Potential and prospect of various raw materials for bioethanol production in Indonesia: A review

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Abstract. An increased population has an impact on rising fuel needs. Fuel has relied on non-renewable sources in the last few decades and therefore, alternative renewable materials are needed to be developed. Bioethanol is one of the bioenergy sources that can replace gasoline. Bioethanol generates very low emission and uses renewable sources. The development of bioethanol has three beneficial aspects, i.e. environment, energy security, and socio-economy. Various studies have been conducted on the potential materials that can be used as raw materials for bioethanol. Raw materials for bioethanol production are divided into three categories, i.e. first generation, second generation and third generation. Analysis of the characteristics, yield, productivity, availability and economy are mostly done to get the most prospective raw materials for bioethanol production. This paper discusses various raw materials for bioethanol based on differences in characteristics, sources, yield, productivity and availability of materials in Indonesia. In addition, the advantages and disadvantages of each as prospective materials are discussed.

1. Introduction

The increase in population has an impact on increasing fuel demand. Non-renewable fossil has recently dominated the sources of fuel globally. Therefore, renewable fuels need to be researched and developed. Bioethanol is one of the renewable energy sources. The development of bioethanol has three beneficial aspects, namely environment, energy security, and socio-economy [1]. In terms of the environmental impact, bioethanol is considered environmentally friendly, low in emissions, and reduces greenhouse gases that cause global warming. Bioethanol is a potential sustainable source of energy as it is produced from renewable raw materials. Furthermore, the development of bioethanol industry will improve the socio-economy through business and labor.

Indonesia is geographically located in a tropical climate which is suitable for the growth of macro and microorganisms producing raw material for bioethanol. Therefore, Indonesia has the potential to be independent of renewable energy. However, there has not been any detailed review on identifying the most potential source from the existing raw materials in Indonesia. Raw materials for bioethanol production are divided into three categories, i.e., first generation, second generation, third generation and fourth generation [2]. The first three categories of raw material will be discussed in Indonesia and global contact covering their characteristics, abundance and productivity. The fourth generation is not discussed specifically in this paper. The fourth generation bioenergy is from genetically modified algae (microalgae, macroalgae, and cyanobacteria) to enhance produce biofuels.
[3]. The advantage of the fourth generation is that it does not compete with food, relatively easy processed and high productivity. The limitation of this fourth generation is that it requires much research to produce potential genetic modification algae, efficient and economical ways of harvesting and risk mitigation, legal regulation and risks related to the environment and health need to be considered if it is widely produced.

2. First generation (sugar and starch)

Various types of raw materials can be used for bioethanol production with different types of production lines. The characteristics of the raw material content determine the number of stages of the production process affecting the production cost.

2.1. Sugar

The use of sugar as a raw material can accelerate the production process because sugar can be used directly by microorganisms to form ethanol through fermentation, separation and purification. However, in Indonesia, sugar is one of the staples of public consumption. Therefore, there is concern that the use of sugar as a raw material for bioenergy can compete with food and the price is too expensive to be used as a raw material for bioethanol. In Indonesia, the plants that produce sugar are sugar cane (Saccharum officinarum L.), coconut (Cocos nucifera), Aren (Arennga pinnata), lontar or siwalan (Borassus flabellifer L.), nipa (Nypa fruticans) and sorghum (Sorghum bicolor L. Moench). Sugarcane has a productivity of 68 tons ha\(^{-1}\) y\(^{-1}\) [4]. The total sugar in sugarcane and sorghum sap is 16.32% and 11.0–16.0%, respectively [5][6]. Many countries developed sorghum sap as raw material, i.e. the United States, India, and China that has productivity totaled 10,000 L/ha, 3,000-4,000 L/ha, and 7,000 L/ha, respectively [6].

| Palm species          | Age of tree ready for tapping (years) | Sap production [L/(day.palm)] | Time of the tapping process (months) | Sap production life span (years) | Sugar content in palm sap (%) | Ref.          |
|-----------------------|--------------------------------------|-------------------------------|---------------------------------------|---------------------------------|------------------------------|--------------|
| Arenga pinnata        | 8-10                                 | 8-30                          | 2-3                                   | 3-5                             | 13.9-16.08                  | [7]–[10]     |
| Cocos nucifera        | 6-8                                  | 2-7.5                         | 1-1.5                                 | 60                              | 12.03-14.85                 | [12][14]–[16]|
| Borassus flabellifer  | 12-20                                | 6.7                           | 6-8                                   | 80                              | 10-15                       | [13]–[15]    |
| Nypa fruticans        | 5                                    | 0.5-2                         | 2-3                                   | 50                              | 12-26                       | [16][19]     |
| Elaeis guineensis trunk | 25                                  | 3-10                          | 1                                     | -                               | 8.3-15.3                    | [16][20][21] |

The Indonesian government is trying to diversify sugar sources, but the use of sugarcane is still prominent. By product from the sugarcane industry is molasses, which is still rich in sugar content. The sugar content of molasses is 57.01% [19]. The average of molasses production from 2010 to 2014 is 1.46 million tons/year [20]. Molasses has the potential to be a raw material for bioethanol, but there is a chance of competing in the use of molasses with industrial need, such as food, feed and other chemical industries.
### 2.2. Starch

Starch is one type of carbohydrate consisting of sugar polymers with α bonds. A simple hydrolysis process easily breakdown this α bond to produce monosaccharides. The substrates require liquefaction, saccharification (hydrolysis), fermentation, separation, and purification to form ethanol. Materials containing starch include Canna edulis tubers [24,25], tofu waste [23], and cassava [24]. In Indonesia, starch is produced from corn (Zea mays), sago (Metroxylon sagu Rottb.), cassava (Manihot esculenta or Manihot utilissima), sweet potatoes (Ipomoea batatas) and breadfruits (Artocarpus communis Forst.) [25, 26]. The conversion factor for starch to sugar is 1.11 [27]. The theoretical conversion of glucose to ethanol is 0.51 [28].

| Materials            | Starch content (% d.w.) | Productivity (tons ha⁻¹ y⁻¹) | Theoretical sugar (tons ha⁻¹ y⁻¹) | Theoretical ethanol (tons ha⁻¹ y⁻¹) | Ref. |
|----------------------|-------------------------|-------------------------------|-----------------------------------|-------------------------------------|-----|
| Corn                 | 70.82                   | 5.29                          | 4.16                              | 2.12                                | [29]|
| Sago                 | 86.88-87.25             | 20-40                         | 19.29 – 38.74                     | 9.84 – 19.76                       | [30]|
| Cassava              | 77-94                   | 24.13                         | 20.62 – 25.18                     | 10.52 – 12.84                      | [24]|
| Sweet potatoes       | 64.58                   | 11-40                         | 7.88 – 28.67                      | 4.02 – 12.62                       | [25]|
| Breadfruit           | 89                      | 16-32                         | 15.81 – 31.61                     | 8.06 – 16.12                       | [26]|
| Potato skin          | 22-28                   | 3.49-8.73                     | 0.85 – 2.71                       | 0.43 – 1.38                        | [31]|
| The tuber of Canna edulis | 60.2                  | 45                            | 30.07                             | 15.34                              | [22]|

*a.d.w. (dry weight).

Another potential feedstock containing starch is tapioca solid waste and tofu waste. Tapioca solid waste with polysaccharide, fiber, and reduced sugar content is 37.7%, 21%, and 31.3%, respectively [32]. The number of tapioca solid waste is 2/3 part of cassava [33]. Based on the FAO database, the average cassava productivity, in Indonesia from 2016 to 2018, is 24.13 tons ha⁻¹ y⁻¹, so that the potential of tapioca solid waste produced is 16.09 tons ha⁻¹ y⁻¹. The number of tofu waste is about 100-120% from soya that used and its starch content is 39.23±0.20% [23]. Tofu waste is usually utilized for animal feed and formed to food (soft tempeh or Indonesian called “tempe gembos”).

### 3. Second generation (lignocellulosic materials)

Lignocellulosic materials are biomass consisting of cellulose, hemicellulose, and lignin [34]. This substrate requires the initiation stage (pretreatment). Pretreatment aims to eliminate hemicellulose and lignin, reduce the crystallinity of cellulose, increase the porosity of biomass, and increase hydrolysis of cellulose enzymatically [38,39]. The processes required to form ethanol from this material are pretreatment, saccharification, fermentation, separation, and purification. The exploration of bioethanol feedstock is focused on waste materials because the development of alternative solutions to deal with energy problems is expected not to conflict with other problems [37]. Some potential wastes are agricultural waste, industrial waste, forest waste, and municipal / household solid waste. The conversion factor for cellulose and hemicellulose to sugar is 1.11 and 1.14, respectively [27].

#### 3.1. Agricultural wastes

Agricultural wastes are biomass that contains a significant fraction of lignocellulose, i.e., rice straw [38], corn stover [42,43], wheat straw [44,45], sugar beet pulp [43], coconut fiber [44]. Agricultural waste is produced annually. The general public’s handling of agricultural wastes is burning, utilizing it as animal feed, and only a few of it is utilized for fertilizer. The abundance of agricultural waste biomass can be utilized as bioethanol. In term of economics and availability,
agricultural wastes are very potential because it is cheap and easy to obtain. Things to consider for this substrate are the waste collection strategy and the appropriate pretreatment process because the pretreatment process has unique characteristics depending on each substrate type. The characteristics of agricultural waste are described in table 3.

Table 3. Lignocellulose substrate characteristics of agricultural wastes.

| Substrates          | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Theoretical sugar (%) | Ref. |
|---------------------|---------------|-------------------|------------|-----------------------|------|
| Rice straw          | 40.21         | 22.35             | 17.15      | 70.11                 | [38] |
| Corn stover         | 37.0±0.1      | 28.9±0.1          | 19.4±0.0   | 74.02                 | [40] |
| Coconut fiber       | 32.18±0.12    | 27.81±0.74        | 25.02±0.21 | 67.42                 | [44] |

3.2. Industrial and agro-industrial wastes

Agro-industrial lignocellulosic wastes are pineapple waste [53][54], sugarcane bagasse [47], sorghum stalk [48], sweet sorghum bagasse [57][58], empty fruit bunch (EFB) [51]. Industrial wastes are paper waste [52] and newspaper waste [61][62]. Arabica coffee waste has a fiber content of 27.21% and carbohydrate 79.16% (dry base) [55]. Agro-industrial wastes have a uniform shape, so it does not require a sorting process. Utilizing industrial lignocellulose wastes for bioethanol feedstock can be added to an advanced production process for supporting integrated industries. Therefore, the industry can be independent of energy need.

Table 4. Characteristics of lignocellulose substrates from industrial and agro-industrial wastes.

| Substrates                  | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Theoretical sugar (%) | Ref. |
|-----------------------------|---------------|-------------------|------------|-----------------------|------|
| Pineapple peels             | 21.98         | 74.96             | 2.68       | 109.85                | [45] |
| Cocoa pods                  | 16.9          | 4                 | 69         | 23.32                 | [56] |
| Sugarcane bagasse pith      | 37.6          | 36.5              | 24.4       | 83.35                 | [57] |
| Sweet sorghum bagasse       | 48.65         | 17.63             | 7.47       | 74.10                 | [49] |
| OPEFB                       | 40.52         | 33.72             | 22.90      | 83.42                 | [51] |
| Paper waste (glucan)        | 58.8          | 11.2 (xylan)      | 1.0        | 78.04                 | [52] |
| Newspaper waste             | 41.2          | 24.85             | 23.07      | 74.06                 | [53] |

Cocoa pod is one of the agro-industrial chocolate wastes. The weight percentages of cocoa beans and cocoa pod in cocoa fruit (Theobroma cacao) are 9% and 75%, respectively [66][67]. This material has a relatively great cultivation area (1,678,269 ha) but relatively low productivity and high of lignin content. Therefore, the substrate is less suitable for bioethanol feedstock. Palm oil is one of the main plantation commodities in Indonesia. The area of land for oil palm cultivation is 6,777,449 ha in 2018 [20]. The average productivity of oil palm fruits (Elaeis guineensis Jacq), in Indonesia from 2016 to 2018, is 17.05 tons ha⁻¹ y⁻¹ [20]. The percentage of the weight of oil palm empty fruit bunches (OPEFB) in the oil palm fruit (Elaeis guineensis Jacq) is 21% [60], so the OPEFB productivity is 3.58 tons ha⁻¹ y⁻¹. Paper waste is 9% of total waste; it is around 5.76 million tons [61].

3.3. Municipal solid wastes/household solid wastes

Population growth has an impact on increasing waste generated every day. This large waste will be very beneficial if it can be converted into renewable energy. Municipal solid wastes are organic
waste [62] and kitchen wastes [63]. Organic waste is the remnants of household consumption (food scraps, as well as parts of fruits and vegetables that cannot be eaten, leaf litter, twigs, etc.) that can be decomposed by microorganisms. Kitchen waste is one of the organic wastes which is from households, restaurants and food processing industries that produce unused food items such as leftover rice, meat, fruits, vegetables, bread, and other products. The composition of organic waste usually consists of 60% carbohydrates, 20% protein, and 10% fat [62]. Carbohydrates consist of simple sugars, starches, cellulose, and hemicellulose. Indonesia produces 64 million tons of waste per year and 60% of the total waste is an organic waste [61]. That is around 38.4 million tons y⁻¹. The household food waste has sugar source component, that is sucrose (4.38), total reducing sugar (12.54), pectin (3.92), cellulose (18.30), hemicellulose (7.55) [64]. The yield of bioethanol from household food waste is 107.58 g/kg dry matter [64]. Based on the yield, Indonesia has the potential to produce 4.13 million tons of ethanol y⁻¹.

![Figure 1. The composition of waste in Indonesia [61].](image)

Some plants that are considered invasive and problematic to the environment, such as water hyacinth (Eichhornia crassipes), are also organic material sources. Water hyacinth contains cellulose, hemicellulose, and lignin components by 16.4%, 42%, and 5.5%, respectively [65]. Low lignin content can facilitate the pretreatment process to reduce production costs.

### 3.4 Forestry plant and waste

Sengon wood (Paraserianthes falcataria), gmelina wood, pine [66], betung bamboo [67], [68] have been used as a substrate to produce bioethanol. Bamboo has a total sugar content of 64.2% on a dry basis [69]. The problem with this substrate is that it requires an additional process, a difficult pretreatment, and a substrate collection process. This forest waste, however, does not compete with food and has high cellulose content.

Cellulose and hemicellulose are sugar polymers that can be converted by microorganisms into bioethanol. Cellulose has β-chemical bonds, which are more challenging to break. Cellulose will form hexose sugars (C6). The decomposition of hemicellulose produces hexose and pentose sugars [34]. Not all microorganisms can digest pentose sugar properly. The metabolic results of pentose sugar usually produce furfural, which can inhibit the fermentation process. The breakdown of cellulose and hemicellulose requires a more complicated pretreatment process. The presence of lignin can inhibit the pretreatment process so that the higher the lignin content need the complicated process that can take up most of the production costs and produces hazardous wastewater for the environment, thus requiring additional costs for wastewater treatment [38]. Several types of pretreatment are pyrolysis, steam explosion, ammonia fiber (AFEX), CO₂ explosion, and acid hydrolysis [70].
4. Third generation (Microalgae)

The third generation’s bioethanol feedstock uses aquatic microorganisms [71]. Microalgae is called as the third generation of bioethanol feedstock because it has advantages that can cover the limitation of the first and second generation. The use of microalgae as bioethanol feedstock does not compete with food and land use. Microalgae biomass contains carbohydrates that can be used as a source of carbon in bioethanol fermentation. In addition to carbohydrates, microalgae also produce lipids that can be used as biodiesel feedstock. Microalgae proliferate faster than land plants, even doubling the biomass in less than a day so that the harvest time of microalgae is faster that lignocellulosic materials [71]. Microalga biomass productivity is 28 tons ha\(^{-1}\) y\(^{-1}\) [72]. The carbohydrate content of microalg is 29.9 to 70.4% [73]. The estimation of theoretical sugar and ethanol is 929.29 to 2188.03 tons ha\(^{-1}\) y\(^{-1}\) and 473.94 to 1115.90 tons ha\(^{-1}\) y\(^{-1}\).

Microalgae are relatively easy to cultivate. Indonesia, as a tropical country, has suitable conditions for microalgae growth. Microalgae can get maximum sunlight to carry out photosynthesis. The process of photosynthesis absorbs CO\(_2\) from the air so that it can reduce emissions [74]. Growth media can be in the form of saline water, freshwater, even industrial wastewater as a source of CO\(_2\), N, and P [73, 75]. Microalg accumulate carbohydrates in the cell [71]. The outer layer of cell walls can store carbohydrates in the form of pectin, agar, alginate. The cell wall layer contains cellulose and hemicellulose. Layer in cells can store starch [74]. Starch content in microalgae can be increased by controlling important factors that affect metabolism, such as light supply, nutrient starvation, temperature, and CO\(_2\) supply [74]. Some potential microalgae species as bioethanol feedstocks in Indonesia are Tetraselmis chuii [76], Spirogyra sp. [77], Chlorella vulgaris, Chlorella sorokiniana, Chlorococcum sp., Closterium sp., Monoraphidium sp. [78]. Some types of microalgae and its carbohydrate content can be seen in Table 5.

Table 5. The biomass composition of native microalgae.

| Microalgae species          | Carbohydrate (% d.w.) | Protein (% d.w.) | Lipid (% d.w.) | Dry cell (g.L\(^{-1}\)) |
|-----------------------------|-----------------------|------------------|---------------|-------------------------|
| *Pseudokirchneriiella* sp. Strain C1D | 40.5 ± 0.7            | 31.8 ± 1.3       | n.d.          | 0.8 ± 0.1              |
| *Scenedesmus* sp. Strain SP2-9   | 52.9 ± 4.1            | 13.9 ± 1.9       | 14.3 ± 0.5    | 0.9 ± 0.0              |
| *Scenedesmus abliquus* strain C1S  | 29.9 ± 8.3            | 15.6 ± 1.2       | 49.9 ± 3.0    | 1.5 ± 0.9              |
| *Desmodesmus* sp. Strain FG      | 53.5 ± 14.2           | 16.3 ± 6.9       | n.d.          | 0.7 ± 0.0              |
| *Chlorella* sp. Strain M1        | 57.8 ± 16.6           | 17.5 ± 8.2       | 11.0 ± 2.2    | 0.7 ± 0.3              |
| *Ankistrodesmus* sp. Strain LP1   | 51.3 ± 9.0            | 28.9 ± 3.6       | n.d.          | 0.5 ± 0.1              |

Note: n.d. (non-defined)
Source: [73]

The processes required for bioethanol production using microalgae as raw materials are less pretreatment [74], hydrolysis (saccharification), fermentation, separation, and purification. The functions of pretreatment process release carbohydrates by damaging the cell walls of microalgae. The process of extracting carbohydrates from biomass microalgae is important in the whole process because it will affect the productivity of the bioethanol produced. Pretreatment can be done chemically (acidic and basic), enzymatic, mechanical, and others [71]. Velazquez-Lucio (2018) states that physical microalgae biomass pretreatment can be done with hydrothermal, ultrasonic, microwave, pulsed electric field (PEF), freezing/thawing pretreatment. This pretreatment process can be efficient by taking into account the morphology of cell walls and microalgae species [79]. The process is relatively easy because there is no lignin. The hydrolysis process is used to break down carbohydrates into simple sugars that can be used by microbes. Hydrolysis can be done with acids, bases, or enzymatic [80]. Enzymatic hydrolysis uses enzymes, such as endo-amylase, amyloglucosidase,
cellulase, hemicellulase, etc. [83][88]. Hydrolysis using acids requires lower costs and can occur more quickly than hydrolysis using enzymes. However, the results of enzymatic hydrolysis are better and the waste is more environmentally friendly than using acid [78]. However, the constraints of this material are the cultivation and harvest method if it is produced in large quantities.

5. Discussion and concluding remarks

The criteria for materials that can be used as raw materials for bioethanol are low price, abundance, high productivity, not competing with food, no conflict of land use, clear supply chain, no or low lignin content, easily obtained, processed (no or less pretreatment), cultivated and collected. In Indonesia, the first generation of raw material that is potential to be developed is the diversified sugar, nipa (Nypa fruticans), and the tuber with high starch content, Canna edulis and sweet potato. In term of sugar content and ease of cultivation, nipa has a relatively high sugar content (12-26%) and no intensive care is required for nipa cultivation [16]. This material is one type of diversified sugar, so that is easily processed (direct fermentation). Furthermore, Indonesia is an archipelagic country with 3.24 million ha of mangrove area, of which 973,205.54 ha is nipa vegetations [81]. This palm has high sap productivity [0.5-2 L day⁻¹ palm⁻¹] with the tapping process time until 4-5 months) [16], it is estimated that nipa can cultivate up to 1000 palms ha⁻¹ [82]. There is also less likely to compete in land and freshwater use for nipa development as nipa can be cultivated in brackish water. The difficulties in the tapping process of sap recently faced by farmers could be resolved with the support of the government, for example by improving access in the cultivation areas.

The second potential of raw material from the first generation is the tuber with high starch content, Canna edulis and sweet potato. The tuber of Canna edulis has high productivity and starch content, 45 tons ha⁻¹ y⁻¹ and 60.2%, respectively [22]. It can be cultivated on marginal land and does not require intensive care [21]. In Indonesia, it is usually used for garden decoration and not used for the food source. Therefore, this material has great potential to be developed into bioethanol feedstock.

The second generation of raw material does not compete with food and most are waste. Based on material abundance and high carbohydrate content, organic wastes are potential feedstock. Organic waste has a high carbohydrate content (60%) [62]. The main issue is separating the organic and non-organic wastes as it is high labor cost and is not a common practice at the household level. Organic wastes have various contents with an unstable ratio, including carbohydrates, fats, and proteins, as well as some minerals [62]. Various components of organic waste have positive and negative sides. The high diversity of components from organic waste provide nutrient sources required by microorganism and therefore, no nutritional addition is needed. However, when the component of organic wastes exceed the capacity of microbes to utilize can inhibit the growth of microbes to produce bioethanol [83]. Therefore, to anticipate this problem, the addition of microbial consortium is needed to improve the capacity of microbes in digesting the complex component of organic waste [84]. This pure compound then later can be converted into bioethanol by fermenting microbes.

Rice straw is very abundant and does not compete with food [85]. This material is inexpensive, easily collected and has a clear supply chain because rice is the main agricultural in Indonesia. The cellulose content in rice straw is high (40.21%) and relatively low lignin content (17.15%) [38]. The disadvantage is the lignin content so that pretreatment is needed. Usually, farmers burn straw directly in the field and used as animal feed [85]. Therefore, it will be an added value if this rice straw can be used as bioethanol raw material.

Another potential raw material from agricultural waste is corn stover. Furthermore, corn stover also has great potential to be developed as raw material for bioethanol [86]. Agriculture in Indonesia is always done every year. Almost every land produces rice and corn alternately, so this material will always be available for production. In term of abundance and source sustainability, similar to rice straw, corn stover is annually produced in Indonesia.

Pineapple solid waste in agroindustry that is cut using pineapple cutter is in the form of peels and core, which reach 51.6% of the whole fruit weight [87]. It has great productivity (63.36 tons ha⁻¹ y⁻¹) [20]. This material only needs slightly expansion of the cultivation area to get great abundant yield.
The substrate contains relatively high sugar and low lignin, and the fiber composition in pineapple peels is dominated by hemicellulose [53][65]. The conversion factor of hemicellulose to sugar is more than cellulose. However, only certain microbes can produce enzymes to breakdown hemicellulose and use pentose sugar to form ethanol. This problem can be assisted by saccharification and co-fermentation technology that can utilize different types of substrates in a single reactor.

The following table 6 present data on the amount of theoretical ethanol of lignocellulosic biomass (the data in 2018). The theoretical conversion of glucose to ethanol is 0.51 [28].

**Table 6. The theoretical ethanol of biomass.**

| Materials          | Productivity (tons ha\(^{-1}\) y\(^{-1}\)) | Land area (ha) | Total (million tons) | Theoretical ethanol (million tons) | Ref. |
|--------------------|---------------------------------------------|---------------|----------------------|-----------------------------------|------|
| Rice straw         | 7.79                                        | 15,995,000    | 124.60               | 4455.34                           | [20] |
| Organic wastes     | -                                           | -             | 38.40                | 566.37                            | [61] |
| OPEFB              | 3.57                                        | 6,777,498     | 24.20                | 1029.54                           | [20] |
| Corn stover        | 5.96                                        | 5,680,360     | 33.85                | 1277.77                           | [20] |
| Coconut fiber      | 1.90                                        | 3,247,986     | 6.17                 | 212.16                            | [20] |
| Paper wastes       | -                                           | -             | 5.76                 | 229.24                            | [61] |
| Pineapple peels    | 63.36                                       | 14,704        | 0.93                 | 52.10                             | [20] |
| Cocoa pods         | 2.95                                        | 1,678,269     | 4.95                 | 58.87                             | [20] |

Microalgae, as the third-generation raw material, have excellent prospects for the future as a bioethanol feedstock. This material is expected to resolve limitations on previous generation materials. Various types of microalgae can be utilized as raw material for bioenergy, both bioethanol, biodiesel, biohydrogen, and others. Microalgae *Scenedesmus* sp. and *Chlorella* sp. has a high carbohydrate content and dry cell weight so that it has the potential as a bioethanol substrate [73]. Productivity, climatic conditions, and ease of processing are its advantages for this substrate and are supported by cultivation media in the form of industrial wastewater. In economic analysis, the challenges of this substrate are high investment cost for closed cultivation and harvesting if it will be cultivated on large scale. There is no continuous cultivation and no specific pilot plant. Therefore, government support is needed for both laboratory and pilot plant development.

The first alternative to obtain potential bioethanol raw materials is an abundant by-product or waste containing residual sugar or starch and lignocellulosic materials with low lignin content. The use of sugar and starch substrates can facilitate the process of bioethanol production. Sugar and starch can be a source of nutrition for the initiation of microbial activity. After cell multiplication, microbes will break down cellulose and hemicellulose as carbon sources. The second alternative is the development of microalgae as the third generation as raw material for bioethanol with wastewater growth media that is energy efficient and cost-effective [65]. The third alternative is the synergy of solid waste (lignocellulosic biomass) and liquid waste (wastewater) for the growth of microalgae to form a waste-based renewable energy system. Based on the criteria, a more detailed further study is needed to set the recommended priority scale of the potential and prospective materials that should be developed further in the future.

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