale for pursuing the expansion of the ethanol fuel sector. Such a sector will be constrained by feedstock availability. Today, the most common feedstock for production of ethanol are raw sugars from sugarcane, starch from cassava, corn, or starch found in the grain of cereal crops [5]. This ethanol from edible source is called first generation bioethanol.

The long-term viability of this process is in question because it will require significantly increased amounts of cultivatable land and significant hike in food prices that will ultimately lead to food insecurity [6]. Food security is top priority in Indonesia, so that all of the program must refer to this criteria. So the feedstock will be considered are only when the crops cannot be as a food source, including when it will indirectly disturb the food security program.

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An option for expanding the ethanol industry is to utilize lignocellulosic residues from agricultural waste, palm oil waste and wood industry waste as a feedstock for the process. Lignocellulosic materials are a combination of three polymers interlinked in a dense matrix, creating challenges for bioconversion process [2]. Their composition contains cellulose, hemicelluloses, lignin, ashes and the extractive.

Cellulose is the principle component of lignocellulosic biomass. Cellulose is a straight chain polymer consisting of units of glucose connected via (1,4)-β-D-linkages. The degree of polymerization and crystallinity of cellulose varies from species to species and this is shown to have a significant impact on hydrolytic process (acidic and enzymatic) [7]. Hemicelluloses are a heterogeneous material made up of five sugars, including glucose, galactose, mannose, xylose and arabinose [2]. Softwood hemicellulose mainly contains mannose as a major constituent whereas hardwoods mainly contain xylans [8]. Lignin is composed of a number of phenolic compounds that may act as an inhibitor the hydrolysis or fermentation of sugar. Lignin acts as cementing agent and an impermeable barrier for enzymatic attack [9]. Lignin provides plants with the structural support and impermeability they need as well as resistance against microbial attack and oxidative stress.

Indonesia is rich in biomass so the utilization of biomass as energy source potential to be developed. Being abundant lignocellulosic waste is derived from agricultural wastes (grass, reeds, rice hulls, rice husk, wheat straw, the remnants of the harvest/crop residues, corn cob/corn Stover, etc.), livestock wastes (animal manure), industrial wastes (industrial byproduct of fermentation/silage, molasses, bagasse, pieces of wood/wood chips, remnants of canning food products/agri-food wastes, etc.), waste paper, cardboard former, newspaper, etc [10]. This material can be resources for ethanol production [5]. The renewable energy policy drivers provide a strong rationale for pursuing the expansion of the ethanol fuel sector. Such a sector will be constrained by feedstock availability, which has spurred significant interest in alternative feedstocks. This paper will be discusses about the lignocelluloses waste that potential as a feedstock for bioethanol. The objective of this paper are to identify and collection the potential biomass as raw material in bioethanol production, and to be use as raw material in pilot plant bioethanol production.

2. Bioconversion process of lignocellulosic biomass to bioethanol.

There are mainly three processes involved in the conversion lignocellulosic to bioethanol, which are pretreatment to remove lignin or delignification, hydrolysis of cellulose in the lignocellulosic biomass to produce reducing sugars by chemical or enzymatic process, and fermentation of the sugars to ethanol by yeast. Some of the important reasons for the pretreatment step are to (i) break the lignin-hemicellulose-pectin complex, (ii) disrupt/loosen-up the crystalline structure of cellulose and (iii) increase the porosity of the biomass. These changes in lignocellulosic materials make it easier for enzymatic saccharification (hydrolysis), results in higher fermentable sugars levels and will have a significant impact on the overall process [11][12][13].

Mechanical pretreatment refers basically to the mechanical and physical actions to clean and size the biomass, and destroy its cell structure to make it more accessible to further chemical or biological treatment. Each type of feedstock biomass, soft or hard, requires a particular pretreatment method, to minimize the degradation of the substrate, and to maximize the sugar yield.

To make the cellulose feedstock more digestible by enzymes, the surrounding hemicellulose and/or lignin is removed and the cellulose microfibre structure is modified. By chemical, physical or biological treatment, lignin and all or part of the hemicellulose is solubilised. Subsequently, when water or steam is added, the free hemicellulose polymer is hydrolyzed to monomeric and oligomeric sugars.

Where lignin and hemicellulose hydrolysis are classed as pretreatment, cellulose hydrolisis is considered as a major hydrolysis step. In hydrolysis, the cellulose is converted into glucose sugars. The goal of this process is to generate fermentable monomeric sugars from hemicellulose and cellulose content of lignocellulosic biomass. This can be accomplished by two different processes, namely, acid hydrolysis using sulphuric acid and enzymatic hydrolysis using enzyme cellulose and β-glucosidase [14].

Under oxygen free conditions, a variety of microorganisms, generally either bacteria, yeast, or fungi, ferment carbohydrates to ethanol. According to their reactions, the theoretical maximum yield is 0.51 kg ethanol and 0.49 kg carbon dioxide per kg sugar [15]:

\[
H_2C_2O_4 \rightarrow 2 C_2H_5OH (ethanol) + 2CO_2
\]

\[
3C_6H_12O_6 \rightarrow 5 C_2H_5OH + 5 CO_2
\]

Methods and technology for C6 sugar (hexoses) fermentation are well established. Conversion of C5 sugars (pentoses) to ethanol is relatively a recent practice. The ability to ferment pentoses along with hexoses is not widespread among micro microorganisms. Saccharomyces cerevisiae is capable of converting only hexose sugars to ethano. The most promising yeasts that have the ability to use both C5 and C6 sugars are Pichia stipitis, Candidashehatae and Pachysolan tannophilus. Thermotolerant yeast could be more suitable for ethanol production at industrial level. In high energy process energy saving can achieved through the reduction in cooling costs.

The production of bioethanol from lignocellulosic material is summarized in below equation [1].

\[
Bioethanol yield = \text{cellulose} \times \text{theoretical yield} \times \text{glucose recovery efficiency} \times \text{fermentation efficiency}
\]

\[
\text{Bioethanol from cellulose} = \text{cellulose} \times 0.5111 \times 0.76 \times 0.75
\]
3. Feedstock for bioethanol production

There is a growing interest worldwide to find out new and cheap carbohydrate sources for production of bioethanol [16]. Currently, a heavy focus is on bio-fuels made from crops, such as corn, sugar cane, and soybeans, for use as renewable energy sources. Though it may seem beneficial to use renewable plant materials for bio-fuel, the use of crop residues and other biomass for bio-fuels raises many concerns about major environmental problems, including food shortages and serious destruction of vital soil resources [17]. For a given production line, the comparison of the feedstocks includes several issues: (1) chemical composition of the biomass, (2) cultivation practices, (3) availability of land and land use practices, (4) use of resources, (5) energy balance, (6) emission of greenhouse gases, acidifying gases and ozone depletion gases, (7) absorption of minerals to water and soil, (8) injection of pesticides, (9) soil erosion, (10) contribution to biodiversity and landscape value losses, (11) farm-gate price of the biomass, (12) logistic cost (transport and storage of the biomass), (13) direct economic value of the feedstocks taking into account the coproducts, (14) creation or maintain of employment, and (15) water requirements and water availability [18].

Any bio-ethanol project attacks seven major national issues: (1) sustainability, (2) global climate change, (3) biodegradability, (4) urban air pollution, (5) carbon sequestration, (6) national security, and (7) the farm economy. Lignocellulosic biomass is envisaged to provide a significant portion of the raw materials for bio-ethanol production in the medium and long-term due to its low cost and high availability [18].

Several biomasses from agricultural waste, palm oil waste and forest/wood industry waste will be explained below.

3.1. Agricultural waste

Biomass has become the most attractive option for Indonesia since it produce huge amount of agriculture waste every year. Production of bioethanol from lignocellulosic agriculture waste provides another alternative option to convert these wastes into valuable products.

Rice straw

The annual global production of dry rice is about 526 Tg. Asia is the primary production region with over 90% of global production and the largest harvested area for rice, 140 million hectares. The rice yield in Asia is 3.5 dry Mg ha⁻¹, which is equal to the global average rice yield [19]. Most rice (about 88% of global production) is used for human food. About 2.6% of global production is used for animal feed. About 4.8% of world rice production is lost as waste.

The Indonesia’s rice production in 2010 is around 66 million tons; with harvested area is 12 Million hectares. The detail increasing harvested area and rice production in Indonesia can be shown in Table 1. Rice straw is waste from rice harvesting. In traditional farmers, commonly rice straw is using again for fertilizer. The rice straw in contain cellulose and hemicelluloses that possible to convert to bioethanol. Every hectares of farming will produce 10-15 ton rice straw. The chemical composition and ethanol production potentially of rice straw can be shown in Table 2. The amount of rice straw is very potential for bioethanol feedstock, but the paddy field is scattered in some location, beside that the rice straw is using for livestock feed.

Bagasse

Asia is the primary production region of sugarcane, and South America is the second largest production region. The annual yield of dry sugar cane ranges from 14 to 22 Mg ha⁻¹ with an average of 17 Mg ha⁻¹. Food manufacturing is the major use of sugar cane, consuming about 92% of sugar cane (a yield of 400 kg of sugar per dry ton of sugar cane). The fraction of other uses such as animal feed, human food, and so on, is less than 3%. Sugar cane bagasse is a co-product in sugar cane food manufacture, and the yield of bagasse is about 0.6 dry kg per 1 dry kg of sugar cane [19].

The Indonesia’s sugar production in 2010 is around 2.7 million tons; with harvested area is 340,000 hectares. Besides bagasse, solid biomass energy can be from cane tops and cane leaves potentially, but people recently are utilizing these for feed of cattle. Indonesia now is developing integrated farming (cattle and sugar) in several areas. So from sugar plantation biomass energy will be only from bagasse that has been utilized by sugar factory since long time ago [20]. The chemical composition and ethanol production potentially of bagasse can be shown in Table 2. In 2010 about 1.6 million tons sugarcane bagasse is produced and be utilized and could produce about 178 million tons of bioethanol.

Corn stover

The agricultural residues from maize production are potential sources of sugar for ethanol production, in addition to starch and by-products. When maize is harvested in the field, the corn grain is separated from the cobs, stalks, and leaves. While the grain is transported for storing and processing, the stover is currently not widely collected. However, this biomass could be used for lignocellulosic ethanol production. Corn stover includes stalks, leaves, and corn cobs. Unlike the corn grains, of which the major component is starch, the main components of corn stover are cellulose, hemicellulose, and lignin [22].

About 520 Tg of dry corn is produced annually in the world. In 2010, Indonesia produced 18 Million tons dry corn from 4.1 million hectares corn field (Table 1). Most corn is used for food use for human and for animal feed. About 5% of global production is lost as waste [19]. Less than 1% of corn stover is collected for industrial processing, and about 5% is baled for animal feed and bedding [23]. The ratio of grain : stover is about 1:1, with...
the grain accounting for slightly more weight than stover [24]. The corn cob represents approximately 20% of the weight of corn stover [22]. Cellulose and hemicelluloses content of corn stover is shown in Table 2. Ethanol potential from corn stover is a 299.04 l/ha is equal to 1.1 million tons ethanol production in 4.1 million hectares field.

3.2. Oil palm waste

Oil palm is one of the largest commodity in Indonesia. Table 1. shown that in 2010, Indonesia’s oil palm plantation is around 8.4 million hectares which produced 19.7 million tonnes of CPO. Each kg of CPO production will generated three times of lignocellulosic waste.

As a lignocellulosic biomass Oil Palm Empty Fruit Bunch (OPEFB) contains cellulose, hemicellulose and lignin. Cellulose content of OPEFB is 41.3 – 46.5%, while hemicellulose content is 25.3 – 33.8% (Table 3). The types of main carbohydrates in OPEFB are glucan, xylan, and arabinan, each is 31.0; 17.3, and 0.5%. Extraction of OPEFB using 10% sodium hydroxide solution revealed that major neutral sugar in cellulose (insoluble fraction) was glucose (95.48%), while that in hemicellulose (soluble fraction) was xylose (88.39%) [4]. Potential ethanol production from EFB is shown in Table 3.

Oil palm fronds

Kelly-Yong et al. (2007) [27] reported that each hectare of oil palm plantation produces 10.88 tons of oil palm fronds on the average. Oil palm fronds are pruned when fresh fruit bunches are harvested from the trees in order to allow cutting of ripe fruit branches. In 2010, Oil palm plantation in Indonesia reached 8.4 million hectares can generate around 91 million tons oil palm frond waste. If cellulose and hemicelluloses content in frond is 62.3 % and 24.2 %, respectively [1], every hectare can produce 1,600 liter of bioethanol (Fig. 1).

Oil palm trunks

Yeoh and Lim (2000) [28] proposed that oil palm trunks and fibers have the potential to produce glucose which could be further fermented to ethanol. Moisture content of oil palm trunk was approximately 68% - 82%. Compared to wood timber, whose moisture content is normally between 40% and 50%, oil palm trunk contains far more moisture, indicating the presence of a large quantity of sap.

Especially, the inner part of the trunk contained an extremely high level of moisture. Glucose was found to be the dominant sugar in all parts, accounting for approximately 86.9%, 86.3% and 65.2% of the total free sugars contained in the inner, middle and outer parts, respectively [29]. On the other hand, when the trees are cropped every 25 years, there are 2.52 tons of trunks generated from each hectare of oil palm cultivation. In the year 2010, total area of oil palm cultivation was 8,430,026 Ha, which mean 848 thousand tons/year of trunks were obtained. Potential ethanol production from oil palm frond is shown in Table 3.

Table 2 Composition of lignocellulosic material from agricultural waste

<table>
<thead>
<tr>
<th>Types</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Potential ethanol (l/ha)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice straw</td>
<td>39 %</td>
<td>27.5%</td>
<td>783.66</td>
</tr>
<tr>
<td>Bagasse</td>
<td>50 %</td>
<td>25%</td>
<td>397.30</td>
</tr>
<tr>
<td>Corn stover</td>
<td>36 %</td>
<td>26%</td>
<td>299.04</td>
</tr>
</tbody>
</table>

*Calculated basis of cellulose and hemicelluloses content using equation (4)-(5) divided by density

Table 3 Composition of lignocellulosic material from oil palm waste

<table>
<thead>
<tr>
<th>Types</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Potential ethanol (l/ha)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm EFB</td>
<td>41.3%</td>
<td>25.3%</td>
<td>566.45</td>
</tr>
<tr>
<td>Oil palm Frond</td>
<td>62.3%</td>
<td>24.2%</td>
<td>1,600.37</td>
</tr>
<tr>
<td>Oil palm Trunks</td>
<td>41.2%</td>
<td>34.3%</td>
<td>9.75</td>
</tr>
</tbody>
</table>

*Calculated basis of cellulose and hemicelluloses content using equation (4)-(5) divided by density.
The potential of bioethanol production per hectare, and estimated ethanol production in 2010 from agricultural waste and oil palm waste is summarize in Figure 1.

3.3. Forest/wood industry waste

Another potential source for lignocellulosic biomass is forest residues, which include woods and straws from pulp and paper industries and logging activities. While these vigorous industries generate profits, they also generate an enormous quantity of waste simultaneously. Similar to oil palm wastes, the lignocellulosic waste might be good feedstock for production of bioethanol. Wood industry generated 20% of waste every logging activity [30]. For the purpose of ethanol production, lower quality woods are quite acceptable [31].

Biomass wastes from forest/wood industry can be grouped into two categories: primary and secondary wastes. The primary wastes are the residue of traditional industrial activities directly associated with forestry; these include forest residues (logging slash, non-merchantable trees, land-clearing and sort-yard debris), mill residues (sawdust, bark, shavings, solid trim and clarifier sludge and spent pulping liquor). Secondary lignocellulosic wastes are derived from domestic commercial and industrial activities. These include municipal solid wastes (paper, cloth, garden debris) and commercial and logging wastes (paper, packing materials, textiles, demolition wood) [31]. Chemical composition of common wood biomass is shown in Table 4.

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Hardwood (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>40 to 50</td>
<td>40 to 50</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>25 to 35</td>
<td>25 to 30</td>
</tr>
<tr>
<td>Lignin</td>
<td>20 to 25</td>
<td>25 to 35</td>
</tr>
<tr>
<td>Pectin</td>
<td>1 to 2</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Starch</td>
<td>Trace</td>
<td>Trace</td>
</tr>
</tbody>
</table>

Table 4 Chemical composition of common lignocelluloses[5]

Fig. 1. Potential of ethanol production from lignosellulose waste feedstock

4. Conclusion

Lignocellulosic biomass feedstock has been explored as the cheapest feedstock for bio-ethanol production. It is essentially free as waste product from agriculture sector and forest residues. Utilization of these wastes could solve the disposal problem and reduce the cost of waste treatment. Palm oil plantation waste such as empty fruit bunch, frond and trunk palm oil are most potentially alternatives as bioethanol feedstock.

References