The potential of biomass waste in Malaysian palm oil industry: A case study of Boustead Plantation Berhad

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Abstract. The oil palm industry is known as the primary producer of biomass in Malaysia. The massive production of oil palm biomass has resulted in a significant waste disposal problem. This study aims to assess the potential of waste derived from oil palm plantations and processing mills to be transformed into value-added products for various applications. The study was conducted on three oil palm estates managed by Boustead Rimba Nilai Berhad using data on the generation rates of fresh fruit bunches (FFB), crude palm oil (CPO), and oil palm biomass waste from 2018 to 2020. The availability of FFB, CPO, empty fruit bunches (EFB) and excess fibers, and palm oil mill effluents (POME) in 2030 was predicted using a forecasting approach, with trend analysis as the tool of choice. From 2018 to 2020, the output of FFB, EFB and excess fibers, as well as POME grew by 16%, 14%, 23%, and 14% respectively. Based on trend analysis, the projection of FFB, CPO, EFB and excess fibers, and POME outputs in 2030 is expected to be 80%, 56%, 92%, and 56% respectively, which are greater than the figures recorded in 2020. The state of the palm oil industry in Malaysia was described in this study and also highlighted the potential of oil palm biomass in various industries and as a source of green energy. Oil palm biomass can be commercialized in a wide range of value-added products.

1. Introduction
Lignocellulose fibers have a great potential for use as important raw materials in a developing country such as Malaysia with high agricultural production. Oil palm is one of the most important crops grown in Malaysia, accounting for 34.56 %, followed by rubber (39.67 %), cocoa (6.75 percent), rice (12.68 %), and coconut (6.34 %). Oil palm is a high-yielding crop that produces one of the most affordable vegetable oils. Palm oil acts as a natural preservative, extending the shelf life of the product. Most of the products we used daily contain palm oil [1]. It is the most extensively traded vegetable oil globally, with 50 million tonnes produced every year. Since the 1970s, the Malaysian palm oil industry has thrived, with oil palm plantations spreading across rural and suburban areas. As of 2021, oil palm cultivation occupied 5.9 million hectares of land, producing around 19.86 million tonnes (MT) of palm oil and 2.32 MT of palm kernel oil [2].

The financial feasibility of palm oil is undeniable. Malaysia is one of the world's leading suppliers and exporters of palm oil, producing 8.4% of global oil and fat production and 19.1% of worldwide oil and fat export commerce [2]. Agriculture continues to be an important element of Malaysia's economy, with oil palm cultivation helping to revolutionize the sector. This development has a tremendous impact on the country's economic prosperity, increasing gross domestic product (GDP) and creating jobs to improve the economic well-being of the people [3]. The nation's export
revenues from palm oil and palm oil products totalled RM 72.8 billion in 2020 [2]. Aside from the excellent monetary returns, the receiving environment is a crucial factor to consider. Despite the visible advantages of such industrial growth, the Malaysian palm oil industry has encountered significant challenges as the environmental impact of palm oil monoculture has become more widely recognized.

The majority of the oil palm tree (90%) is perceived as biomass, in which palm oil constitutes only 10% of the total biomass [4]. Oil palm biomass refers to agricultural by-products produced by the oil palm industry during replanting, pruning, and milling operations. Oil palm trunks (OPT) and oil palm fronds (OPF) are formed at plantations during replanting and pruning. In contrast, oil palm shell (OPS), palm kernel shell (PKS), empty fruit bunch (EFB), and palm oil mill effluent (POME) are generated during the milling process at the oil palm processing mills [5].

The oil palm sector is often associated with the environment because it is a land-intensive industry. The annual total dry matter (TDM) production rate is around 55 tonnes per hectares of land [6]. It is frustrating to learn that a significant portion of oil palm biomass waste is either disposed of by burning or dumped into the fields, posing a severe environmental hazard. The generation of massive amounts of biomass waste has heightened concerns regarding the sustainability and environmental implications of oil palm cultivation and processing, notably in terms of biodiversity loss, degradation of rainforest, and air pollution [1].

Palm oil is derived from the fruit of oil palm tree, which grows in tropical climates. However, edible oil production has a severe impact on the environment, leading to deforestation and loss of wildlife habitat. Deforestation and palm oil production go hand in hand. Palm oil producers damage biodiverse ecosystems by cutting down trees in tropical rainforests to construct oil palm plantations. Deforestation is the main contributor to climate change, causing global warming. A large portion of land in Malaysia is covered in tropical peat soils. Carbon is sequestered in this nutrient-dense soil. When the trees are lost, a large amount of carbon is emitted into the atmosphere, contributing to global warming [4]. Besides that, animals inhabiting biodiverse regions where oil palm is cultivated are at risk. Animals lose their habitats as a result of deforestation. Orangutans, Sumatran tigers, Sumatran rhinoceros, clouded leopards, and sun bears are among the wildlife species endangered by deforestation. Furthermore, the massive volumes of pesticides and herbicides required to sustain the oil palm plantation pollute the watercourse nearby [7].

Malaysia generates a substantial amount of biomass waste as a prominent player in the palm oil industry, which presents a great potential for this biomass to be commercialized in a wide range of biomass-based products. Several studies have been performed to transform this widely available and sustainable biomass into value-added products with various applications to minimize the challenges caused by improper disposal [5]. Oil palm biomass fibers have been reported to have exceptional properties when compared to other fibers. As a result, they can be utilized as reinforcement fillers to assist enzyme immobilization matrices and renewable sources of materials for the production of value-added products, like pulp and paper, bio-composite, and hybrid composites in the paper and furniture industries. In addition, oil palm biomass waste can be utilized for harnessing biomass energy in an eco-friendly and commercially viable manner [8].

Boustead Plantations Berhad (BPB) is one of Malaysia's most well-established upstream oil palm plantation companies with decades of experience. BPB is a subsidiary of Boustead Holdings Berhad (BHB), one of the oldest and biggest diversified conglomerates in Malaysia. Supported by BHB's involvement in the plantation sector, BPB has more than 50 years of experience managing oil palm plantation estate. BPB and its subsidiaries and associates managed the Group's plantation activities. They are primarily involved in the ownership and management of oil palm plantations, cultivation of oil palm and harvesting its fresh fruit bunches (FFB), and the processing and selling of crude palm oil (CPO) and palm kernel oil (PKO).

Boustead saw a 34.78% year-on-year increase to RM167.06 million in 2020 from RM123.95 million in the previous year, mainly due to higher pricing of palm goods, which boosted sales of CPO and PKO around the world [9]. BPB owns and manages 48 oil palm plantation estates in Malaysia, with 19 in Peninsular Malaysia, 20 in Sabah, and 9 in Sarawak. They also operate ten palm oil mills, with three in Peninsular Malaysia, five in Sabah, and two in Sarawak. One of its subsidiaries is...
Boustead Rimba Nilai Sdn Bhd, which manages the group estates and mill on the East Coast of Malaysia. This review study was carried out on three oil palm plantation estates managed by Boustead Rimba Nilai Sdn Bhd using FFB processing data from 2018 to 2020.

Given the rising global demand for biomass, an overview of Malaysia's palm biomass industry is required to assess the country's biomass utilization potential. In addition to incorporating Malaysia into the current global trade pattern, the growth of Malaysia's palm biomass industry positions the country better for potential market challenges. Based on this notion, this review study aims to assess the potential of waste resulting from oil palm plantations and palm oil processing industries and provide information on the opportunity to utilize them further.

2. Data Collection and Analysis Techniques

This study relied on secondary data. The study was conducted using the information collected from the Sg Jernih Business Unit of Boustead Rimba Nilai Sdn Bhd. Three oil palm plantations located on the East Coast of Malaysia have participated. The oil palm plantations include Sg Jernih Estate (SJE), Bebar Estate (BBE), and Ladang Tabung Tentera Terengganu Estate (LTTE). Among the participating estates, SJE is the only one with a palm oil mill, known as Sg Jernih Palm Oil Mill (SJPOM). Since the estates are close to each other and there are no other mills nearby, BBE and LTTE supply their fresh fruit bunches (FFB) to the SJPOM. The location of the Boustead Plantations estates and mills in Peninsular Malaysia is depicted in Figure 1.

![Figure 1. Location of Boustead Plantations estates and mills in Peninsular Malaysia.](image-url)
The production and economic performances of SJPMO were investigated. As a result, the yield of FFB and FFB processed data was obtained from all participating estates from 2018 to 2020. The FFB data is critical for estimating the generation of oil palm by-products. The current condition and potential of oil palm production and the availability of oil palm waste were defined, explained, and characterized using descriptive analysis. The analysis was conducted using graphic and cross-tabulation techniques to provide explanations and detailed estimates, and statistical tools to process the data. The availability of fresh fruit bunches (FFB), crude palm oils (CPO), and oil palm wastes in 2030 was predicted using a forecasting approach, with trend analysis as the tool of choice. The data on the supply of FFB, CPO, and oil palm wastes in SJPMO from 2018 to 2020 was used to conduct the trend study.

2.1. Participating Estates
The study sites are located on the East Coast of Malaysia, where most of the existing plantations or estates involve oil palm cultivation. The oil palm plantations estates that participated in this study include Sg Jernih Estate (SJE), Bebar Estate (BBE), and Ladang Tabung Tentera Terengganu Estate (LTTTE).

Sg Jernih Estate (SJE) is situated along the Tun Razak Highway (Federal Route 12), which runs from Segamat in Johor to Kuantan in Pahang. The estate is located 1.5 kilometres southeast of the Pahang Peat Swamp Forest and 2.11 kilometres southwest of the Bukit Ibam Forest Reserve. Muadzam Sham is the closest town, which is about a 20-minute drive from the estate. The primary activities of the estate are oil palm cultivation (mature, young mature, replanting, and nursery). SJE is the only plantation with a palm oil mill located on the East Coast of Malaysia. The mill is known as Sg Jernih Palm Oil Mill (SJPOM), and it began operations in 1992. Therefore, the estate received a substantial supply of FFB from neighboring plantations such as BBE and LTTTE since it was the only one with mills. As of 2020, the mill has a processing capacity of 30 MT/h and consumes over 140,000 metric tonnes (MT) of FFB per year. The mill has two steam boilers that generate electricity from fiber and shell. POME is treated in eleven ponds (three of which are anaerobic) before being released and applied to plantation land within the SJE through channels and drains. The total land applications for the SJE comprise around 30 ha. At present, all of the EFB produced by the mill is applied directly to the estate. The electricity generated by the boiler was used for the mill operation, office, and housing complex of the SJPOM and the SJE. As of 2020, the mill produces approximately 32,000 MT of CPO, 119,000 MT of POME, and over 32,000 MT of EFB and excess fiber annually.

Ladang Tabung Tentera Terengganu Estate (LTTTE) is situated about 66 kilometres from Kuantan and 38 kilometres from Kemaman on the Jerangau-Jabo highway. Other plantations nearby include Felda Neram, Felda Sebarang Tayur Estate, Ketengah Perwira Estate, and Ladang Rakyat. The rivers of Sg Dadong and Sg Paloh flow along the estate's north and south borders, respectively, draining into Sg Kemaman and Sg Cherul. The estate generated 22,722.86 MT of FFB in the year 2010, which was all supplied to SJPOM. LTTTE is more hilly and undulating from a topographic perspective. Nonetheless, LTTTE introduced suitable agricultural practices such as vegetative ground cover maintenance, slope planting of Guatemala grass, proper frond stacking, and even gabion construction.

Bebar Estate (BBE) is situated approximately 65 kilometres from Gambang to Bandar Muadzam Shah on the left side of the Tun Razak Highway. The land is neighboring the Felda Merchong in the south, Lam Soon Estate in the north and northeast, Bukit Musuh State Land Forest in the mid-west, and Prosper Jawasa Estate in the east. Hutan Simpan Bukit Ibam marks the estate's northern boundary. A drain has been built through the estate, allowing surface water to flow from north to south and eventually into Sg Bebar. From 2005 to 2012, BBE is actively going through replanting. Ramets (tissue culture) and D x P seedlings were used in the plantings. Rhinoceros beetle damage on seedlings was common in the field, and pheromone traps were used to combat the problem. Both BBE and LTTTE supplies FFB to SJPOM.
3. Result and Discussion

3.1. Area coverage and Annual Production of FFB, CPO, and Oil Palm waste from 2018-2020

Oil palm plantations in the three estates (SJE, BBE, and LTTTE) remain constant from 2018 to 2020. Thus, the combined area for the three estates has been 6405.6 ha, with SJE accounting for 2571.6 ha, BBE for 2241.1 ha, and LTTT for 1592.9 ha. The plantation area for all estates is depicted in Figure 2.

Figure 2. Plantation Areas (2018-2020).

The oil palm industry generates a large amount of oil palm biomass waste in the field and at oil palm mills. The wastes from the mill comprised of empty fruit bunches (EFB), oil palm shell (OPS), palm kernel shell (PKS), and palm oil mill effluent (POME). In contrast, oil palm fronds (OPF) and oil palm trunks (OPT) are wastes generated during replanting activities after reaching their economic life spans. During replanting, the increase in oil palm plantations has resulted in large quantities of wastes, particularly OPT and OPF. Approximately 24% of OPF is obtained from every oil palm tree over the course of a year of FFB harvesting in the field. Besides that, OPT was accounted for 70% of the replanting activities. Meanwhile, EFB is thought to be 22% of the FFB, and OPS are projected to be 5.5% of the FFB. The mill produces 0.67 tonnes of POME for every ton of FFB processed [1]. Based on the data obtained from Boustead Rimba Nilai Sdn Bhd, the participating estates (SJE, BBE, and LTTTE) directly supply all of their harvested FFB to the SJPOM for the production of CPO. Table 1 depicts the cumulative amount of FFB, CPO, and oil palm waste production obtained from all three estates from 2018 to 2020.

Table 1. Total FFB, CPO and oil palm waste production in 2018-2020

| Year | FFB      | CPO      | Oil Palm Waste (EFB, Excess Fiber and etc.) | POME      |
|------|----------|----------|--------------------------------------------|----------|
| 2018 | 118,315.21 | 27,756.00 | 25,041.19                                   | 101,978.00 |
| 2019 | 124,268.55 | 29,152.00 | 28,106.48                                   | 101,681.00 |
| 2020 | 140,930.28 | 32,054.00 | 32,579.48                                   | 119,586.00 |
Based on Table 1, the amount of FFB received from the three estates increased rapidly from 2018 to 2020, rising from 118,315.21 MT in 2018 to 140,930.28 MT in 2020 representing a 16% growth in FFB output from 2018 to 2020. Besides that, crude palm oil (CPO) production grew 14% from 27,756.00 MT in 2018 to 32,054.00 MT in 2020, indicating an upward trend as shown in table 1. The increase was primarily attributed to an increase in the amount of FFB yielded per hectare as a result of improved management and agricultural inputs. The volume of waste, which includes EFB and excess fibers, rises by 23% from 25,041.19 MT in 2018 to 32,579.48 MT in 2020. However, the amount of POME generated decreased marginally from 101,978.00 MT in 2018 to 101,681.00 MT in 2019, before steadily increasing to 119,586.00 MT in 2020. Between 2018 and 2020, the amount of POME generated increased by about 14%.

3.2 Projection of FFB, CPO, and Oil Palm Waste Production in 2030
A forecasting approach was used with trend analysis as the method of choice to predict the growth trend of FFB, CPO, and oil palm wastes output in the coming years. The data collected on the supply of FFB, CPO, and oil palm wastes in SJPMO from 2018 to 2020 was used to conduct the trend study. This estimate was used to measure the potential production of FFB, CPO, and oil palm wastes in 2030. As of 2020, the total oil palm harvested area for the three participating estates is about 6405.6 ha. Likely, the cultivated area does not grow significantly in the immediate future. This is a rational assumption given that Malaysian governments are limiting the expansion of oil palm plantations due to the rising concerns on the environmental impacts such as tropical deforestation, biodiversity loss, air pollution, and water pollution. Table 1 shows that between 2018 and 2020, the FFB output grew by 16%. Therefore, based on the trend analysis, the first forecast is that the FFB production will increase steadily to 80% by considering a 16% growth for every two years until 2030. On the other hand, the CPO sees a 14% increase in yield from 2018 to 2020. Therefore, this rising trend can forecast CPO production in 2030, resulting in a 56% increase in output. Furthermore, if the growth of 23% every two years is assumed until 2030, the yield of EFB and excess fibers is projected to increase to around 92%. Finally, based on a 14% increase in volume from 2018 to 2020, the volume of POME generated in 2030 is expected to be 56% higher than the value recorded in 2020.

4. The Scenario of Oil Palm in Malaysia
Malaysia is a tropical country with hot and humid weather throughout the year. This climate promotes oil palm growth and, subsequently, increased the oil palm cultivation in Malaysia. Oil palm (Elaeis guineensis) was originally an African plant that has been extensively cultivated in semi-wild orchards in tropical Africa. Even though oil palm is historically an African crop, South East Asia currently produces most global palm oil. It was first introduced to the region of South East Asia in the early 19th century. The oil palm was initially introduced in Malaysia in 1870 as an ornamental plant for planting in the Botanical Gardens in Singapore.

The first commercial oil palm estate in Malaysia was created in 1917 at Tennamaran Estate in Selangor. In the late 1950s, there was a massive shift from rubber to oil palm due to government funding for crop diversification. The oil palm has been developed fast as the most important commodity crop in Malaysia since 1960 due to the rapid growth of planting areas [7]. There is a surge in replanting across the country in the 1990s. By 1999, the land used for the cultivation of oil palm was reported to have grown to 3.31 million hectares, with 62% of the total area in Peninsular Malaysia, while 28% and 10% are in Sabah and Sarawak [10]. Malaysia becomes the second-largest producer of palm oil in the world after Indonesia by the 2000s [7].

The seedlings for oil palm cultivation take about three months to germinate, after which they are cultivated in small plastic bags and kept in the so-called pre-nursery for a few months. They are then transplanted into larger plastic bags and nurtured in a nursery for several months before being planted in the field at around one year of age. The new enhanced crosses begin to blossom and bear their first bunches of fruit after less than a year of transplantation. Their leaves are taller than 2 meters in height and diameter at this age. In its early stages, the trunk grows at a rate of 35 to 75 cm per year and
produces alternate rows of leaves, depending on the gene. The number of leaves in oil palm crops increases from 30 to 40 every year at the age of 10-20 years, and the palm tree reaches a height of 7-13 meters. At the age of more than 20 years, the base of the old leaves covers the stem and starts to fall off. Growth and production had declined at this stage [1]. Leaf production decreased roughly 20 to 25 annually after that. Thus, the average economic lifespan of oil palm is between 25 years and 30 years [6].

Substantial growth in oil palm plantations started in the 1960s, with a peak in replanting in the 1990s. During replanting, the oil palm reaches heights of 7 to 13 meters and has a width of 45 to 65 cm, 1.5 meters above the soil's surface. Each frond of the mature oil palm has about 41 leaves. The re-plantation method yields approximately 8.36 million tons of dried biomass in 2000, comprising 7.02 million tons of trunk and 1.34 million tons of leaves [6]. The freshly cut tree trunk cannot be burnt in the plantation because of the high moisture content of roughly 70% fresh weight. Leaving the old trunk for natural decomposition impedes the replanting process and attracts insects, harming the new trees. It usually takes five to six years for the tree trunk to decompose [6]. Many crude palm oil mills harness the fiber and shell inside their low-pressure boilers, and the EFBs are either burned, causing air pollution, or sent to the plantation to decompose naturally.

Palm oil is dominant in the global economy, where palm oil is one of the seventeen main oils and fats on the international market. The oil palm fruit contains two different palm oils, such as crude palm oil (CPO) and palm kernel oil (PKO). CPO is extracted from mesocarp, whereas PKO is produced from seed or kernel. Palm oil is mainly utilized for the manufacture of margarine and compounds in cooking fats and oils and the manufacture of soap, cosmetics, candles, and detergents. The generation of PKO accounts for nearly 12% of its palm oil production [7]. The progress of the palm oil industry in Malaysia is the product of ideal weather, advanced technologies, and facilities for milling and processing, practical and good management skills, and research and development. The government of Malaysia is wholly committed to the industry's growth and supports the global expansion of palm oil production. As a result, palm oil is now readily embraced internationally, and palm oil has been exported to more than 140 countries in the world by Malaysia [1].

5. Waste Generation
The Malaysian palm oil industry has grown rapidly in the last decades. This growth has resulted in a rapid expansion of oil palm cultivation areas, as well as a rise in the number of operating palm oil mills. The oil palm industry generates a large amount of oil palm biomass waste in the field and at oil palm mills. Waste such as oil palm trunks (OPT) and oil palm fronds (OPF) are created during replanting and pruning at oil palm plantations after their economic life span has elapsed. In palm oil mills, converting fresh fruit bunch (FFB) into crude palm oil (CPO) has led to the production of high volumes of solid and liquid waste. The solid wastes from mills include empty fruit bunches (EFB), oil palm shells (OPS), and palm kernel shells (PKS). Meanwhile, the liquid waste is palm oil mill effluent (POME) [1,4].

For every kg of palm oil produced, about 4 kg of dry biomass is generated, with roughly a third of this represented by FFB derived wastes and the remaining two-thirds by trunk and frond material [11]. Oil palm trunk (OPT) is a solid waste that is abundantly available throughout the year. Huge volumes of OPT biomass wastes are collected during replanting, as trees that have outlived their useful lifespan are felled. It is considered the least expensive lignocellulosic raw material when compared to wood. In contrast, oil palm fronds (OPF) fibers are made up of varying sizes of vascular bundles. Vascular files are common in parenchymal tissue with a thin wall. Each bundle is composed of vessels, fibers, round gloves, phloem, and parenchyma tissue. The xylem and phloem tissues are easily distinguished, with the phloem separated into two distinct sections in each bundle [12].

Empty fruit bunches (EFB) are abundant as fibrous material of solely biological origin in a standard palm oil mill. EFB fibers are hard and solid multicellular fibers with a central section known as a lacuna that has porous surface morphology. The cross section of a fiber is a polygon with a compact bundle or vascular packet enclosed by dense cell layers. In monocytes, vascular fibers are normally covered by a few layers of thick cell walls, which provide tensile strength as well as side
compression force. EFB contains no chemical or mineral additives, and depending on how it is handled at the mill, it is free of foreign elements such as gravel, wood residues, nails, waste, and so on. 1 kg of wet EFB is generated for every kg of palm oil. Besides that, EFB contained high amount of water which is over 60% due to biological growth and steam sterilization at the plant [7].

On the other hand, liquid waste is formed by extracting palm oil from a wet process in a decanter. This liquid waste is combined with waste from cooling water and sterilizer to yield palm oil mill effluent (POME). POME is a highly polluting wastewater generated by palm oil milling operations. POME is a viscous brown liquid with fine suspended solids that has a pH range of 4 to 5. POME is also a liquid with high concentrations of organic acids and a COD level greater than 20,000 mg/L. The relatively high content of potassium, nitrogen, phosphorus caused POME to have strong malodor [1,7]. Before it can be released into the waterway, it must be treated properly and effectively. POME is considered as the highest volume of wastes produced in palm oil mill. The higher the amount of FFB used, the more POME produced. For every tons of processed FFB, a standard palm oil mill produces 600-700 kg of POME [5].

In addition, oil palm shells (OPS) is a waste product derived from palm oil mills. The shape of OPS aggregate differs based on the extraction process or breaking of the nut. The shape of OPS may be irregular, circular, angular, flaky, or polygonal. An OPS is also lightweight, with a relatively smooth shell surface texture [13]. Furthermore, the OPS are an organic aggregate with numerous pores and a high water absorption rate. A study demonstrated that water absorption for 24 hours was 23.30% with OPS aggregate sizes ranging from 14 to 5 mm, in comparison with water absorption for 24 hours was 0.76% with granite [14]. The shell fractions remaining after the nut has been extracted after crushing in the palm oil mill is known as palm kernel shells (PKS). Kernel shells are a fibrous material conveniently treated in bulk from the production line to the final application. Dust-like fractions and tiny fibers are combined with large and small shell fractions. PKS has a poor water absorption rate as compared to OPS, with water absorption rates ranging from 11% to 13% [15].

6. Potential of Oil Palm Waste
Over time, the number of palm oil mills in operation has increased. In 1990, only 261 mills with a gross production capacity of 42.8 million tonnes of fresh fruit bunch (FFB) were in the process each year. This has resulted in soil and groundwater contamination and the release of harmful gases leading to rapid environmental degradation. Palm oil mills generate considerable amounts of biomass waste and create a massive volume of waste [15]. The oil palm processing mills, on the other hand, contribute substantially to environmental deterioration on both the input and output sides of their operations. On the input side, crude palm oil (CPO) consumes vast amounts of water and electricity. In contrast, on the output side, processing practices accumulate large quantities of solid waste, wastewater, and air pollution. The solid wastes constitute mesocarp fruit fibers (MF), palm kernel shells (PKS), pressed fruit fibers (PPF), and empty fruit bunches (EFB). Liquid waste is formed by extracting palm oil from a wet process in a decanter. This liquid waste is combined with waste from cooling water and sterilizer to yield palm oil mill effluent (POME) [1].

However, due to biological growth and steam sterilization at the plant, EFB is saturated with water. Since EFB has a moisture content of about 67%, it must be pre-processed before being regarded as good fuel. EFB, in contrast to shells and fibers, are typically burned, creating air pollution, or returned to the plantations as mulch. EFB can be gathered easily and are available for use in all palm oil mills. Since fibers and shells are easier to handle and produce higher-quality fuels than EFB, it would be beneficial to use EFB for on-site energy demand while making fibers and shells available for off-site use generate more revenue than burning on-site [1].

Palm oil processing also produces Palm Oil Mill Effluent (POME), which is highly polluting wastewater. It is often disposed of in disposal ponds, resulting in contaminant leaching into groundwater and soil and the release of methane gas into the atmosphere. Instead, POME could be used to produce biogas via anaerobic digestion. Many palm oil mills have already implemented this method to meet water quality requirements for industrial effluent. The gas, on the other hand, is flared
off [5]. Anaerobic digestion is commonly used as a primary treatment for POME in the industry. Liquid effluents from palm oil mills, for example, can be transformed anaerobically into biogas, which can then be used to generate electricity through gas-fired engines or gas turbines [1]. During POME digestion, the odor emitted into the ambient air lowered the air quality in the surrounding lagoons [7].

Traditionally, mesocarp fiber is combined with kernel shells and used as a solid fuel to power the mill. Mulching sends the extra fiber and EFB to the plantation [15]. Typically, the fibers recovered from pressed palm fruits are burned as sources of energy for palm oil mills. Carotenoids, vitamin E, and sterols were present in abundance in the fibers as well [13]. Because of the high volume of free fatty acid and peroxide values, oil palm fibers are ideal for non-edible applications. Nutraceutical products can be made from minor components such as phospholipids, vitamin E, and carotenes [13].

Since PKS contains palm oil residues, it has a substantially higher heating advantage than traditional lignocellulosic biomass. PKS is a high-quality biomass fuel with a uniform size distribution, simple operation, easy crushing, and minimal biological activity due to reduced moisture content instead of other industry residues [13]. Palm oil mills' press fiber and shell have historically been used as a solid fuel for steam boilers. The steam generated is used to power turbines that generate electricity. These two solid fuels will produce more than enough energy to fulfil the energy requirements of a palm oil mill [1]. Optimization of the utilisation of oil palm wastes into the value-added products is highly essential to ensure the wastes are well managed and not left abundant in the plant estates. However, it is important to ensure that the selected treatment process is effective to ensure mass production of the respective value added products.

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References
[1] Liew WL, Muda K, Azraai M, Affam AC, Kheang S 2017 Agro-industrial waste sustainable management—a potential source of economic benefits to palm oil mills in Malaysia Journal of Urban and Environmental Engineering 11 108-118
[2] Malaysian Palm Oil Council (MPOC) 2021 About the Palm Oil Retrieved on 4 April 2021 http://mpoc.org.my/about-palm-oil/
[3] Aljuboori AH 2013 Oil palm biomass residue in Malaysia: availability and sustainability International Journal of biomass & renewables 2 13-18
[4] Kurnia JC, Jangam SV, Akhtar S, Sasmito AP, Mujumdar AS 2016 Advances in biofuel production from oil palm and palm oil processing wastes: a review Biofuel Research Journal 3 332-346
[5] Khalil HP, Amouzgar P, Jawaid M, Hassan A, Ahmad F, Hadiyana A, Dungani R 2012 New approach to oil palm trunk core lumber material properties enhancement via resin impregnation Journal of Biobased Materials and Bioenergy 6 299-308
[6] Lim KO 2017 The future energy potential of replanting wastes in Malaysia International Energy Journal 10 3-4
[7] Abdullah N, Sulaiman F 2013 The oil palm wastes in Malaysia Biomass now-sustainable growth and use 30 75-93
[8] Abdul Khalil, H P S, Bhat, A H, Jawaid, M, Amouzgar, P, Ridzuan, R, and Said, M R 2010 Agro wastes: Mechanical and physical properties of resin impregnated oil palm trunk core lumber Polymer Composites 31 638-644
[9] Khalid S 2021 Boustead Plantations reports higher productivity than higher palm oil prices Retrieved on 19 May 2021 https://www.theedgemarkets.com/article/boustead-plantations-reports-higher-palm-oil-product-prices.
[10] Hai TC, Ng A, Prudente C, Pang C, Yee JT 2001 Balancing the need for sustainable oil palm development and conservation: The Lower Kinabatangan floodplains experience In ISP
National Seminar 1 1-4

[11] Dungani R, Aditiawati P, Aprilia S, Yuniarti K, Karliati T, Suwandhi I, and Sumardi I 2018 Biomaterial from oil palm waste: properties, characterization and applications. Palm Oil 31 1-6

[12] 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 and bioenergy 35 3775-3786

[13] Abd Majid R, Mohammad AW, May CY 2012 Properties of residual palm pressed fiber oil Journal Oil Palm Residues 24 1310-1317

[14] Mannan MA, Ganapathy C 2002 Engineering properties of concrete with oil palm shell as coarse aggregate Journals of Construction and Building Materials 1 29-34

[15] Otti VI, Ifeanyichukwu HI, Nwaorum FC, Ogbuagu FU 2014 Sustainable oil palm waste management in engineering development Civil and Environmental Research 6 121-125