Characteristics and Potential of Renewable Bioresources

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Abstract This chapter presents an overview of solid biomass produced by different sectors in Malaysia. Malaysia is renowned as a tropical country that is rich with diverse biodiversity. The tropical climate is favourable for the production of various crops, fruits, and vegetables in the agricultural sector. The major contributor of biomass is the agricultural sector mainly oil palm, rice, sago, and others. Oil palm biomass is produced abundantly at plantations and mills in their daily operation. Therefore, biomass management at the source and exploitation of the biomass into biofuel and value-added products are essential for the sustainability of the national agricultural sector. Agricultural biomass is composed of lignocellulosic components comprising an interwoven mesh of three primary lignocellulosic components namely cellulose, hemicellulose and lignin possess a crucial determination of a physical and chemical characteristic of the biomass. Hence, the characteristic of the lignocellulosic biomass is a vital key in considering the pretreatment steps, utilization, and final products. Globally, the significant depletion of fossil fuels (oil, coal, and gas) drives many countries to generate clean renewable energy in order to provide for the increasing trend of national energy consumption. Malaysia is also committed to generating renewable energy from local bioresources using biomass from the agricultural sector. This chapter discusses the potential and challenges of biomass

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as feedstock for renewable energy utilization in Malaysia in terms of government assistance, sustainability certification scheme, logistics, and technology feasibility. A strategic plan of biomass utilization, as well as good cooperation between government and private sectors, will improve Malaysia in achieving the target for renewable energy generation in the future.

Keywords Biomass characteristics · Agricultural biomass · Biomass utilization

1 Categories and Types of Biomass Resources in Malaysia

Biomass is extremely valuable for the generation of new, structurally complex, bioactive compounds, and clean energy sources. Biomass-dendromass and phytomass of lignocellulose is a natural material consisting of complex heterogeneous cell-structured macromolecules (lignin, hemicellulose, and cellulose) and various organic and inorganic structures of low molecular weight [1]. Biomass can be considered into several main types; agricultural biomass (phytomass grown on agricultural land), forest biomass (firewood, residual from forestry and wood industry), and residual biomass (by-products of agriculture and manufacturing industry) [2]. Malaysia is a tropical country (warm and wet weather year-long) that has large areas of natural arable land for crop production. The annual production of important crops including the plantation in Malaysia is presented in Table 1. Major biomass resources in Malaysia can be categorized into different sectors: residues from agriculture (palm oil mill waste, paddy straw, rice husk, banana stems, sugarcane bagasse, etc.), forestry (wood from pulp, paper industries, and logging activities), and municipal waste (Fig. 1). In line with the major crop produced in Malaysia, oil palm biomass contributes the largest amount of biomass. Each year about 168 million tonnes of biomass is generated in Malaysia as a prospective bioenergy resource and long-term solution to the nation's energy demand [3].

Table 1 Production and planted area of important crops in Malaysia 2019

Crops	Production (Tonnes)	Area planted (Hectares)	References
Palm oil	19,858,367	5,900,157	[4]
Paddy	2,348,931	671,870	[5]
Rubber	639,830	1,083,992	[4]
Coconut	536,605	86,466	[4]
Sago	199,370	41,082	[4]
Pepper	34,294	7,375	[4]
Sugarcane	20,761	1,403	[6]
Herb	9,018	2,315	[7]
Cocoa	1,004	15,008	[4]

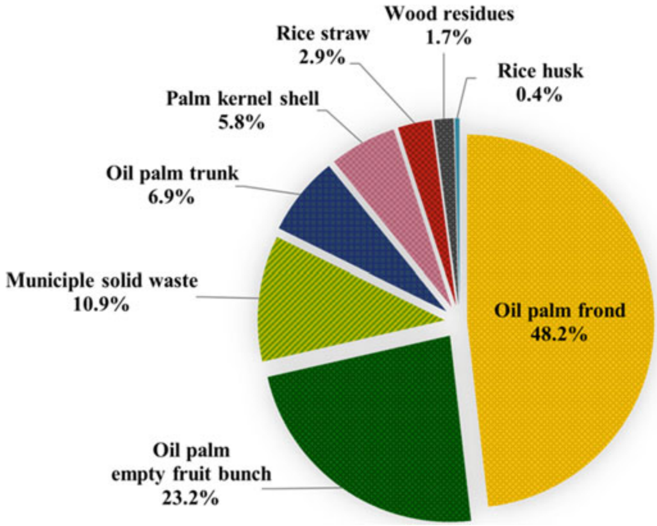

Fig. 1 Biomass availability in Malaysia [9]

Palm oil is majorly produced in Malaysia and served as a long-term agriculture investment in Malaysia [8]. Substantial total agricultural wastes in Malaysia are derived from oil palm plantations [9]. The lignocellulose of oil palm wastes can be converted into value-added products, for example, glucose which could be further fermented into biofuel. Presently, feedstocks of cellulose-based biomass for conversion into biofuels are larger in volume than any other carbohydrate source. Lignocellulose biomass refers to plant materials that are mainly composed of cellulose and hemicellulose that are bound together by lignin (Fig. 2). Each year, the production of rice in Malaysia (Kedah, Penang, Perak, Kelantan, Selangor, and Terengganu) is approximately up to 75% to supply local demand with the remaining sourced out from Southeast Asia countries such as Thailand, Vietnam, and Indonesia [11]. Rice cultivation activities are expected to grow due to increased demand and population. Rice producing industry generates three main by-products: rice straw, rice husk, and rice bran. When the grain had been harvested, the rice straw became the vegetative residue. Rice husk is the hard-protecting coating of grains that is broken up from the brown rice grain. Rice bran is the residues from the milling process that has been the profitable vegetative waste as a protein supplement in livestock farms. In contrast with rice straw and rice husk wastes remain unutilized. On the other hand, sago is also deemed to be one of the most potential feedstocks for the production of value-added products. In brief, sago hampas is a solid by-product resulting from the sago starch extraction process. It is made up of 58% of starch, 32% of cellulosic materials as well as 4% of lignin [12, 13]. It is interesting to mention that the considerably low amount of lignin content in sago hampas suggests no pretreatment process is required before fermentation. Several studies identified sago hampas as a substrate

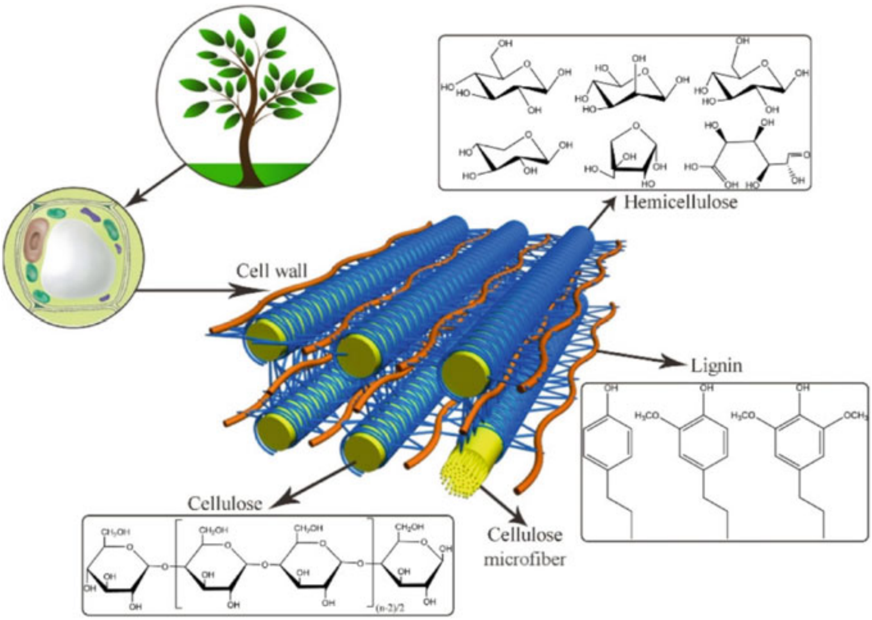

Fig. 2 The simplified general plant cell wall structure [10]

for the production of sugars [14, 15], bioenergy, and biofuels, including biohydrogen [12], bioethanol [16], biobutanol [17], and bioelectricity [18, 19].

1.1 Palm Oil Industry

The commercial oil palm (*Elaeis guineensis*) cultivated in Malaysia originated from Africa. It was introduced into Malaya (later named Malaysia) in 1875 as an ornamental plant and only in 1917; it was first cultivated for commercial purposes in Tennamaran Estate, Kuala Selangor [20]. Since the 1960s, oil palm plantings in many parts of the world including Malaysia have seen significant expansion (Fig. 3). Over the past 50 years (1970–2018), the production of palm oil on the world market has been 35 times higher and the consumption in producing countries themselves has also increased dramatically [21]. Malaysia is the world's second-largest palm oil producer and the largest exporter in the international market [22]. Malaysia's palm oil production is almost 50% of the world's total production (crude palm oil and palm kernels oil) and the industry also produces millions of tonnes of residues or by-products which contain valuable resources yet to be fully utilized. Currently with about 5.9 million hectares of oil palm are cultivated in Malaysia, these plantations produce over 11.9 million tonnes of oil and more than 100 million tonnes of biomass residues per year [23]. This huge quantity of biomass includes the empty fruit bunch

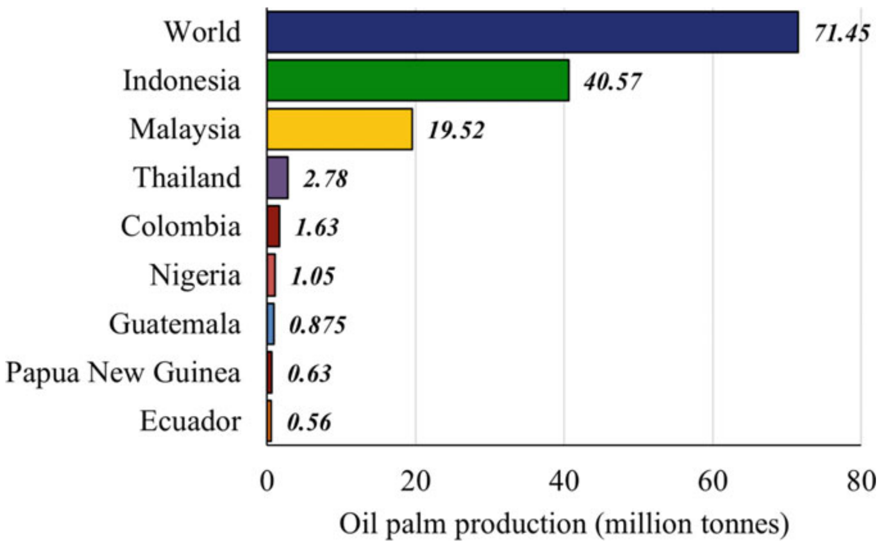

Fig. 3 World major producers of oil palm (1960–2018)

(EFB), pressed fruit fibre (PFF) or mesocarp fibre (MF), palm kernel shell (PKS), palm oil mill effluent (POME), oil palm trunks (OPT), and fronds (OPF). Until now the major portion of resources used is mesocarp fibre and kernel shells as main thermal energy sources in generating process steam and electricity in the palm oil mill. However, only 60% of these resources are used as fuel in boilers [24].

More than 10 million tonnes of EFB are generated from more than 30 million tonnes per annum of fresh fruit bunches (FFB) [23]. Only 10% of the EFB is used as mulching material to protect the soil surface, conserve soil water and nutrients and the rest are burnt in incinerators in the palm oil mills to produce bunch ash or dumped in areas adjacent to the mill which generate environmental problems such as air and odour pollution in the nearby localities [25]. Another barrier that hindered the use of EFB as mulching material is their bulkiness with high moisture content resulting in transportation difficulties [26]. OPF and OPT are other biomass generated in oil palm plantations. OPF is available daily during harvesting of ripe fruit bunches by pruning of fronds and is traditionally used as mulching materials in plantations. OPT becomes available during the felling of old trees and replanting of the oil palm trees every 25 years. Previously, the burning of the OPT was carried out for fast disposal until stringent open burning regulations prevented this method of trunk disposal. The OPT is shredded and left in the field to decompose naturally. Overall, much of palm biomass remains as waste and awaits commercial exploitation. The total production and possible uses of the palm biomass are presented in Table 2. Oil palm biomass enriched with holocellulose can be converted into fermentable sugars and subsequently used for various bioproducts (bioethanol, biomethanol, biohydrogen, polyhydroxyalkanoates, polylactic acid, and others).

Table 2 Production and potential uses of palm biomass for biofuels

Oil Palm biomass	Production	Current uses	Potential uses
Empty Fruit Bunch (EFB)	15.8 million tonnes per annum [30]	• Mulching materials [31] • Ash (Organic fertilizer) and soil conditioner in the plantation [25, 32–34]	• Kraft pulping and bioethanol [35] • Polyhydroxyalkanoates (PHAs) or Polylactic acid (PLA) [36] • Glucose [37, 38] • Bioethanol [39–42] • Biogas [43] • Cellulase enzyme [44]
Pressed Fruit Fibre (PFF)	9.66 million tonnes per annum [45]	• Fuel boilers [24, 46]	• Fillers in thermoplastics and thermoset composites [36] • Oil palm ash (OPA) is produced after the combustion of oil palm fibre and shell as an adsorbent for toxic gas and heavy metal removal [47]
			• As a support carrier for ethanol production by *Candida shehatae* TISTR5843 in immobilization system [48] • Briquettes [46]
Palm Kernel Shell (PKS)	5.20 million tonnes per annum [45]	• Fuel boilers [24] • Road surfacing on estates [25, 49]	• Activated carbon [50] • Charcoal derived from oil palm shells can be coated with chitosan [51] • Briquettes [46]
Oil Palm Trunk (OPT)	2.515 tonnes of oil palm trunks per hectare after 25 years growth before replanting [32]	• Mulch	• Sugars for bioethanol production [52]
Oil Palm Frond (OPF)	10.88 tonnes of oil palm fronds per hectare [32]	• Mulch	• Oil palm frond based ruminant pellet [36]

(continued)

Table 2 (continued)

Oil Palm biomass	Production	Current uses	Potential uses
Palm Oil Mill Effluent (POME)	40 million tonnes of POME per annum [53]	• Organic fertilizer in oil palm areas [25]	• Methane [49, 54] • Biohydrogen [54] • Polyhydroxyalkanoates (PHAs) [55]

1.2 Rice Biomass

Malaysia has contributed 3.1 million tonnes of rice straw and 0.48 million tonnes of rice husk annually [27]. Rice straw is separated from the grains after being threshed either manually, using stationary threshers, or combined harvesters. The rice husk or rice hull is the coating on a seed or grain of rice. It is formed by hard materials comprising silica and lignin to protect the seed during the growing season. Each kilogramme of milled white rice resulted in approximately 0.2 kg of rice husk during milling and 1–1.5 kg rice straw depending on varieties, cutting height of the stubbles, and moisture content during harvest [28, 29]. Common products from rice husks are solid fuel (loose form, briquettes, and pellets), carbonized rice husk produced after burning, and the remaining rice husk ash after combustion.

1.3 Sago

Sarawak, Malaysia is known to be one of the largest sago starch exporters in the world which accounted for 55,000–65,000 tonnes/year [56]. With that matter, it has generated approximately 50–100 tonnes per day of sago hampas, especially in Sibu and Mukah division [57] and it is expected to exponentially increase over the year due to the demand. It is fascinating to note that due to the presence of lignocellulosic fibrous components in the sago hampas, it has been used as animal feed [58], mushroom culture's medium [59, 60] as well as particleboard manufacture [61].

2 Biomass Characteristics and Compositions

In general, about 30–60% cellulose, 20–40% of hemicellulose, and 10–30% of lignin are available in different kinds of lignocellulosic biomass sources [62]. These differences within this range either for the same species or between different biomass would depend on the growing location, season, harvesting methods as well as analytical procedures used [63]. Cellulose and hemicellulose are carbohydrate polymers that are built up by long chains of sugar monomers. Therefore, they are potential sources

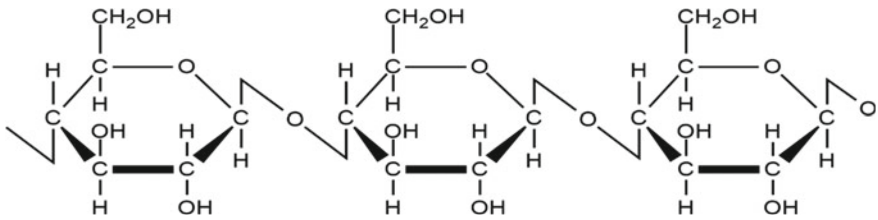

Fig. 4 Partial structure of cellulose molecules showing the β-linkage of glucose units [70]

of fermentable sugars but are not readily available for hydrolysis without pretreatment [64]. Lignin is a phenolic polymer in the plant cell walls. This compound binds cellulose and hemicellulose, imparts further strength, offers rigidity, and provides resistance against pests and diseases [65]. Besides these major constituents, the plant cell wall also contains pectic substances, proteins, waxes, cutin, suberin, and sporopollenin in smaller portions [66].

2.1 Cellulose

Cellulose is a linear polymer of homopolysaccharide (an unbranched polymer) composed of repeating glucose monomers that are linked together by β-1-4-glycosidic bonds or in short it is a highly crystalline polymer of glucose. The basic structure of cellulose is $(C_6H_{10}O_5)_n$. Based on structural characteristics, cellobiose is the repeating subunit in cellulose, in which each glucose unit is rotated 180º relative to its neighbour [67]. The individual cellulose chains are packed together and weakly bound through hydrogen bonding into 'elementary fibrils' [68, 69]. These 'elementary fibrils' about 3–4 nm wide (about 36 chains) are bundled together into organized parallel cellulose-fibrils called crystalline microfibrils which make up the core of a cellulose microfibril and are difficult to degrade [69]. Within the microfibrils, cellulose in plants is also found in the form of an amorphous structure, where the elementary fibrils are attached or cross-linked together by hemicelluloses, with the amorphous polymers of different sugars as well as other polymers such as pectin and covered by lignin [67, 69]. Generally, hydrolysis can reduce the cellulose to a cellobiose repeating unit $(C_{12}H_{22}O_{11})$ and ultimately to a glucose $(C_6H_{10}O_5)$ unit by cellulase. The partial structure of a cellulose molecule is illustrated in Fig. 4.

2.2 Hemicellulose

Hemicellulose, non-cellulosic structural polysaccharides, or sometimes also called polyose are branched heteropolysaccharides that exist in association with cellulose and lignin in the plant cell wall [62, 67]. Hemicellulose is composed of shorter chain

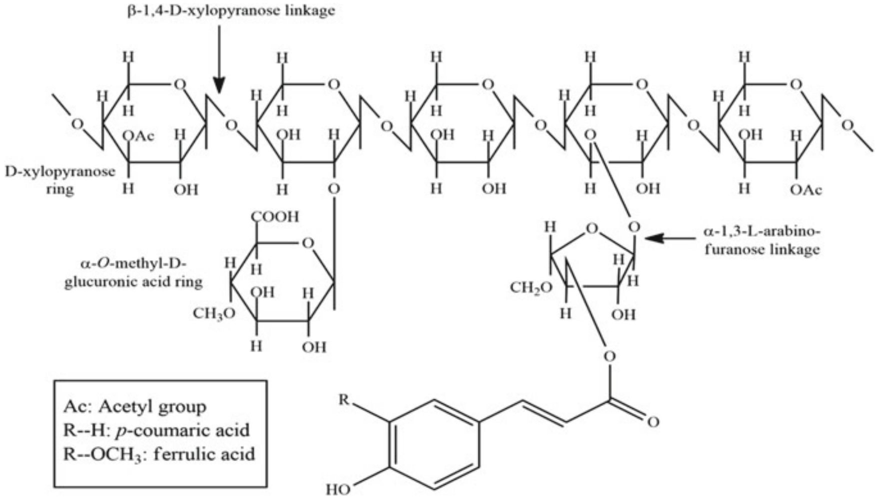

Fig. 5 Schematic illustration of sugar units of hemicelluloses [75]

polysaccharides which act as a linkage between lignin and cellulose. In general, hemicellulose may contain pentoses (β-D-xylose, α-L-arabinose), hexoses (β-D-mannose, β-D-glucose, α-D-galactose) and/or uronic acids (α-D-glucuronic, α-D-4-O-methylgalacturonic and α-D-galacturonic acids) [65, 69, 71, 72]. It is a low molecular weight compound that is much easier to hydrolyze than cellulose [62]. According to Miller et al. [67], hemicelluloses are typically composed of main-chain backbones of xylan which consists of β-1,4-linked-D-glucopyranose and β-D-mannopyranose units with α-1,6 galactose residues. Other non-cellulosic structural polysaccharides like arabinogalactan are also commonly found in the plant cell wall. Many side-chain constituents namely arabinofuranosyl, acetyl, feruloyl, and methylglucoronyl groups branch off the main backbone. The most important hemicelluloses are xylans and glucomannans, with xylans being the most abundant component of hardwoods and herbaceous plants [71]. Xylose is one of the major building blocks of hemicellulose or fermentable sugars present in lignocellulosic biomass and the second most abundant carbohydrate polymer in nature after glucose [73, 74]. Within the plant cell wall structure, the hemicelluloses are thought to coat the cellulose-fibrils resulting in reduced accessibility of the cellulose-fibrils. Therefore, pretreatment and enzymatic hydrolysis of the hemicellulose component is essential to facilitate complete cellulose degradation [65]. The sugar units of hemicelluloses are illustrated in Fig. 5.

2.3 Lignin

Lignin is a phenolic aromatic macromolecule that is primarily formed by free-radical polymerization of ρ-hydroxy cinnamyl alcohol units with varying methoxyl contents

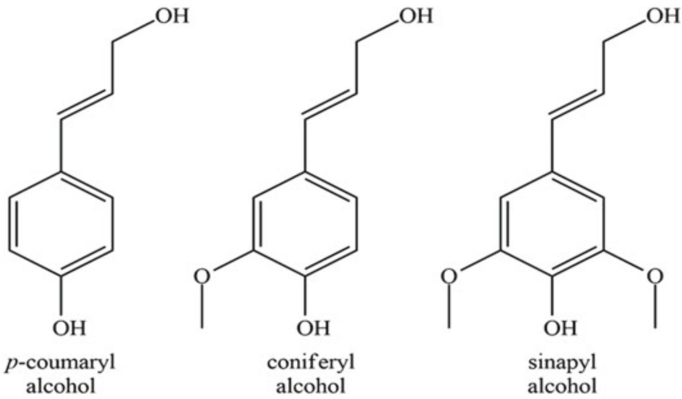

Fig. 6 Schematic illustration of building units of lignin [79]

commonly known as phenylpropane units [65]. The three monomeric unit precursors of lignin are based on: coniferyl alcohol, sinapyl alcohol, and ρ-coumaryl alcohol, and they vary among species [76] (Fig. 6). Lignin, in general, is an important structural component serving as a supporting agent and gives strength to the cell biomass. It glues together the other fractions in the complex phenolic polymers and assists in the resistance of biomass against microbial attack and decay [77, 78]. Therefore, lignin is considered an important barrier to polysaccharide utilization such as hydrolysis by cellulases. It is believed that the existence of strong carbon–carbon ($C - C$) and ether ($C - O - C$) linkages in lignin affect its susceptibility to chemical disruption.

2.4 Empty Fruit Bunch: Production, Structural Characteristics and Uses

The EFB is abundant solid biomass or residue from the palm oil industry which are produced in large amounts from the FFB of oil palm. According to Tan et al. [39], FFB comprises 21% palm oil, 7% palm kernel, 14% PPF, 7% PKS, and 23% EFB. It has been estimated that for every kilogramme of palm oil produced roughly 4 kg of dry biomass is generated [80]. Hence, every year approximately 15 million tonnes of EFB are produced in Malaysia and about 37.7 million tonnes are produced globally [34]. In short, EFB is the largest residual product of the palm oil milling process. EFB is the residual bunch remaining after the reddish palm oil is removed from the FFB by the thresher during oil extraction [39]. The process flow of the palm oil mill demonstrates the types of oil palm biomass available and the EFB generated (Fig. 7) [54, 55, 80, 81]. The typical palm oil milling process in Malaysia is the wet process which uses a lot of water in the sterilization and extraction process.

The milling process generates vast amounts of wastewater effluent (POME) which are from three main sources, namely sterilizer condensate, sludge separator, and the

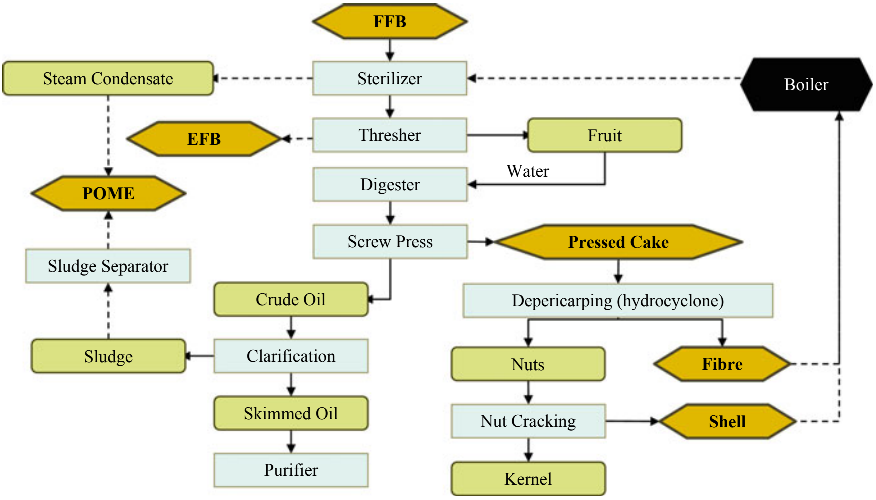

Fig. 7 Process flow diagram of fresh fruit bunch processing and biomass generation in palm oil mills

hydro-cyclone [53]. Sterilization of FFB at high temperature (140 °C) under pressurized steam (0.28 MPa) for 75–90 min is the beginning stage of the milling process. The sterilization process introduces moisture into the nuts, causes the detachment of the kernel from the shell wall, and loosens kernels within their shells. The sterilized FFB is then fed into a rotary drum thresher for stripping the fruits and conveying the empty wet bunches called EFB to the dumping ground. EFB is categorized as fibrous crop residue or known as the lignocellulosic residue. EFB consists of almost 70% of water and 30% solids which comprise lignocellulosic materials [82]. Based on composition EFB is comparable to those of hardwoods (Table 3). The main components of EFB are cellulose, hemicellulose, and lignin. It is estimated that EFB is composed of 43–60% cellulose, 19–34% hemicellulose, and 12–24% lignin. Cellulose is a polymer of the hexose sugar glucose, while hemicellulose is a pentose sugar-containing mainly xylose.

These sugars can be used as substrates for the production of a wide variety of compounds by chemical and biochemical processes. Since the solid EFB bunches are rich in cellulose and hemicellulose that are cross-linked with lignin which is not easily

Table 3 Chemical composition of empty fruit bunch, hardwood, and softwood

Biomass residues	Chemical composition (%)			
	Cellulose	Hemicellulose	Lignin	References
Empty fruit bunch	43–60	19–34	12–24	[38, 83–86]
Hardwood	40–55	24–40	18–25	[87]
Softwood	45–50	25–35	25–35	[87]

decomposed, degraded, or hydrolyzed into their monomers, these bunches must be subjected to pretreatment involving physical, chemical, or biological processes to cleave the chains or dissolve the lignin before production of useful chemicals and biofuels.

2.5 Rice Husk and Rice Straw: Production, Structural Characteristics and Uses

A low bulk density rice husk is produced off-site during grain processing and is normally 20–25% of the overall weight of milled paddy [29]. A rice husk is yellowish in colour, convex shape, and consists of rigid materials such as opaline silica and lignin acting as seed protection. Rice husk has become a source for many silicon compounds, including silica (SiO_2), silica carbide (SiC), silicon (Si), silica nitride (Si_3N_4) meanwhile for the chemical composition contains 74% organic and 26% of inorganic [88]. When rice husk is burned or carbonized rice husk is formed, it generates 17–26% of rice husk ash which is another important product that can be obtained from rice husk [89]. Table 4 shows the chemical composition of rice husk and Table 5 shows the composition of organic compounds in rice husk. Rice husk has a global potential as a renewable feedstock for the generation of biofuels. Moreover, the estimated additional revenue can also be improved by high calorific value lignin after the production of biofuels. Thus, rice husk is an excellent potential raw material, economical, and abundant source for future biofuels production and has the potential to provide a high yield of biofuels [90].

Rice straw is a waste from the collection of rice grains. A substantial large quantity of waste and the fact that it is non-food, this lignocellulosic waste was promoted as a possible source of material for global ethanol production [96]. The quantity of straw

Table 4 Lignocellulosic composition of rice husk

Constituents	Composition (%)			
Cellulose	35.6	34.4	40.0	35.23
Hemicellulose	29.3	29.3	15.0	24.39
Lignin	20.0	19.2	20.0	12.92
References	[91]	[92]	[93]	[94]

Table 5 The composition of the rice husk organic compound [95]

Content	Percentage (%)
Carbon	39.8–41.1
Hydrogen	5.7–6.1
Oxygen	0.5–0.6
Nitrogen	36.6–37.4

Table 6 Chemical composition of rice straw [100]

Biomass	Rice straw (%)
Cellulose	32.0
Hemicellulose	35.7
Lignin	22.3
Extractive matter	10.0

Table 7 Characterize monomers of each component in rice straw [101]

Cellulose	Hemicellulose	Lignin
D-glucose	Pentose Xylose Arabinose	Phenolic monomers Coniferyl alcohol Coumaryl alcohol Sinapyl alcohol
	Hexose Mannose Galactose Glucose	
	Uronic acids 4-o-methyl glucuronic acid D-glucuronic acid D-galacturonic acid	

that can be collected from year to year, such as the annual variability in straw production, the yield of straw varies greatly between regions and countries, the modern grain harvesting method, and also the cereal breeding directly towards the development of short stem varieties [97]. The processing of rice straw sugars by enzymatic reaction attracts manufacturing attention due to the light reaction conditions used and the fairly pure formulation of products [98]. The important components of the rice straw are cellulose, lignin, hemicellulose, phenol fraction, and silica [99]. Table 6 shows the composition of rice biomass and Table 7 is the characterization of monomers of each component. Components of lignocellulosic biomass are the polysaccharides that are built up by different types of monomers. To alter the structure of the polysaccharides, a pretreatment method is required to improve the accessibility of hemicellulose and cellulose in enzymatic hydrolysis or fermentation.

2.6 Sago Hampas: Production, Structural Characteristics and Uses

Generally, based on Table 8, sago hampas is made up of 58% of starch, 32% of cellulosic materials as well as 4% of lignin [12, 13]. The considerably low amount of lignin content in sago hampas and valued as energy feedstock since no pretreatment is needed before the fermentation process.

Table 8 Chemical composition of sago hampas

References	[19]	[18]	[16]
Composition (%) (Dry basis)			
Starch	58.0 ± 0.02	54.6	55.4
Cellulose	21.0 ± 0.71	21.4	23.6
Hemicellulose	13.4 ± 0.94	10.3	9.1
Lignin	5.4 ± 0.55	3.3	4.0
Ash	3.13 ± 0.13	ND	2.2

ND: Not detected

3 Potential of Biomass Utilization as a Feedstock for Renewable Energy in Malaysia

Renewable energy alternatives in Malaysia are primarily solar, biogas, biomass, and mini-hydro. In the recent decades, the utilization of biomass as renewable feedstock increased as the Malaysian government implemented national policies and strategies such as the National Green Technology Policy (2009), National Renewable Energy Policy and Action Plan (2010), New Energy Policy (2010), Renewable Energy Act (2011) and National Biomass Strategy 2020 (2011) [102]. The objectives of these policies are to reduce the national dependency on fossil fuel and promote renewable energy initiatives to meet the national energy requirement that increases yearly which is projected will be 103 million tonnes of oil equivalent (Mtoe) by 2035 [103].

3.1 Government Assistance

Malaysia also pledged and assured to reduce its greenhouse gas emissions of Gross Domestic Product by 45% by 2030 under the Paris Agreement as compared to intensity in 2005 at the 2015 United Nations Climate Change Conference (COP 21) [104]. The recent report from IPCC [105] indicates that the global mean surface temperature which ranged from 1.8 to 4.0 °C would rise sharply in the next century and beyond if existing patterns of human activity are left unchecked. To achieve this voluntary target, an agency in Malaysia such as the Sustainable Energy Development Authority (SEDA) is responsible to execute the action plan to enhance the activity and project related to renewable energy by managing the implementation of the Feed-in Tariff (FiT) mechanism. Figure 8 exhibits that renewable energy generation from biomass is the second-highest contributor after solar photovoltaic from 2012 until 2018. This remarkable potential of biomass utilization in Malaysia should be increased in the coming years as Malaysia has abundant biomass resources that can be utilized to generate electricity.

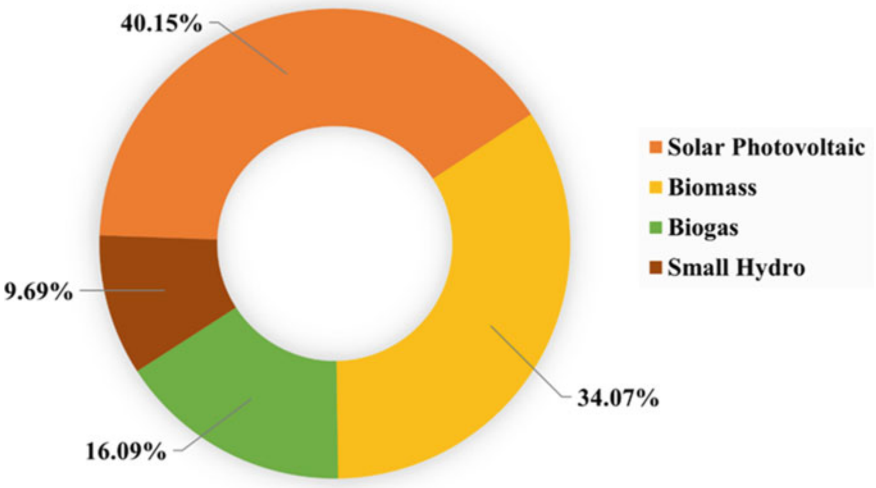

Fig. 8 Renewable energy generation projects that have achieved commercial operations since 2012 in Malaysia [106]

3.2 Environmental Sustainability

In the eco-awakening era, the dramatic rise of concern towards the environment drives the Malaysian government to reduce its greenhouse gas (GHG) emissions from the palm oil industry through the Malaysian Sustainable Palm Oil (MSPO) certification scheme. Figure 9 shows the annual carbon dioxide emission reduction from the commercial operation of solar photovoltaic energy, biomass, biogas, and small hydro in Malaysia. A promising option for renewable energy from biomass is vividly seen as it records the second-highest carbon dioxide reduction after solar photovoltaic energy. The entire oil palm industry (plantation and mill operators) is mandatory to apply the MSPO scheme starting from 31 December 2019 [107]. Currently, 437 out of 455 palm oil mills (96.04%) in the country have been certified as MSPO compliant [108]. MSPO-certified palm oil mills are required to generate renewable energy sources to reduce national GHG emissions. With the vital principle of protecting the environment, the MSPO certification helps to promote and encourage all palm oil millers to generate electricity by their own produced solid biomass. This sustainable certification scheme should be extended to other agricultural sectors in Malaysia to initiate renewable energy from other crops such as rice straw, rice husk, landscape waste, and others.

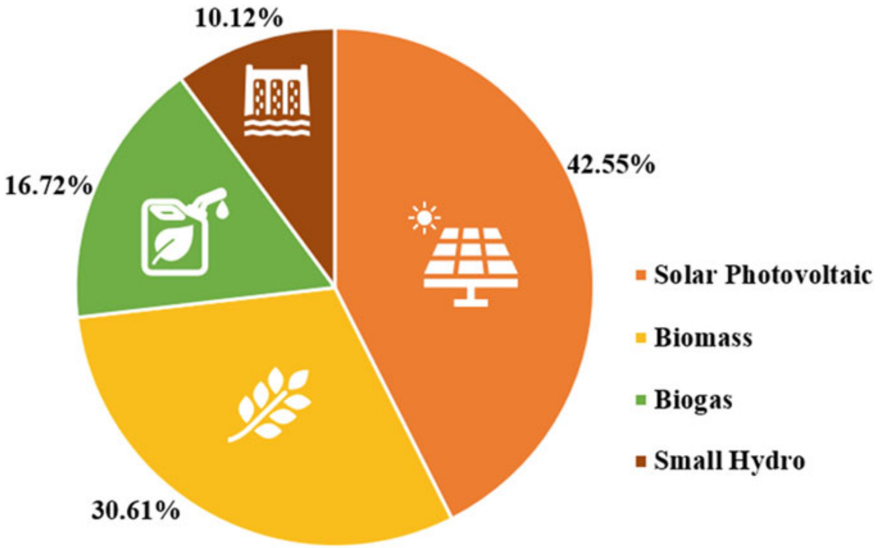

Fig. 9 Annual CO_2 emissions reduction from renewable energy projects that have achieved commercial operations (2012–2018) in Malaysia [106]

3.3 *Biomass Availability and Logistic Facilities*

The agricultural sector contributed 7.1% to the national Gross Domestic Product (GDP) in 2019 with oil palm being the largest contributor at 37.7% [109]. Hence, biomass from the agricultural sector is abundantly produced at the mill and available all year round. The main challenges to utilizing Malaysian biomass as a feedstock for biofuel are collection, transportation, and storage issues. For instance, OPF is the largest biomass produced during pruning in the oil palm plantation area. However, the OPF is not collected and transported out of the oil palm plantation [110]. Eventually, the OPF biomass is left for the plantation nutrient recycling purpose. Another case example is EFB which has a high moisture content of around 50–60%. The biomass undergoes a sterilization step in a digester at the beginning of the FFB processing in the palm oil mill. The water molecule from the steam is locked by oil residue and this contributes to the high moisture content of EFB. Consequently, this condition is very favourable for fungal degradation which caused a serious issue in further exploration of EFB utilization. The EFB is produced abundantly at the palm oil mill and needs to be transported rapidly to the operator or buyer. Some of the palm oil millers have shredded the EFB and increased their opportunity to sell the EFB to other parties. By referring to the module of other developed countries on this issue, for example in the United States, the facility of biomass drying, grinding and briquetting is centralized for a certain number of mills [111]. Therefore, the facility can be shared by the mills and it is considered a cost-effective strategy. This collective effort is essential to achieve the ideal cost of feedstock, quantity, and quality for the future of renewable energy from biomass.

3.4 Technology Feasibility

Lignocellulosic biomass is directly incinerated from the source as solid biofuel for electricity. The biomass power plant at Prolific Yield Palm Oil Mill in Sandakan, Sabah uses EFB as primary fuel with oil palm shells and mesocarp fibres as secondary fuels. The biomass power plant is capable of generating 12 Megawatt of electricity [112]. Meanwhile, liquid biofuel production requires a pretreatment step, saccharification, and fermentation. An efficient pretreatment method is required to release all monomers from lignocellulosic biomass for conversion into biofuels. The inefficiency of pretreatment conversion facility, core technology, and equipment shortage may hinder the production of biofuel. The pretreatment step and hydrolytic enzyme possess a domino effect on the subsequent steps in biofuel production, technically and economically [113]. Moreover, high energy consumption and high capital cost in the pretreatment process lead to the high risk of investment. In the Malaysian scenario, most of the small and medium enterprises (SMEs) in the oil palm industry are operating at a small financial budget and hardly venture into value-added bioproduct from the biomass [114]. Nevertheless, OPF juice exhibited a promising potential as a feedstock for bioethanol production as the OPF only required a pressing machine to obtain the juice and directly can be fermented into bioethanol [115].

4 Conclusion

The utilization of renewable bioresources has become a more promising technology due to the main concern of high dependency on non-sustainable resources. Biomass is one of the best potential candidates to be an alternative source for renewable energy. Hence, Malaysia is blessed with abundant biomass resulting from agricultural sectors, including oil palm, rice, and sago. The biomass generated from each sector has it is before fermentation which is further used in different applications. In this chapter, we have critically summarized each biomass produced from the oil palm, rice, and sago industry in Malaysia. Furthermore, we have details about individual biomass from respective agricultural industries, related to their production, structural characteristics as well as uses. In addition, we also have critically discussed other potential factors contributing to the utilization of biomass in renewable energy production in Malaysia. All in all, Malaysia is deemed to have a strong platform in implementing the biomass utilization strategy and further developing the next new era in renewable energy development.

References

1. Segneanu A-E, Cziple F, Vlazan P, Sfirloaga P, Grozescu I, Gherman VD (2013) Biomass extraction methods. In: Matovic MD (ed) Biomass now sustainable growth and use. IntechOpen, United Kingdom, pp 389–400
2. Greenheartenergy: Biomass-Definition, Division, Use, Risks, Trends (2021) http://www.greenheartenergy.com/biomass. Accessed 14 June 2021
3. Rezania S, Oryani B, Cho J, Sabbagh F, Rupani PF, Talaiekhozani A, Rahimi N, Ghahroud ML (2020) Technical aspects of biofuel production from different sources in Malaysia—a review. Processes 8(8):993
4. Department of Agriculture Malaysia: Industrial Crops Statistic 2019 (2019) http://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/perangkaan_herba_rempah_ratus_2019.pdf. Accessed 14 June 2021
5. Department of Agriculture Malaysia: Statistik Tanaman (Sub-Sektor Tanaman Makanan) 2020 (2020) http://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/booklet_statistik_tanaman_2020.pdf. Accessed 14 June 2021
6. Department of Agriculture Malaysia: Vegetables and Cash Crops Statistic 2019 (2019) http://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/perangkaan_herba_rempah_ratus_2019.pdf. Accessed 14 June 2021
7. Department of Agriculture Malaysia: Herbs and Spices Statistic 2019 (2019) http://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/perangkaan_herba_rempah_ratus_2019.pdf. Accessed 14 June 2021
8. Ng WPQ, Lam HL, Ng FY, Kamal M, Lim JHE (2012) Waste-to-wealth: green potential from palm biomass in Malaysia. J Clean Prod 34:57–65
9. Jing LJ (2017) Biomass landscape in Malaysia & potential collaborations with APEC. https://www.egnret.ewg.apec.org/sites/default/files/download/16-MBIC.pdf. Accessed 14 June 2021
10. Song A, Huang Y, Liu B, Cao H, Zhong X, Lin Y, Wang M, Li X (2017) Zhong, W: Gel polymer electrolyte based on polyethene glycol composite lignocellulose matrix with higher comprehensive performances. Electrochim Acta 247:505–515
11. Rahim FHA, Hawari NN, Abidin NZ (2017) Supply & demand of rice in Malaysia: a system dynamics approach. Int J Supp Chain Mgt 6(4):1–7
12. Jenol MA, Ibrahim MF, Yee PL, Salleh MM, Abd-Aziz S (2014) Sago biomass as a sustainable source for biohydrogen production by *Clostridium butyricum* A1. BioResources 9(1):1007–1026
13. Linggang S, Phang LY, Wasoh MH, Abd-Aziz S (2012) Sago pith residue as an alternative cheap substrate for fermentable sugars production. Appl Biochem Biotech 167(1):122–131
14. Awg-Adeni DS, Bujang KB, Hassan MA, Abd-Aziz S (2013) Recovery of glucose from residual starch of sago hampas for bioethanol production. Biomed Res Int. Article ID 935852. https://doi.org/10.1155/2013/935852
15. Alias NH, Abd-Aziz S, Phang LY, Ibrahim MF (2021) Enzymatic saccharification with sequential-substrate feeding and sequential-enzymes loading to enhance fermentable sugar production from sago hampas. Processes 9(3):535
16. Hung HC, Adeni DSA, Johnny Q, Vincent M (2018) Production of bioethanol from sago hampas via simultaneous saccharification and fermentation (SSF). Nusantara Biosci 10(4):240–245
17. Husin H, Ibrahim MF, Bahrin EK, Abd-Aziz S (2019) Simultaneous saccharification and fermentation of sago hampas into biobutanol by *Clostridium acetobutylicum* ATCC 824. Energy Sci Eng 7(1):66–75
18. Jenol MA, Ibrahim MF, Bahrin EK, Kim SW, Abd-Aziz S (2019) Direct bioelectricity generation from sago hampas by *Clostridium beijerinckii* SR1 using microbial fuel cell. Molecules 24(13):2397

19. Jenol MA, Ibrahim MF, Bahrin EK, Abd-Aziz S (2020) Enhanced volatile fatty acid production from sago hampas by *Clostridium beijerinckii* SR1 for bioelectricity generation using microbial fuel cells. Bioproc Biosys Eng 43(11):2027–2038
20. Basiron Y (2007) Palm oil production through sustainable plantations. Eur J Lipid Sci Tech 109:289–295
21. Ritchie H, Roser M (2020) Palm oil. https://ourworldindata.org/palm-oil. Accessed 11 Sept 2021
22. Derman E, Abdulla R, Marbawi H, Sabullah MK (2018) Oil palm empty fruit bunches as a promising feedstock for bioethanol production in Malaysia. Renew Energ 129:285–298
23. Khalil HPSA, Nur Firdaus MY, Anis M, Ridzuan R (2008) The effect of storage time and humidity on mechanical and physical properties of medium density fiberboard (MDF) from oil palm empty fruit bunch and rubberwood polymer. Plast Technol Eng 47:1046–1053
24. Mohamed H (2006) Application of theoretical combustion analysis in determining the optimum fibre/shell ratio for oil mill boiler. PhD Thesis, Universiti Putra Malaysia
25. Yusoff S (2006) Renewable energy from palm oil—innovation on effective utilization of waste. J Clean Prod 14:87–93
26. Chiew YL, Iwata T, Shimada S (2011) System analysis for effective use of palm oil waste as energy resources. Biomass Bioenerg 35:2925–2935
27. Malaysia Economics Statistic (2011) http://www.statistics.gov.my/portal/index.php. Accessed 14 June 2021
28. Karimi K, Kheradmandinia S, Taherzadeh MJ (2006) Conversion of rice straw to sugars by dilute-acid hydrolysis. Biomass Bioenerg 30(3):247–253
29. Yu J, Zhang J, He J, Liu Z, Yu Z (2009) Combinations of mild physical or chemical pretreatment with biological pretreatment for enzymatic hydrolysis of rice hull. Bioresource Technol 100(2):903–908
30. Mekhilef S, Saidur R, Safari A, Mustafa WESB (2011) Biomass energy in Malaysia: current state and prospects. Renew Sust Energ Rev 15:3360–3370
31. Sung CTB, Joo GK, Kamarudin KN (2010) Physical changes to oil palm empty fruit bunches (EFB) and EFB mat (Ecomat) during their decomposition in the field. Pertanika J Tropika Agric Sci 33(1):39–44
32. Kelly-Yong TL, Lee KT, Mohamed AR, Bhatia S (2007) Potential of hydrogen from oil palm biomass as a source of renewable energy worldwide. Energ Policy 35:5692–5701
33. Thambirajah JJ, Zulkali MD, Hashim MA (1995) Microbiological and biochemical changes during the composting of oil palm empty fruit bunches: effect of nitrogen supplementation on the substrate. Bioresource Technol 52:133–144
34. Akhtar J, Kuang SK, Amin NAS (2010) Liquefaction of empty palm fruit bunch (EPFB) in alkaline hot compressed water. Renew Energ 35:1220–1227
35. Ibrahim MM, Agblevor FA, El-Zawawy WK (2010) Isolation and characterization of cellulose and lignin from steam-exploded lignocellulosic biomass. BioResources 5(1):397–418
36. Shuit SH, Tan KT, Lee KT, Kamaruddin AH (2009) Oil palm biomass as a sustainable energy source: a Malaysian case study. Energy 34:1225–1235
37. Lenihan P, Orozco A, O'Neill E, Ahmad MNM, Rooney DW, Walker GM (2010) Dilute acid hydrolysis of lignocellulosic biomass. Chem Eng J 156:395–403
38. Hamzah F, Idris A, Shuan TK (2011) Preliminary study on enzymatic hydrolysis of treated oil palm (*Elaeis*) empty fruit bunches fibre (EFB) by using combination of cellulase and β-1-4 glucosidase. Biomass Bioenerg 35:1055–1059
39. Tan HT, Lee KT, Mohamed AR (2010) Second-generation bio-ethanol (SGB) from Malaysian palm empty fruit bunch: energy and exergy analyses. Bioresource Technol 101:5719–5727
40. Piarpuzán D, Quintero JA, Cardona CA (2011) Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production. Biomass Bioenerg 35:1130–1137
41. Yunus R, Salleh SF, Abdullah N, Awg Biak DR (2010) Effect of ultrasonic pre-treatment on low temperature acid hydrolysis of oil palm empty fruit bunch. Bioresource Technol 101:9792–9796

42. Jung YH, Kim IJ, Han JI, Choi IG, Kim KH (2011) Aqueous ammonia pretreatment of oil palm empty fruit bunches for ethanol production. Bioresource Technol 102(20):9806–9809
43. Nieves DC, Karimia K, Horvátha IS (2011) Improvement of biogas production from oil palm empty fruit bunches (OPEFB). Ind Crop Prod 34:1097–1101
44. Alam MZ, Mamun AA, Isam YQ, Muyibi S, Salleh HM, Omar NM (2009) Solid state bioconversion of oil palm empty fruit bunches for cellulase enzyme production using a rotary drum bioreactor. Biochem Eng J 46(1):61–64
45. Chiew TL, Bhatia S (2008) Catalytic processes towards the production of biofuels in a palm oil and oil palm biomass-based biorefinery. Bioresource Technol 99(17):7911–7922
46. Husain Z, Zainac Z, Abdullah Z (2002) Briquetting of palm fibre and shell from the processing of palm nuts to palm oil. Biomass Bioenerg 22:505–509
47. Zainudin NF, Lee KT, Kamaruddin AH, Bhatia S, Mohamed AR (2005) Study of adsorbent prepared from oil palm ash (OPA) for flue gas desulfurization. Sep Purif Technol 45:50–60
48. Riansa-Ngawong WR, Suwansaard M, Prasertsan P (2012) Application of palm pressed fibre PhD as a carrier for ethanol production by *Candida shehatae* TISTR5843. Electron J Biotechn 15(6):1–9
49. Sulaiman F, Abdullah N, Gerhauser H, Shariff A (2011) An outlook of Malaysian Energy, oil palm industry and its utilization of wastes as useful resources. Biomass Bioenerg 35:3775–3786
50. Hussein MZ, Tarmizi RSH, Zainal Z, Ibrahim R, Badri RM (1996) Preparation and characterization of active carbons from oil palm shells. Carbon 34(11):1447–1453
51. Nomanbhay SM, Palanisamy K (2008) Removal of heavy metal from industrial wastewater using chitosan coated oil palm shell charcoal. Electron J Biotechn 8(1):43–53
52. Yamada H, Tanaka R, Sulaiman O, Hashim R, Hamid ZAA, Yahya MKA, Kosugi A, Arai T, Murata Y, Nirasawa S, Yamamoto K, Ohara S, Mohd Yusof MN, Ibrahim WA, Mori Y (2010) Old oil palm trunk: a promising source of sugars for bioethanol production. Biomass Bioenerg 34(11):1608–1613
53. Yacob S, Shirai Y, Hassan MA, Wakisaka M, Subash S (2006) Start-up operation of semi-commercial closed anaerobic digester for palm oil mill effluent treatment. Process Biochem 41:962–964
54. Lam MK, Lee KT (2011) Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win-win strategies toward better environmental protection. Biotechnol Adv 29:124–141
55. Mumtaz T, Yahaya NA, Abd-Aziz S, Abdul Rahman NA, Yee PL, Shirai Y, Hassan MA (2010) Turning waste to wealth-biodegradable plastics polyhydroxyalkanoates from palm oil mill effluent a Malaysian perspective. J Clean Prod 18:1393–1402
56. Department of Agriculture Sarawak: Sarawak Agriculture Statistics 2013 (2013) http://www.doa.sarawak.gov.my/modules/web/pages.php?mod=webpage&sub=page&id=712. Assessed 6 June 2021
57. Amin N, Sabli N, Izhar S, Yoshida H (2019) Sago wastes and its applications. Pertanika J Tropika Agric Sci 27(4):1841–1862
58. Rasyid TH, Kusumawaty Y, Hadi S (2020) The utilization of sago waste: prospect and challenges. IOP Conf Ser Earth Environ Sci 415(1):012023
59. Wang Z, Liu J, Ning Y, Liao X, Jia Y (2017) *Eichhornia crassipes*: Agro-waste for novel thermostable laccase production by *Pycnoporus sanguineus* SYBC-L1. J Biosci Bioeng 123(2):163–169
60. Kumaran SSCA, Sastry CA, Vikineswary S (1997) laccase, cellulase and xylanase activities during growth of *Pleurotus Sajor-Caju* on sago hampas. World J Microb Biot 13(1):43–49
61. Phang SM, Miah MS, Yeoh BG, Hashim MA (2000) Spirulina cultivation in digested sago starch factory wastewater. J Appl Phycol 12(3):395–400
62. Peters D (2007) Raw materials. Adv Biochem Eng Biot 105:1–30
63. Agblevor FA, Batz S, Trumbo J (2003) Composition and ethanol production potential of cotton gin residues. Appl Biochem Biotech 105–108:219–230

64. Keshwani DR, Cheng JJ (2009) Switchgrass for bioethanol and other value-added applications: a review. Bioresource Technol 100(4):1515–1523
65. Chandra RP, Bura R, Mabee WE, Berlin A, Pan X, Saddler JN (2007) Substrate pretreatment: the key to effective hydrolysis of lignocellulosic. Adv Biochem Eng Biot 108:67–93
66. Smith GS (1971) Plant cell wall structure and cell wall growth. Tuatara 19(1):43–49
67. Vertés AA, Qureshi N, Blaschek HP, Yukawa H (2010) Biomass to biofuels: strategies for global industries. Wiley, United Kingdom
68. Hendriks ATWM, Zeeman G (2009) Pretreatments to enhance the digestibility of lignocelluloses biomass. Bioresource Technol 100(1):10–18
69. Taherzadeh MJ, Karimi K (2007) Enzymatic-based hydrolysis processes for ethanol from lignocellulosic materials: a review. BioResources 2(4):707–738
70. Acharya S, Chaudhary A (2012) Bioprospecting thermophiles for cellulase production: a review. Braz J Microbiol 844–856
71. Gírio FM, Fonseca C, Carvalheiro F, Duarte LC, Marques S, Bogel-Łukasik R (2010) Hemicelluloses for fuel ethanol: a review. Bioresource Technol 101:4775–4800
72. Saxena RC, Adhikari DK, Goyal HB (2009) Biomass-based energy fuel through biochemical routes: a review. Renew Sust Energ Rev 13:167–178
73. Matsushika A, Inoue H, Kodaki T, Sawayama S (2009) Ethanol production from xylose in engineered *Saccharomyces cerevisiae* strains: current state and perspectives. Appl Microbiol Biot 84:37–53
74. Watanabe S, Saleh AA, Pack SP, Annaluru N, Kodaki T, Makino K (2007) Ethanol production from xylose by recombinant *Saccharomyces cerevisiae* expressing protein engineered NADH-preferring xylose reductase from *Pichia stipites*. Microbiology 153:3044–3054
75. Khan MA (2010) Hydrolysis of hemicellulose by commercial enzyme mixtures [Lulea University of Technology]. https://www.diva-portal.org/smash/get/diva2:1022825/FULLTEXT01.pdf. Accessed 14 June 2021
76. Ramos LP (2003) The chemistry involved in the steam treatment of lignocellulosic materials. Quim Nova 26:863–871
77. Jojima T, Omumasaba CA, Inui M, Yukawa H (2010) Sugar transporters inefficient utilization of mixed sugar substrates: current knowledge and outlook. Appl Microbiol Biot 85:471–480
78. Lira C (2018) Autohydrolysis pretreatment of mixed lignocellulosic biomass. Ph.D. thesis, The University of Western Ontario
79. Karimi K, Chisti KY (2017) Bioethanol production and technologies. In: Abraham MA (ed) Encyclopedia of Sustainable Technologies, vol 3. Elsevier, London, pp 273–284
80. Sulaiman F, Abdullah N (2011) Optimum conditions for maximizing pyrolysis liquids of oil palm empty fruit bunches. Energy 36:2352–2359
81. Prasertsan S, Prasertsan P (1996) Biomass residues from palm oil mills in Thailand: an overview on quantity and potential usage. Biomass Bioenerg 11(5):387–395
82. Baharuddin AS, Hock LS, Md Yusof MZ, Rahman NAA, Md Shah UK, Hassan MA, Wakisaka M, Sakai K, Shirai Y (2010) Effects of palm oil mill effluent (POME) anaerobic sludge from 500 m^3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process. Afr J Biotechnol 9(16):2427–2436
83. Goh CS, Lee KT (2010) Palm-based biofuel refinery (PBR) to substitute petroleum refinery: an energy and energy assessment. Renew Sust Energ Rev 14:2986–2995
84. Mission M, Haron R, Ahmad Kamaroddin MF, Amin NAS (2009) Pretreatment of empty palm fruit bunch for production of chemicals via catalytic pyrolysis. Bioresource Technol 100:2867–2873
85. Rodríguez A, Serrano L, Moral A, Pérez A, Jiménez L (2008) Use of high-boiling point organic solvents for pulping oil palm empty fruit bunches. Bioresource Technol 99:1743–1749
86. Astimar AZ, Das K, Husin M, Mokhtar A (2002) Effects of physical and chemical pretreatments on xylose and glucose production from oil palm press fibre. J Oil Palm Res 14:10–17
87. Sun Y, Cheng J (2002) Hydrolysis of lignocellulosic materials for ethanol production: a review. Bioresource Technol 83:1–11

88. Sankar S, Sharma SK, Kaur N, Lee B, Kim DY, Lee S, Jung H (2016) Biogenerated silica nanoparticles synthesized from sticky, red, and brown rice husk ashes by a chemical method. Ceram Int 42:4875–4885
89. Gibson S (2016) Rice husk composite. http://www.builderonline.com/products/building-materials/rice-husk-composite. Accessed 14 June 2021
90. Banerjee S, Sen R, Pandey RA, Chakrabarti T, Satpute D, Giri BS, Mudliar S (2009) Evaluation of wet air oxidation as a pretreatment strategy for bioethanol production from rice husk and process optimization. Biomass Bioenerg 33(12):1680–1686
91. Isikgor FH, Becer CR (2015) Lignocellulosic biomass: a sustainable platform for the production of bio-based chemicals and polymers. Polym Chem 6(25):4497–4559
92. Williams PT, Nugranad N (2000) Comparison of products from the pyrolysis and catalytic pyrolysis of rice husks. Energy 25(6):493–513
93. Issagulov AZ, Kim VA, Kvon SS, Tussupova AU (2014) Production of technical silicon and silicon carbide from rice husk. Biotechnol Biofuels 53(4):685–688
94. Wu G, Qu P, Sun E, Chang Z, Xu Y, Huang H (2015) Physical, chemical, and rheological properties of rice husks treated by composting process. Int J Emerging Technol Adv Eng 10(1):227–239
95. Korotkova TG, Ksandopulo SJ, Donenko AP, Bushumov SA, Danilchenko AS (2016) Physical properties and chemical composition of the rice husk and dust. Oriental J Chem 32(6):3213–3219
96. Townsend TJ, Sparkes DL, Wilson P (2017) Food and bioenergy: reviewing the potential of dual-purpose wheat crops. GCB Bioenerg 9:525–540
97. Bakker R, Elbersen W, Poppens R, Lesschen JP (2013) Rice straw and wheat straw. Potential Feedstocks for the Biobased Economy. https://www.researchgate.net/publication/283416921_Rice_Straw_and_Wheat_Straw_-_Potential_feedstocks_for_the_Biobased_Economy. Accessed 14 June 2021
98. Dos Santos Rocha MSR, Pratto B, de Sousa R, Almeida RMRG, da Cruz AJG (2017) A kinetic model for hydrothermal pretreatment of sugarcane straw. Bioresource Technol 228:176–185
99. Zemnukhova L, Kharchenko U, Beleneva I (2015) Biomass-derived silica-containing products for removal of microorganisms from water. Int J Environ Sci Te 12:1495–1502
100. Lim JS, Abdul Manan Z, Wan Alwi SR, Hashim H (2012) A review on utilization of biomass from rice industry as a source of renewable energy. Renew Sust Energ Rev 16(5):3084–3094
101. Lau C (2012) Characterization and quantification of monomers, oligomers, and byproducts from xylan during biomass pretreatment. PhD. Dissertation, University of Arkansas, Fayetteville, AR
102. How BS, Ngan SL, Hong BH, Lam HL, Ng WPQ, Yusup S, Rambli J (2019) An outlook of malaysian biomass industry commercialization: perspectives and challenges. Renew Sust Energ Rev 113
103. Asia Pacific Energy Research Centre: APEC energy demand and supply outlook, 5th edn (2013) https://www.apec.org/Publications/2013/02/APEC-Energy-Demand-and-Supply-Outlook-5th-Edition. Accessed 14 June 2021
104. SEDA (2020) Sustainable Energy Malaysia. http://www.seda.gov.my/download/magazine/. Accessed 14 June 2021
105. IPCC (2011) Climate change 2011: the physical science basis—fourth assessment report of the IPCC. Cambridge University Press, Cambridge, United Kingdom
106. SEDA (2019) Annual report 2018. Sustainable Energy Development Authority (SEDA) Malaysia, vol. 4. https://doi.org/10.3934/Math.2019.1.166. Accessed 14 June 2021
107. Majid NA (2021) Sustainable palm oil certification scheme frameworks and impacts: a systematic literature review. Sustainability (Switzerland) 13(6)
108. Shankar AC (2021) 4 % of Malaysia's total licensed oil palm planted area MSPO-certified, says MPOB, pp 8–10. https://news.drtakiri.my/2021/03/864-of-malaysias-total-licensed-oil.html. Accessed 13 June 2021
109. DOSM (2020) Press release. Selected agricultural indicators, Malaysia, 2020 Department of Statistics Malaysia. https://www.dosm.gov.my/v1/index.php?r=column/pdfPrev&id=RXVKUVJ5TitHM0cwYWxlOHcxU3dKdz09. Accessed 13 June 2021

110. Abdullah SSS, Shirai Y, Ali AAM, Mustapha M, Hassan MA (2016) Case study: preliminary assessment of integrated palm biomass biorefinery for bioethanol production utilizing non-food sugars from oil palm frond petiole. Energ Convers Manage 108:233–242
111. Berry MD, Sessions J (2018) The economics of biomass logistics and conversion facility mobility: an oregon case study. Appl Eng Agric 34(1):57–72
112. MHC Plantations Berhad: Renewable energy power plants (2021). https://www.mhc.com.my/our-business-power-plant/. Accessed 13 June 2021
113. Singhvi MS, Gokhale DV (2019) Lignocellulosic biomass: hurdles and challenges in its valorization. Appl Microbiol Biot 103(9)
114. Hafizuddin-Syah BAM, Shahida S, Fuad SH (2018) Sustainability certifications and financial profitability: an analysis on palm oil companies in Malaysia. Jurnal Pengurusan 54(2018):143–154
115. Abdullah SS, Bahrin EK, Shirai Y, Hassan MA (2021) Influence of storage conditions on oil palm frond juice as a renewable feedstock for bioethanol production. Biomass Bioenerg 150(January):106101