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# The Oil Palm Wastes in Malaysia

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/55302>

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## 1. Introduction

Oil palm is the most important product from Malaysia that has helped to change the scenario of its agriculture and economy. Lignocellulosic biomass which is produced from the oil palm industries include oil palm trunks (OPT), oil palm fronds (OPF), empty fruit bunches (EFB) and palm pressed fibres (PPF), palm shells and palm oil mill effluent palm (POME). However, the presence of these oil palm wastes has created a major disposal problem. The fundamental principles of waste management are to minimise and recycle the waste, recover the energy and finally dispose the waste. These principals apply to agro-industrial wastes such as palm oil residues as they do to municipal waste. We can simply no longer afford to dispose the residues when there is an economically useful alternative. We must first consider the current uses and disposal of mill residues in order to address the potential for recovery of energy in the palm oil industry. One of the unique aspects of Malaysian renewable energy sources is that the palm oil mill is self-sufficient in energy, using PPF, EFB and shell as fuel to generate steam in waste-fuel boilers for processing, and power-generation with steam turbines as described in Section 2.2.

World palm oil production in 1990 doubled to 11.0 million tonnes from 5.0 million tonnes in 1980, and by the year 2000, the production doubled to 21.8 million tonnes. Malaysia produced about half of the world palm oil production (10.8 million tonnes), thus, making Malaysia as world's largest producer and exporter of palm oil during this period [1]. In 2008, even though Malaysia had produced 17.7 million tonnes of palm oil based on 4,500,000 hectares of land used for its plantation, Indonesia became the world's largest producer and exporter of palm oil, replacing Malaysia as a chief producer [2,3] Palm oil has made impressive and sustained growth in the global market over the past four decades, and it is projected in the period 2016 – 2020, the average annual production of palm oil in Malaysia will reach 15.4 million tonnes [4]. In 1999, the land area under oil palm plantation is about 3.31 million hectares, and it has been projected that Sarawak will have about one million tonnes hectares of oil palm by the year 2010 [5].

The oil palm industry has always been linked to the environment because it is a land intensive industry. Any unplanned development will lead to the degradation of the forest systems, loss of habitats including plants and animals, extreme land degradation and pollution (water and airborne) due to the use of large quantities of pesticides and herbicides required to maintain the plantation. The Roundtable for Sustainable Palm Oil (RSPO) was established in recent years with the support from the government and Malaysia Palm Oil Council (MPOC). RSPO consists of palm oil producers, processors, traders, consumer goods manufacturers, retailers and non-governmental organizations (NGOs), and they will develop the principles and criteria of a sustainable palm oil industry, and facilitate the development of sustainable palm oil production. The proposed guidelines include commitment to transparency, compliance with all applicable local, national and ratified international regulations, adoption of sustainable cultivation practices (including water management, pesticide control and soil erosion), conservation of resources and biodiversity and community development [6]. The oil palm industry has long avoided the openings of virgin forest land, which thus minimize environment degradation and enhance the sustainability of oil palm growing. As initiatives, the Ministry of Plantation Industries and Commodities (MPIC) had announced in 2006, the RM20 million Malaysian Palm Oil Conservation Fund (MPOCF) with aims to help protect affected wildlife (including orang utan and other protected species) and to sustain biodiversity conservation programmes that are expected to be beneficial to both the industry and society.

Oil palm is the most important product of Malaysia that has helped to change the scenario of its agriculture and economy. Despite the obvious benefits, oil palm mill also significantly contributes to environmental degradation, both at the input and the output sides of its activities. On the input side, crude palm oil mills use large quantities of water and energy in the production processes, and on the output side, manufacturing processes generate large quantities of solid waste, wastewater and air pollution. The solid wastes may consist of empty fruit bunches (EFB), mesocarp fruit fibers (MF) and palm kernel shells (PKS). The liquid waste is generated from an extraction of palm oil of a wet process in a decanter. This liquid waste combined with the wastes from cooling water and sterilizer is called palm oil mill effluent (POME). During POME digestion, odor released into surrounding air, thus, reduces air quality in the surrounding lagoons area. Disposal of EFB into oil palm plantation without recovering remnant oil in the EFB contributes to oil spills. Incineration of EFB means wasting renewable energy source and heat which actually could be provided for boiler in palm oil mill. At present, PKS and MF wastes are used extensively as fuel for steam production in palm-oil mills. EFB is a resource which has huge potential to be used for power generation, currently not being utilized. The application of shells for road hardening has no impact to the environment, however, current practice is actually wasting potential renewable energy source. Methane gas is one among other green house gases which can cause ozone depletion. However, at present, methane in biogas generates during POME digestion is not being utilized or captured and it just escapes into the atmosphere. Palm oil mill residues are currently underutilised; therefore, maximizing energy recovery from the wastes is desirable for both economic and environmental reasons.

All economic activity begins with physical materials and energy carriers such as fuels and electric power. Without materials, there might be no food and shelter technology; without energy, there might be no work, thus, no economic activity. The reliable sustainable resource is important to fulfill the need of energy. Oil palm waste is a reliable resource because of its availability, continuity and capacity for renewable energy solution. Furthermore, in current situation the presence of oil palm wastes has created a major disposal problem, thus, affect the environmental. The technological, economic, energy balance, and environmental considerations must be kept at a balance to meet the best solution of utilization oil palm wastes. There is abundance of raw materials available of the palm tree consisting of around 90% of biomass wastes and only around 10% of oil. About 90 million tonnes of oil palm fruit production was recorded in 1998; however, 43-45% of this was mill residues in the form of EFB, shell and fibre. Palm fronds and stems are currently underutilised, and the presence of these oil palm wastes has created a major disposal problem. Therefore, maximising energy recovery from the wastes is desirable for both the environmental and economic reasons. Direct combustion, gasification, pyrolysis, liquefaction, fermentation and anaerobic digestion are alternate conversion technologies available to maximise energy recovery. Therefore, sustainable development can be promoted by encouraging energy projects for the long term, utilising local skills and creating employment.

## 2. Oil palm industry

Traditionally the oil palm (*Elaeis guineensis*) was grown in semi-wild groves in tropical Africa. It was first introduced to Malaysia for planting in the Botanical Gardens in Singapore in 1870 [7]. Germination takes around 3 months, after which the seedlings are planted in small plastic bags where they are left in a so-called pre-nursery for several months. They are transplanted into bigger plastic bags and grow in a nursery for several more months to a size of about 1 meter, before they are transplanted into a field at an age of around 1 year.

The new improved crosses begin to flower after less than one year of transplantation and produce their first bunches of fruit after less than 2 years. At this age, their leaves have a size of over 2 meters in height and diameter. During its young age, the trunk grows at a rate of about 35 to 75 cm per year and produces alternate rows of leaves, depending on its gene [8]. The base of the old leaves surround the stem and begin falling off at the age of 12 to 15 years [9]. By this time, growth and production have slowed down.

The number of leaves in an oil palm plant increase from 30 to 40 in a year at the age of 5 to 6 years. After that, the generation of leaves decreases to about 20 to 25 per year [9]. The average economic life-span of the oil palm is 25 years to 30 years [10]. A marked increase in the cultivation of oil palm began in 1960 [11], for which by the year 1990 onwards there was a peak in replanting. This provided a good opportunity to harness the by-products of the oil palm. During the re-plantation, the heights of the oil palm tree are in the range of 7 m to 13 m, with a width of between 45 cm to 65 cm, measuring 1.5 m from the surface of the soil. There are about 41 leaves in each frond of the mature oil palm tree. It is estimated that in the

year 2000, the process of re-plantation would generate about 8.36 million tonnes dried biomass, consisting of 7.02 million tonnes of trunk and 1.34 million tonnes of leaves [5]. Due to the high moisture of about 70% fresh weight, the newly chopped tree trunk cannot be burnt in the plantation. To leave the old trunk for natural decomposition not only obstructs the re-plantation process but harbours insects that would harm the new trees as well. The tree trunk usually takes between five to six years to decompose [12].

Most crude palm oil mills harness the energy from the fibre and shell in their own low pressure boilers and normally, the EFB's are burnt causing air pollution or returned to the plantation. A 60 tonnes of fresh fruit bunches (FFB) per hour mill based within a 10,000 hectare plantation, can generate enough energy to be self sustaining and supply surplus electricity to the grid if it utilises all of its wastes. In order to provide a better understanding of the palm oil industry in Malaysia, the following sections give an overview of the oil palm industry in Malaysia including oil palm plantation and the mass balance of the oil palm industry as it is self-sufficient in energy.

## **2.1. Malaysian palm oil scenario**

The first commercial oil palm estate in Malaysia was set up in 1917 at Tennamaran estate, Selangor. Palm oil is one of the seventeen major oils and fats in the world market. The government encouraged crop diversification from rubber to oil palm in the late 1950s. The area utilised for oil palm plantations in Malaysia has increased to 3.31 million hectares by the year 1999; where 62% of the total area is located in Peninsular Malaysia while Sabah and Sarawak 28% and 10%, respectively [4].

The oil palm fruit produces two distinct oils which are palm oil and palm kernel oil. Palm oil is obtained from the mesocarp while palm kernel oil is obtained from the seed or kernel. Palm oil is used mainly for the production of margarine and compounds in cooking fats and oils and also for the production of candles, detergents, soap and cosmetic products. Production of palm kernel oil is about 12% of the production of its palm oil.

The success of the Malaysian palm oil industry is the result of the ideal climatic conditions, efficient milling and refining technologies and facilities, research and development, and efficient and adequate management skills. Practically all palm oil mills generate their own heat and power through the co-generation system [13]. The Malaysian government is fully committed to the expansion of the industry and encourages global expansion of palm oil production. Palm oil is now readily accepted globally and Malaysia has exported palm oil to more than 140 countries in the world.

Most palm oil is currently produced in South East Asia, even though the oil palm is originally an African crop, which was introduced to South East Asia in the 19th century. The two largest producers are Malaysia and Indonesia, who together account for roughly 85% of the world palm oil production [14]. In 2004 Malaysian production exceeded Indonesian production. However, the US Department of Agriculture notes that mature palm area in Indonesia is being expanded from 5 to 8 million hectares, which should easily overtake

Malaysia in the near future [15]. There are plans for expansion of palm area in South America [16] and Africa [17], both of which in principle offer large tracts of suitable tropical land. Compared to the potential expansion, however, these plans are embryonic and current production is low and largely for domestic consumption.

Palm oil and related products represented the second largest export of Malaysia in the first nine months of 2005, after electronics, but just ahead of crude oil [18]. In 2005, Malaysian palm oil production is projected to reach approximately 15 million tonnes (301,000 barrels per day), which is very close to the actual value of 14.96 million metric tonnes recorded by Malaysian Palm Oil Board (MPOB) [19,20]. By comparison, Malaysian petroleum production in 2004 is estimated at 43 million tonnes (855,000 barrels per day), of which 16 million tonnes (321,000 barrels per day) were exported. Domestic petroleum demand of 26 million tonnes represented 44% of the total energy demand of 60 million tonnes of oil equivalent [21].

The total oil palm planted area in Malaysia increased by 2.8% to 4.17 million hectares in 2006. The area expansion occurred mainly in Sabah and Sarawak with a combined growth of 4.5% compared to 1.6% in Peninsular Malaysia [22]. Sabah remained the largest oil palm planted state with 1.24 million hectares or 30% of the total planted area. Table 2.2 shows the oil palm planted areas by state in Malaysia for 2005 until 2008 (in hectares) [22,23].

State	2005	2006	2007	2008
Johor	667,872	671,425	670,641	na
Kedah	75,472	76,329	75,096	na
Kelantan	89,886	94,542	99,763	na
Melaka	52,015	52,232	49,113	na
N.Sembilan	155,164	161,072	170,843	na
Pahang	606,821	623,290	641,452	na
Perak	340,959	348,000	350,983	na
Perlis	278	258	260	na
P.Pinang	14,074	14,119	13,304	na
Selangor	132,100	128,915	129,315	na
Terengganu	163,967	164,065	161,287	na
<b>Peninsular Malaysia</b>	<b>2,298,608</b>	<b>2,334,247</b>	<b>2,362,057</b>	-
Sabah	1,209,368	1,239,497	1,278,244	na
Sarawak	543,398	591,471	664,612	na
<b>Sabah &amp; Sarawak</b>	<b>1,752,766</b>	<b>1,830,968</b>	<b>1,942,856</b>	-
<b>Malaysia</b>	<b>4,051,374</b>	<b>4,165,215</b>	<b>4,304,913</b>	<b>4,487,957</b>

**Table 1.** Oil Palm Planted Area 2005 - 2008 (Hectares) [22,23]

The production of crude palm oil increased by a further 6.1% to 15.9 million tonnes in 2006 from 15.0 million tonnes the previous year as shown in Figure 2.3. Figure 2.4 shows that the increase was mainly attributed to the expansion in matured areas by 2.0% and rise in the average fresh fruit bunches yield per hectare by 3.8% to 19.6 tonnes due to better management and agricultural inputs. Figure 2.4 also shows that the oil yield per hectare

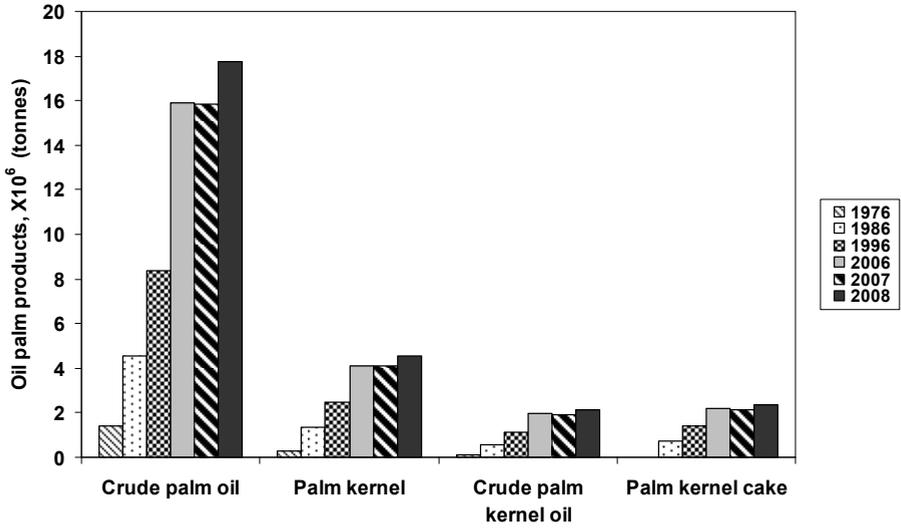


Figure 1. Production of Palm Oil Products every Ten Years from 1976 – 2006, 2007 and 2008 [18,23]

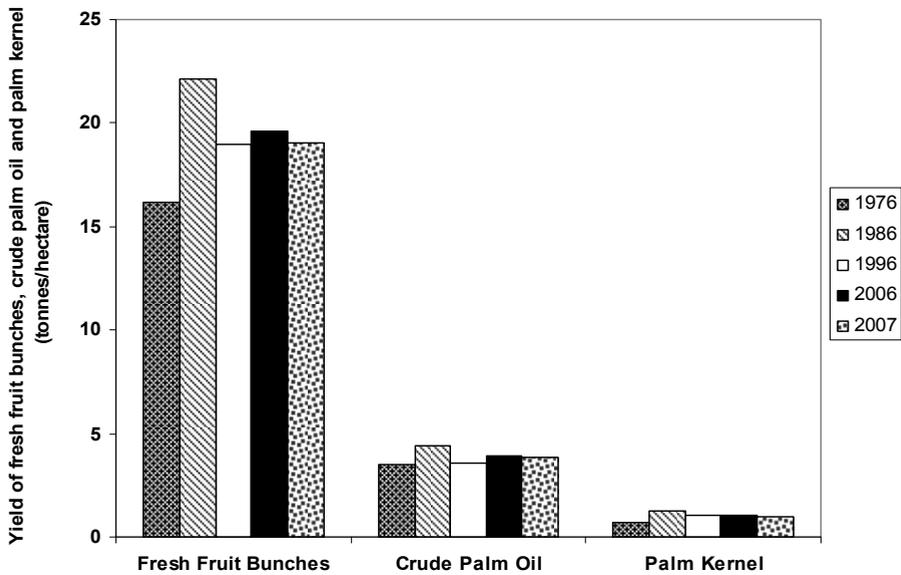
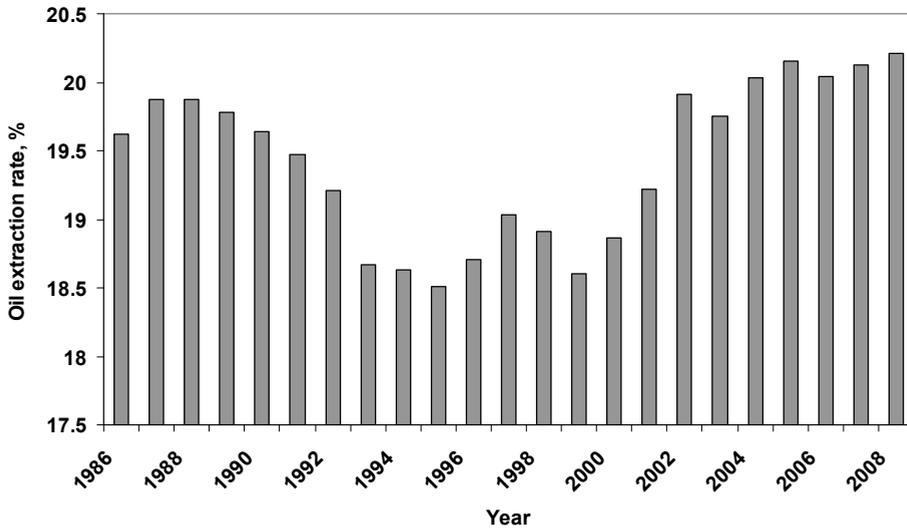


Figure 2. Yield of Fresh Fruit Bunches, Crude Palm Oil and Palm Kernel every Ten Years from 1976 – 2006 and 2007 [18].



**Figure 3.** Annual Oil Extraction Rate (OER) for 1986-2008 (%) [22,23]

had increased by 3.4% to 3.9 tonnes, despite the oil extraction rate (OER) declining marginally by 0.5% to 20.04% as shown in Figure 2.5. The decrease in OER in the years 1993 to 2001 which is significant is due to the global recession accounting for a lower demand of export market. However, despite a weak global economy, there is a significant recovery in 2002 as the government implemented prudent policies to assist the Malaysian oil palm industry. These include the expansion of oil palm in matured areas and the campaign on improved productivity in the oil palm industry, coupled with providing competitive prices of oil palm, liberalization of export duties and the encouragement of counter-trades for higher exports [24]. Crude palm kernel oil production rose by 6.1% to 1.96 million tonnes in tandem with a 4.1% growth in palm kernel production as shown in Figure 2.3 [18,23].

The rapid expansion of oil palm cultivation has raised concerns about the sustainability and environmental impact of oil palm plantations, in particular with regard to biodiversity, destruction of old growth rainforest and air pollution [25,26]. To illustrate the potential impact, it is worthy to reflect on the fact that with a palm oil yield of 4 tonnes per hectare tropical forest of roughly the size of the United States would be required to satisfy current world crude oil demand. Increased yields are one avenue for reducing the area imprint for oil palm plantations. It is estimated, based on fundamental factors and actual yields achieved on experimental plots that yields as high as approximately 10 tonnes per hectare may eventually be achievable [27]. At these yields, current world oil demand could be met on roughly 4 million square kilometres, which is 40% of the area of the United States, or over half the land mass of Brazil.

## 2.2. The mass balance of the oil palm industry

The palm oil mill is self-sufficient in energy, using waste fibre and shell as fuel to generate steam in waste-fuel boilers for processing, and power-generation with steam turbines. As an example, The Federal Land Development Authority (FELDA) palm oil mill in Sungai Tinggi, Selangor, Malaysia, employs the standard oil extracting process [28]. In the standard milling process, used in the factories with a milling capacity of over 10 tonnes of raw material per hour, water is added into a digester [29]. More than 19.7 million tonnes FFB were processed in 2000 [28]. The standard sized mills processing 60 tonnes/hour of fruit bunches normally produce 40 tonnes/hour of steam. Part of the steam is used to generate 800 kW of electricity and the rest is used as process steam. It is estimated that the total generating capacity of the mills is about 200 MW [28]. Typically palm oil mills use fibre and shell as a boiler fuel to produce process steam for sterilisation, etc and also possibly for electricity generation to supply electricity for other parts of the mill complex. These oil palm wastes make oil palm mills self sustainable in energy. The shell and fibre alone can supply more than enough energy to meet the mill's requirements using low pressure relatively inefficient boilers. The EFB have traditionally been burnt in simple incinerators, as a means of disposal and the ash recycled onto the plantation as fertiliser. However, this process causes air pollution and has now been banned in Malaysia, furthermore, under this route of disposal, no energy is recovered. Alternatively EFB can be composted and returned to the plantation, or returned directly as mulch. Figure 2.1 shows a proposed plan for the operational process and product of the palm oil industry if EFB is used as fuel beside palm shell and fibre.

Referring to Figure 2.1, as the fresh fruit bunches reach the processing plant, the sterilisation process begins with the steam temperature at 140°C, pressure at 2.5 to 3.2 kg/cm<sup>2</sup> for 50 minutes [28]. After this process, the stripping process will take over. In the stripping process, a rotating divesting machine is used to separate the sterilized oil palm fruit from the sterilized bunch stalks. The empty fruit bunches (EFB) will fall in the collector and are brought to the burning place as a fuel. After the bunches have been stripped, the sterilised fruits are fed into a digester where water at 80°C is added. This is performed in steam-heated vessels with stirring arms, known as digesters or kettles. The most usual method of extracting oil from the digested palm fruit is by pressing. The type of press used in this palm oil is the screw type press.

The crude oil extracted from the digested palm fruit by pressing contains varying amounts of water, together with impurities consisting of vegetable matter, some of which is dissolved in the water. Centrifugal and vacuum driers are used to further purify the oil before pumping it into a storage tank. When the digested fruit is pressed to extract the oil, a cake made up of nuts and fibre is produced. The composition of this cake varies considerably, being dependent on the type of fruit. The cake is given a preliminary breaking treatment before being fed into the nut/fibre separator called depericarper. When the fibre has been separated from the nuts, the latter can then be prepared for cracking. Any uncracked nuts must be removed and recycled and the shell separated from the kernels. The waste fibre and shell are also transported to the burning place as a fuel. The kernels are packed and sold to kernel oil mills.

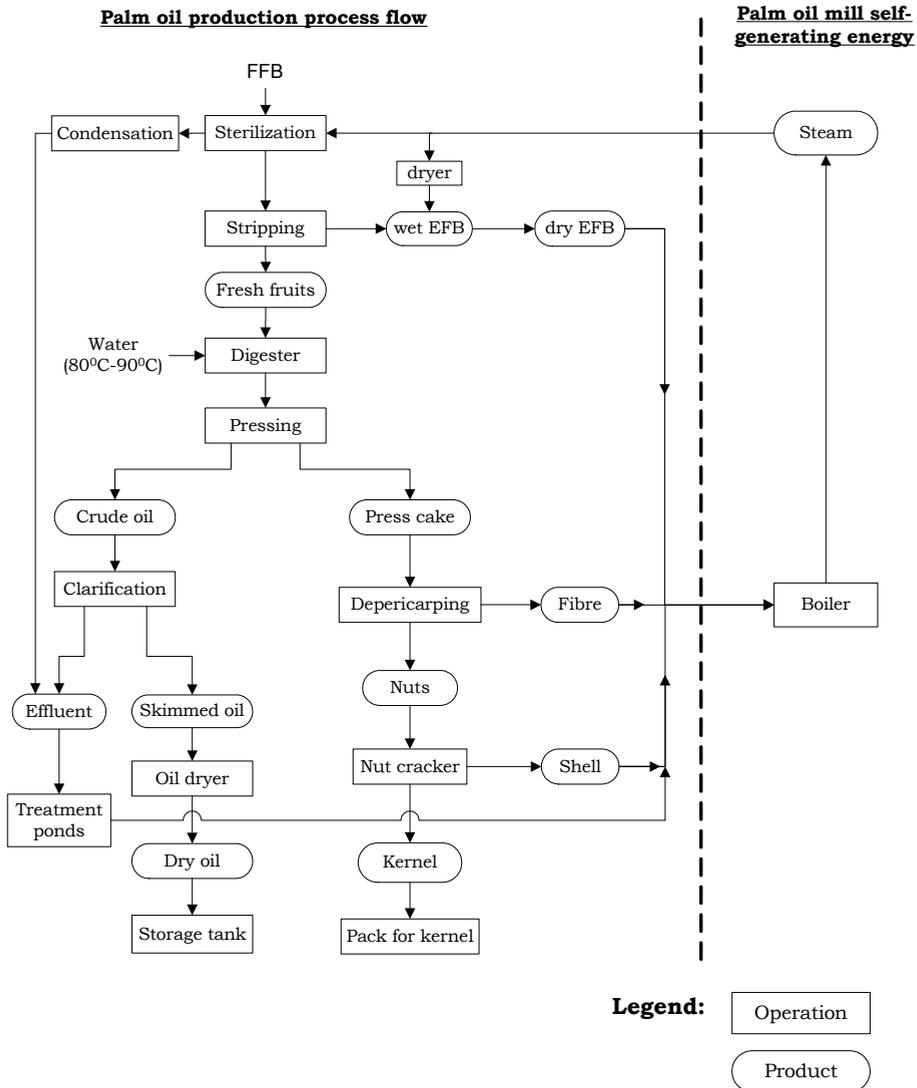
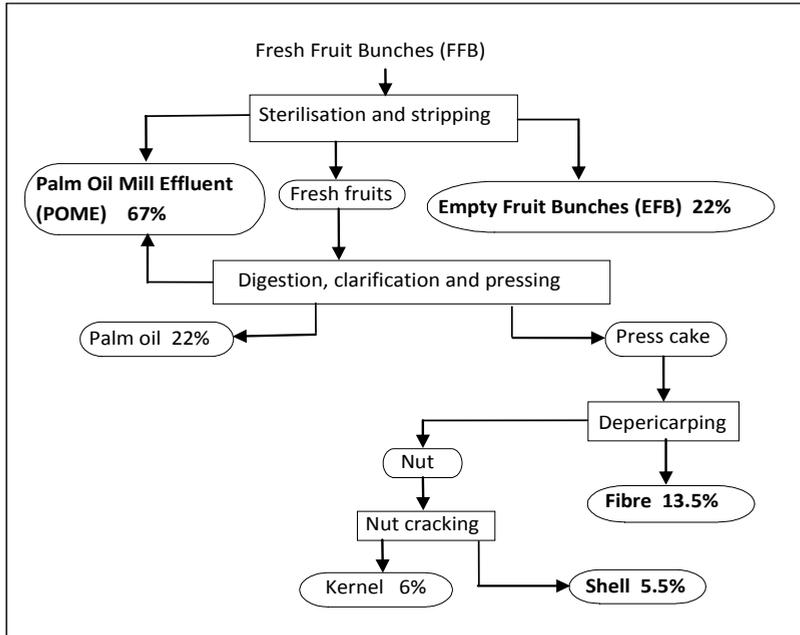


Figure 4. Proposed plan for operation of a Palm Oil Mill (adapted from [28])

Palm oil mills in Malaysia typically meet most of their electricity and process steam requirements by burning some of the wastes, with energy for start-up generally being provided by back-up diesel [13,28,30]. Not all of the wastes are burnt. For each kg of palm oil, electricity consumption is around 0.075-0.1 kWh and steam demand around 2.5 kg. This represents a steam to electricity ratio of around 20 to 1 and could be met by burning 0.3-0.4 kg of waste. As the boiler efficiency is only around 70%, actual consumption is correspondingly higher [31]. Little effort was made in the past to optimise process steam

consumption or boiler or turbine efficiency, as the fuel was substantially treated as a waste that was incinerated to be disposed of. The electricity co-generated in Malaysian palm oil mills therefore only amounts to roughly 1-1.5 billion kWh or less than 2% of 2003 generation of over 82 billion kWh. To illustrate the kinds of waste available, the process flow of a palm oil mill is summarised in Figure 2.2 (simplified from [28]) and a typical product stream distribution is shown in Table 2.1 (adapted from [30]). The total product stream distribution in oil palm mills is greater than 100% in wet basis as extra water is added during the process, for example during sterilization with steam. Most of this water ends up in POME.



Note: main waste streams in bold, all percentages on wet FFB basis

**Figure 5.** Simplified process flow diagram of an oil palm mill

As can be seen in Table 2.1, the moisture content of fresh EFB is very high. Typically it is over 60% on a wet EFB basis. Consequently, it is a poor fuel without drying and presents considerable emissions problem that its burning is discouraged by the Malaysian government. Palm oil mills therefore typically use shell and the drier part of the fibre product stream, rather than EFB, to fuel their boilers [31]. Palm Oil Mill Effluent (POME) is so wet that it is usually treated by anaerobic digestion before the discharge of the effluents [32].

For each kg of palm oil, roughly a kg of wet EFB is produced. As over 60% of the wet EFB consists of water, and the heating value of the dry EFB is roughly half that of palm oil, the energy obtainable from the EFB product stream amounts to roughly 0.2 kg of oil equivalent per kg of palm oil. Based on Malaysia's 2005 palm oil production of 15 million tonnes, the

energy value of the EFB waste is therefore around 3 million tonnes of oil equivalent, which would amount to \$1.2 billion for an assumed \$400 per tonne (\$55 per barrel).

	Wet FFB basis		Dry FFB basis	
	(tonnes per hectare)	% FFB	(tonnes per hectare)	% FFB
FFB	20.08	100	10.6	100
Palm oil	4.42	22.0	4.42	41.7
Palm kernel	1.20	6.0	1.20	11.4
EFB	4.42	22.0	1.55	14.6
POME	13.45	67.0	0.67	6.3
Shell	1.10	5.5	1.10	10.4
Fibre	2.71	13.5	1.63	15.4
Total	27.3	136.0	10.6	99.8

**Table 2.** Typical product stream distribution in oil palm mills [30]

As mentioned before, most crude palm oil mills harness the energy from the fibre and shell in steam boilers. However, the introduction of advanced cogeneration (combined heat and power) also can play a role in combatting climate change, as well as introducing significant economic benefits. Through cogeneration, the costs of energy will be cut because it uses fuels at high conversion efficiencies can reduce the emissions of carbon dioxide and other pollutants. However, it is only worth doing if one can sell the additional surplus energy (electricity) to customers at an economical rate. Today, the ability to sell electricity into the local grid provides an opportunity to turn waste into a valuable commodity.

### 2.3. Options for the disposal of oil palm wastes

The total land area in Malaysia amounts to 32.90 million hectares. According to Hoi and Koh [32], the major agricultural crops grown in Malaysia are rubber (39.67 %), oil palm (34.56 %), rice (12.68 %), cocoa (6.75 %) and coconut (6.34 %) which indicated that major production of the agricultural sector had been rubber derived products including wood residues, however, by 1995 oil palm products became more significant [34].

Lignocellulosic biomass which is produced from the oil palm industries include oil palm trunks (OPT), empty fruit bunches (EFB), fronds, palm pressed fibres (PPF) and shells. Table 2.3 shows the breakdown of wastes from palm oil production in 2007 [35].

Wastes	Quantity (ktonnes)
Fronds	46,837
Empty fruit bunches (EFB)	18,022
Palm pressed fibres (PPF)	11,059
Oil palm trunks (OPT)	10,827
Shell	4,506

**Table 3.** Wastes from palm oil production [35]

One of the major characteristics of the forestry and agricultural sector is the production of large quantities of processing residues that have no economic value other than energy generation. Their presence in recent years has created a major disposal problem due to the fact that open burning is being discouraged by the Department of Environment in Malaysia. Other than biomass from the plantations, the palm oil industry also produces other types of waste in large quantities mainly EFB, PPF, shell and palm oil mill effluent (POME). Table 2.4 shows the breakdown of product or waste from each bunch of fresh fruit (FFB) [36].

Products/Wastes	Percentage by weight to FFB (dry basis)
Palm oil	21
Palm kernel	7
Fibre	15
Shell	6
Empty fruit bunches	23
POME	28
Total	100

**Table 4.** Products/wastes from each bunch of FFB [36]

The EFB are usually air dried until the moisture content reaches about 40% when it is ready to be used as fuel in the palm oil processing plant [37]. The burnt waste is then used as fertiliser in plantations [38]. Other than that, EFB were also used in the plantations as a mulch, thus, can reduce the applied fertiliser cost and is a step towards environmental conservation by reducing dependence on fossil fuel required for the manufacture of inorganic fertilizer [39]. It is claimed that using the EFB as mulch has several advantages for the nutritional sustainability of the plantation. Some plantation owners claimed that the benefits of EFB as a fertiliser and as a soil conditioning agent are significant, because it releases nutrients slowly to the soil via microorganisms therefore effectively recycling the plant nutrients. It improves the soil structure due to better aeration, increases the water holding capacity and increases the soil pH, whilst other mill owners welcomed alternative methods of disposal. This is due to the inconvenience of handling and transporting, as well as the costs and problems concerning disposal of the waste on the plantation. However, open burning is no longer allowed by the authority because this process causes air pollution and by this means of disposal no energy is recovered [40].

Oil-palm fronds have been successfully used as a substitute for tropical grasses by ruminant producers in Malaysia [41]. Nowadays, the PPF is usually burnt in the palm oil processing plant as fuel and the excess is disposed of in the plantations [42]. The PPF are burnt in a boiler with some palm shells to produce the power for running the mill (self-sufficient). The boilers used are normally of grate-type beds which are manufactured locally [13]. Most of the crude palm oil mills harness the energy from the shell and fibre in their own low-pressure boilers and normally the oil palm trunk would be left to decompose naturally at the plantation [37]. This practice not only disturbs the process of plantation due to the low decomposition rate, it also encourages the spread of diseases and insects like *rhinoceros beetles*

and *ganoderma* that are harmful to the plantation [37]. Moreover, most of the plantations have to adopt the push-felling technique and trunk-shredding which leads to burning [43].

The utilization and generation of oil palm biomass is widely accepted and offers benefits for rural areas related to employment, rural infrastructure, the conservation of cultivated areas and hence the attractiveness of rural regions. The new markets for Malaysia can be developed, especially for developing countries, where oil palm biomass has a higher contribution to the overall energy supply. Also the establishment of an industry related to 'oil palm biomass for energy' technology could be supported.

### 3. Utilization of oil palm wastes

Another route to obtain more energy from oil palm plantations is the more efficient use of oil palm biomass other than the palm oil. There are no detailed statistics for oil palm dry matter production. Such statistics are only compiled for palm oil, palm kernel and fresh fruit bunches (FFB). Rough extrapolations, however, can be made based on estimates of the ratio of palm oil to other dry matter. For each kg of palm oil roughly another 4 kg of dry biomass are produced; approximately a third of which is found in FFB derived wastes and the other two thirds is represented by trunk and frond material [27,30,44]. On an energy basis, the palm oil represents roughly a third of the biomass yield, as it has roughly twice the heating value of the other oil palm dry matter, which therefore amounts to approximately 2 kg on a palm oil equivalent basis. Based on 2005 production, around 30 million metric tonnes of oil equivalent of non palm oil dry biomass matter were available for energy production from Malaysian palm oil plantations, or in other words approximately half of 2004 total primary energy demand. Only a small fraction of this potential was used, and that vary inefficiently. Open burning is still too common and responsible for substantial air pollution problems in South East Asia, indicating that other solutions urgently need to be found. Some of the biomass is used for mulching and as fertiliser, though this use is limited by labour and logistical limitations and concerns about encouraging oil palm pests [45].

Generally, oil palm mills generate a numbers of oil palm wastes. The oil palm wastes contribute about RM6379 million of energy annually [46]. However, there is much to be done to optimise the utilization of oil palm wastes for cogeneration in Malaysia. Various studies conducted in Malaysia have indicated that the used of biomass as a source of energy is one of the most promising ways of effectively using the residues. Some of the commercial projects and research activities are include treatment of palm oil mill effluent [47,48], pyrolysis of oil palm shell [49], chars from oil palm waste [50], solid biofuels from biowastes [51], briquetting of palm fibre and shell [36], palm oil effluent as a source of bioenergy [52] ethanol fermentation from oil palm trunk [53] and converting oil palm trunks and cocoa wood to liquid fuels [37]. In the following sections, potential uses of oil palm wastes are presented.

#### 3.1. Potential uses of Pome

POME is the effluent from the final stages of palm oil production in the mill. It is a colloidal suspension containing 95-96% water, 0.6-0.7% oil and 4-5% total solids including 2-4%

suspended solids [54]. Most palm oil mills and refineries have their own treatment systems for POME, which due to its high organic content is easily amenable to biodegradation. The treatment system usually consists of anaerobic and aerobic ponds. However, because of silting and short circuiting many do not reach discharge standards to water courses. This situation can be significantly improved by introducing enclosed anaerobic digestion systems which reduce the biological oxygen demand (BOD) of the effluent and capture methane, one of the more potent greenhouse gases. The energy in the methane can then be recovered, either as a supplementary boiler fuel, or in a biogas engine generator. For each tonne of crude palm oil (CPO) produced, about an average of 0.9-1.5m<sup>3</sup> POME is generated. The biological oxygen demand (BOD), chemical oxygen demand, oil and grease, total solids and suspended solids of POME ranges from 25000 to 35000 mg/L, 53630 mg/L, 8370 mg/L, 43635 mg/L and 19020 mg/L respectively [55]. Therefore, this had created environmental problem because the palm oil mill industry in Malaysia produces the largest pollution load into the rivers throughout the country [56]. However, POME contains high concentrations of protein, nitrogenous compounds, carbohydrate, lipids and minerals that could be converted into useful material using microbial process [57,58]. As example, bio-gas can be produced by processing POME through anaerobic treating system. Anaerobic digestion is a series of processes in which microorganism break down biodegradable material in the absence of oxygen. About 400m<sup>3</sup> of bio-gas produced from 100 tonnes of POME, of which this amount of POME had been released during processing of 20 tonnes of fresh fruit bunches [59-61].

Currently, fertilizers is also derived from POME and used in the farms and vegetation areas [62]. It is also found that the gas composition contained hydrogen (66-68%) and carbon dioxide (32-34%) that can be produced from POME using anaerobic micro flora and this generated gas is free from methane [63]. At present, a renewable energy power plant developer in Malaysia, known as Bumibiopower is in the progress of setting up a plant from methane extraction and power generation using POME near Pantai Remis at the west coast of Peninsular Malaysia. A closed anaerobic system is installed to produce and collect consistently high quality of methane-rich biogas from POME. The installation of a generator of size between 1 and 1.5 MW is also included in this project [64].

### **3.2. Potential uses of bio oil derived from oil palm wastes**

Bio-oil is a renewable, which is produced from biomass through a process known as fast pyrolysis. Fast pyrolysis represents a potential route to upgrade the biomass to value added fuels and renewable chemicals. There is an urgent need to develop a sustainable energy supply as the impact of burning fossil fuels on our climate is becoming ever more obvious and the availability of fossil fuels is decreasing. Bio-oil contributes to the reduction of greenhouse gas emissions and it offers several advantages, as it is easy to use, to store, and to transport. Bio-oil that can be extracted from dried biomass including dried oil palm wastes is currently under investigation as a substitute for petroleum [65]. Bio-oil contains fragments of cellulose, hemicelluloses, lignin, and extractives and they are typically brown liquids with a pungent odor. For woody feedstocks, temperatures around 500°C together with short vapour residence times are used to obtain bio-oil yields of around 70%, and char

and gas yields of around 15% each [66]. Bio-oil is a high density oxygenated liquid, which can be burned in diesel engines, turbines or boilers, though further work is still required to demonstrate long term reliability [67]. It is also used for the production of speciality chemicals, currently mainly flavourings. Renewable resins and slow release fertilisers are other potential applications, which have been the subject of research [68]. At this stage, fast pyrolysis is a novel and relatively untested technology. There are several pilot plants in North America and Europe, but no consistent track record yet outside of the manufacture of flavourings.

To date, fast pyrolysis of biomass has received very limited attention by researchers in Malaysia. Normally, fibre and shells are burnt in the palm oil processing plants to generate fuel to produce power for running the mill (self-sufficient) [13,69]. So far, research involving fast pyrolysis has been carried out by Universiti Teknologi Malaysia and Universiti Malaya on oil palm shell, rubber waste and rice husk waste, scrapped tyres and tubes [70-74]. One of the authors of this book and the research group from MPOB investigated on the fast pyrolysis of empty fruit bunches (EFB) [75,76].

The utilisation of bio-oil derived from pyrolysis process of oil palm wastes to substitute for synthetic phenol and formaldehyde in phenol formaldehyde resins is possible. Phenol can be used to manufacture moulding products for automotive parts, household appliances, and electrical components; in bonding and adhesive resins for laminating, plywood, protective coating, insulation materials, abrasive coating; in foundry industries for sand moulds and cores. However, producing resins from bio-oil has received very limited attention by researchers in Malaysia and still in research stage. A group of researchers from Universiti Teknologi Malaysia had studied the extraction of phenol from oil palm shell bio-oil [77]. They found that the quantity of phenol in the extracted oil was 24.2 wt% of total extracted oil.

In 2005, with the co-operation between Malaysian based Genting Sanyen Bhd and BTG Biomass Technology Group BV from The Netherlands, the first commercial bio-oil plant has already started production in Malaysia on a scale of 2 t/hr [78,79]. The main achievements of this project are more than 1,000 tonnes of bio-oil have been produced, the bio-oil is co-fired, replacing conventional diesel in a waste disposal system located 300 km from site, maximum capacity of the plant so far is about 1.7 t/hr on a daily continuous basis, the bio-oil quality can be controlled by the operating conditions, the drying of EFB to 5 wt.% moisture is possible using the excess heat from the pyrolysis process, the energy recovered from the process can be used effectively for drying the wet EFB, and potentially to generate the electricity required. Indeed, this is a breakthrough step in Malaysia for the utilisation of oil palm wastes as a source of bio-oil [80].

### **3.3. Potential uses of dry residues from oil palm wastes**

The main products produced by the palm oil mills are crude palm oil and palm kernels. However, it also produces huge quantities of residues such as fibre, shell and empty fruit bunches as shown in Figure 2.2. Dry residues from oil palm wastes can be utilised to

produce various types of products. EFB had been studied to convert into paper-making pulp by the researches from MPOB because EFB can be categorized as fibrous crop residues known as lignocellulosic residues. The high number of fibres/unit weight indicates the paper from EFB would have good printing properties and a good formation within paper making. EFB could produce thin, high quality printing paper, speciality papers for example for cigarette and photographic papers and security papers. The total chlorine-free methods had been used to bleach the pulp for producing paper [59,81]. Products such as paper and pulp that are obtained by processing the oil palm wastes can be used in many ways such as cigarette paper and bond papers for writing [82]. Normally, the excess shell are used to cover the surface of the roads in the plantation area.

Various types of wood such as saw-wood and ply-wood or lumber had been produced from oil palm trunk. Oil palm trunks have been chipped and waxed with resin to produce pre formed desk tops and chair seats for schools. The furniture is characterised for resistance against knocks, scratches, ink, termites and fungus. The ply-wood or lumber can be utilised as core in producing blackboard. The saw-wood is used for furniture but it is not suitable as building material due to its low specific density. It was found that the strength of the ply-wood made from oil palm trunk was comparable with the commercial ply-wood. The particle board with chemical binders also can be produced from oil palm trunk. Some of the oil palm trunks are mixed with EFB and palm fibres to be combusted to produce energy [81,83,84]. Besides this, the palm shell and palm fibres have been converted into briquettes in a study [36].

Medium density fibre-boards and blackboards can be produced from EFB and palm fibre [84,85]. Currently, the MDF industry has 14 plants with a total annual installed capacity of 2.9 million. The total export of MDF was RM1.2 billion in 2008. The industry has started utilising *acacia mangium* and mixed hardwood to produce MDF as alternatives to rubber wood. At present, Malaysia is the world's third largest exporter of MDF, after Germany and France. MDF from Malaysia has attained international standards such as British (BS), European (EN), Asia-Pacific: Japan Australia and New Zealand (JANS) standards [86]. High-density fiberboard (HDF), also called hardboard, is a type of fiberboard, which is an engineered wood product. It is similar to MDF, but is denser and much harder and stronger because it is made out of exploded wood fibers that have been highly compressed. Agro-Bio Fibre Sdn Bhd in Malaysia holds the patent for the EFB-based MDF over the last 10 years, has invested RM30 million to develop the technology to produce MDF and other products from the oil palm wastes. This company had signed a MoU with the Forest Research Institute of Malaysia (FRIM) to develop HDF used mainly for the production of floorboards that would use 100% EFB as its raw material [87].

Oil palm fibre is non-hazardous biodegradable material extracted from empty fruit bunch that are considered as waste after the extraction oil palm fruits. The fibres are clean, non-carcinogenic, and free from pesticides and soft parenchyma cells. Palm fibres are versatile and stable and can be processed into various dimensional grades to suit specific applications such as erosion control, mattress cushion production, soil stabilization, horticulture and landscaping, ceramic and brick manufacturing, paper production, acoustics control,

livestock care, compost, fertilizer and animal feed. Palm fibres can also be used as fillers in thermoplastics and thermoset composites which have wide applications in furniture and automobile components. Production of thermoplastic and thermostat composites has reached commercialization stage when PROTON (Malaysian national car maker) entered into agreement with PORIM (Palm Oil Research Institute of Malaysia) [88,89].

Similar to EFB, according to a study fronds from oil palm trees can be converted into pulp [90]. Oil palm fronds also can be processed as roughage source for ruminants such as cattle and goats [91]. A new product known as oil palm frond based ruminant pellet can be used as balanced diet for fattening beef cattle which is developed by the Malaysian Agricultural Research and Development Institute (MARDI) [91].

Oil palm ash (OPA) can be utilised as an absorbent for removing pollutant gases such as nitrogen oxide and sulphur oxide. The combustion of oil palm fibre and shell as boiler fuel to generate steam in palm oil mill will produce OPA. It was found that OPA contains high amount of calcium, silica, potassium and alumina which can be utilised to synthesize active compounds to absorb the pollutant gases into absorbent [92,93]. The presence of some functional groups such as hydroxyl, lactone and carboxylic in oil palm shell have a high affinity towards metal ions. Thus, the charcoal derived from oil palm shell can be coated with chitosan to use as a remover of heavy metal especially chromium from wastewater industry; however, it is still at research stage [94].

Processing the oil palm wastes such as EFB, fibre, shell and palm kernel cake into a uniform and solid fuel through briquetting process will be an attractive option. Palm kernel cake is a by-product of crushing and expelling oil from palm kernel. Briquetting is a process of compacting loose material to form a homogeneous and densified product. The material can be densified into briquettes at high temperature and pressure using screw of extrusion techniques either with or without binder addition. Oil palm briquettes are often favoured for household and industrial heating unit operation such as boiler because of their enhanced physical properties, as well as being easy to handle and feed. According to a study, the equilibrium moisture content for the briquettes made of palm fibre and palm shell is about 12 mf wt.% [36]. It was found that briquettes made from 100% pulverised EFB exhibited good burning properties. It is recommended to blend with sawdust in order to produce better quality briquettes from EFB and palm kernel cake [95]. Oil palm briquettes can be used as fuel in producing steam, district heating and electricity generation for larger commercial scale. The local sawdust briquettes or charcoal briquettes are rarely used in the local market because it could not compete with the availability of cheap fuels such as charcoal and wood which are widely used in the rural areas and restaurants [96]. Therefore, the products are exported for oversea markets [97].

One of the promising technologies which utilise the oil palm wastes or plant matter involves the production of carbon molecular sieve (CMS) from lignocellulosic materials. Production of CMS from oil palm wastes which are cheap and abundant carbon source will enhance the economical feasibility of adsorption process. A CMS is a material containing tiny pores of a precise and uniform size that is used as an adsorbent for gases and liquids, and normally it

is used to separate nitrogen from the other gases contained in air. A survey of literature indicated that palm shell have been used the most as the substrate for CMS production by many researcher in Malaysia [97-101]. Basically, there are three steps involve to prepare the CMS from oil palm wastes which are carbonisation of the wastes, activation of the chars produced and pore modification of the activated carbons to obtain CMS. Activated carbon is produced from carbonaceous source materials such as nutshells, oil palm wastes, peat, wood, coir and lignite. Activated carbon also called activated charcoal is a form of carbon that has been processed to make it extremely porous and have a very large surface area, thus available for adsorption or chemical reactions. Activated carbon can be produced by either physical reactivation or chemical activation. In physical reactivation, the precursor is developed into activated carbons using gases by carbonization and/or oxidation process. For chemical activation, prior to carbonization, the raw material is impregnated with certain chemicals such acid, base or salt [102]. According to a study, the optimum conditions for preparing activated carbon from EFB for adsorption of 2,4,6-TCP were found as follows : activation temperature of 814°C, CO<sub>2</sub> activation time of 1.9h and IR of 2.8, which resulted in 168.89 mg/g of 2,4,6-TCP uptake and 17.96% of activated carbon yield [103].

Biochar is commonly defined as charred organic matter, produced to abate the enhanced greenhouse effect by sequestering carbon in soils and improve soil properties. Biochar is a stable carbon compound that can be kept in the ground for a long time, until thousands of years. Biochar is created when biomass is heated to temperatures between 300 and 1000°C, under low or zero oxygen concentrations. Universiti Putra Malaysia (UPM) with the collaboration of Nasmach Technology Sdn Bhd have successfully built a plant producing biochar from EFP and also the first large-scale biochar production plant in the region. They have constructed a carbonator - driven plant to produce the biochar from residue materials including the EFB about 20 tonnes daily [104].

Besides converting dried oil palm wastes into various value added products, it also have potential as a source of renewable energy. Utilization of oil palm wastes as a source of energy will bring other environmental benefit like reduction in CO<sub>2</sub> emissions. The greenhouse gases that are present in the atmosphere include water vapor, CO<sub>2</sub>, methane and ozone, and the increase of greenhouse gases primarily CO<sub>2</sub> is the major cause for global warming. Oil palm wastes such as fiber, shell and EFB can be used to produce steam for processing activities and for generating electricity [105]. At present, there are more than 300 palm oil mills operating with self-generated electricity from oil palm wastes. The electricity generated is for their internal consumption and also sufficient for surrounding remote areas [106].

A cement company in Malaysia had used palm shell as fuel in the boiler and they found they the emissions of CO<sub>2</sub> can be reduced by 366.26 thousand metric tonnes in the year 2006 alone [107]. Hence, the emission of CO<sub>2</sub> in Malaysia can be decreased significantly if all industries in Malaysia can replace or partially replace fossil fuel with oil palm wastes to generate energy without degrading the environment.

Hydrogen is a synthetic fuel, which can be obtained from fossil fuels, nuclear energy and renewable energy sources such as oil palm wastes. In almost any application replacing fossil

fuels, hydrogen may be used as fuel especially as feedstock for synthesis of clean transportation fuels or as a gaseous fuel for power generation [108,109]. Gasification is one of the technologies for producing hydrogen. Oil palm wastes such as EFB, fiber, shell, trunks and fronds can be used for gasification [109,110]. The benefits of using hydrogen as transportation fuel are higher engine efficiencies and zero emissions [111]. However, production of hydrogen from oil palm wastes is still at the early stage of research in Malaysia.

#### 4. Conclusions

Malaysia is one of the world's primary palm oil producers and has been taking steps to promote the use of renewable energy. The utilization of renewable energy resources, in particular oil palm wastes is strategically viable as it can contribute to the country's sustainability of energy supply while minimizing the negative impacts of energy generation on the environment. It will help the government to achieve its obligation to prolong the fossil fuel reserves. The efficient use of oil palm biomass other than the palm oil itself for food consumption is a promising route to obtain more energy from oil palm plantations. It will also solve the agriculture disposal problem in an environmental friendly manner while recovering energy and higher value chemicals for commercial applications like bio-fuel, coal replacement, building products and many others. The current principle adopted in Malaysia is a cost pass-through mechanism for electricity generation which is the same principle adopted for renewable power generation. This method would result in a small increase in the price of electricity paid by electricity consumers, but at the same time, the consumers may benefit from revenues derived from renewable energy generation. Although this effort pales in comparison to other countries which had become leaders in renewable energy growth, the acceptance of this form of renewable energy contribution calls for a paradigm shift among the people in the realm of sustainable energy. In general, the maturity of the country is marked by an acceptance of the need for the country to wean reliance on a depleting and environmentally damaging fuel source.

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#### Acknowledgement

The authors would like to acknowledge the three research grants provided by Universiti Sains Malaysia, Penang (1001/PFIZIK/814087, 304/PFIZIK/6310087, 304/PFIZIK/6310073) that has made this research possible.

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## 5. References

- [1] Yusof Basiron. Palm Oil and Its Global Supply and Demand Prospects. *Oil Palm Industry Economic Journal* 2002; 2:1, 1-10.
- [2] Malaysian Palm Oil Industry Performance 2008. *Global Oils & Fats Business Magazine* Vol.6 Issue 1 (Jan-March), 2009 Available on line at <<http://theoilpalm.org/wp-content/themes/oilpalm/pdf/GOFB%206-1%20Malaysian%20Palm%20Oil%20Industry%20Performance%202006.pdf>>, (accessed 25 June 2012).
- [3] World Growth Palm Oil Green Development Campaign: Palm Oil – The Sustainable Oil a Report by World Growth September 2009. Available on line at <[http://www.worldgrowth.org/assets/files/Palm\\_Oil.pdf](http://www.worldgrowth.org/assets/files/Palm_Oil.pdf)>, (accessed 25 June 2012).
- [4] Teoh Cheng Hai. Land Use and the Oil Palm Industry in Malaysia, A bridged report produced for the WWF Forest Information System Database under project MY 0057 – Policy Assessment of Malaysia Conservation Issues, Kinabatangan, November 2000.
- [5] Lim KO. The Future Energy Potential Of Replanting Oil Palm Tree In Malaysia. *Renewable Energy* 1986; 8: 76 – 85.
- [6] United Nations Development Programme. Malaysia Generating Renewable Energy from Oil Palm Wastes, UNDP, Kuala Lumpur. 2007.
- [7] Government of Malaysia. The Oil Palm in Malaysia. Report published by the Ministry of Agriculture and Cooperatives, Kuala Lumpur, Government of Malaysia. 1966.
- [8] Corley RHV, Hardon JJ, Wood BJ. *Developments in Crop Science 1, Oil Palm Research*, Amsterdam:New York:Elsevier Scientific Publishing Company. 1976.
- [9] Hartley CWS. *Oil Palm (Elaeis Guineensis Jacq.)* 2<sup>nd</sup> ed., London:Longman. 1977.
- [10] Lim KO, Zainal Alauddin ZA, Gulam Abdul Qadir, Abdullah MZ. Energy Productivity of Some Plantation Crops in Malaysian and the Status of Bio Energy Utilization. To appear in *Proceeding of WREC*. 1999.
- [11] Kamaruddin H, Abdul Halim H, Riazuan R, Mohd. Zain J. Improvement of Oil Palm Fronds CTM-Pulp Brightness-A Preliminary Study, in *Proceeding of Seminar on Oil Palm Trunks and Other Palmwood Utilization (Oil Palm Tree Utilization Committee of Malaysia)*, Kuala Lumpur, Malaysia. 1991.
- [12] Mohamad Husin, Abd. Halim Hj. Hassan, Ahmad Tarmizi Mohammed. Availability and Potential Utilisation of Oil Palm Trunks and Fronds up to the year 2000, PORIM occasional paper. 20, 1-7. 1986.
- [13] Noor, M.A., Ani, F.N. and Kannan, K.S. *Renewable Energy Scenario In Malaysia*, 2<sup>nd</sup> International Seminar on Renewable Energy for Poverty Alleviation at IEB, Dhaka, Bangladesh, 1999.
- [14] Foreign Agricultural Service, USDA, Oil Seeds Circular, Growing Industrial Use of Vegetable Oil Expected to Impact EU Oilseeds and Products Trade. October 2005.
- [15] USDA, Oil Crops Outlook, Indonesian Production and Exports of Palm Oil Are Expanding Rapidly. September 2005.
- [16] da Costa RC. Potential for Producing Bio-Fuel in the Amazon Deforested Areas. *Biomass and Bioenergy* 2004, 26:405-15.

- [17] Baryeh EA. Effects of Palm Oil Processing Parameters on Yield. *Journal of Food Engineering* 2001, 48:1-6.
- [18] Department of Statistics Malaysia, Malaysian External Trade Statistics, September 2005.
- [19] Foreign Agricultural Service, USDA, Oil Seeds Circular, Table 9. October 2005.
- [20] Review of Annual Production Of Oil Palm Products : 1975 - 2005. Malaysian Oil Palm Board (MPOB). <[http://econ.mpob.gov.my/economy/Production1\\_05.htm](http://econ.mpob.gov.my/economy/Production1_05.htm)>, (accessed 5 July 2009).
- [21] Energy Information Administration (EIA), US Department of Energy, Country Analysis Brief Malaysia, Update January 2005.
- [22] Review of the Malaysian Oil Palm Industry 2006. Malaysian Oil Palm Board (MPOB).
- [23] A Summary On The Performance if The Malaysian Oil Palm Industry .(2008). Report by Malaysian Oil Palm Board. <<http://econ.mpob.gov.my/economy/Performance-130109.html>>, (accessed 1 August 2009).
- [24] Overview of the Malaysian Oil Palm Industry. (2002). Report by Malaysian Oil Palm Board. <<http://econ.mpob.gov.my/review 2002.html>>, (accessed 6 May 2009).
- [25] Radzi Abas M. Oros DR, Simoneit BRT. Biomass Burning as The Main Source of Organic Aerosol Particulate Matter in Malaysia During Haze Episodes. *Chemosphere* 2004; 55:1089–95.
- [26] Basiron, Y. and Weng, C.K. The Oil Palm and Its Sustainability. *Journal of Oil Palm Research* 2004; 16, 1:1-10.
- [27] Wahid MB, Abdullah SNA, Henson IE. Oil Palm – Achievements and Potential. In: *New Directions for a Diverse Planet*, Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia. <[www.cropscience.org.au](http://www.cropsscience.org.au)>, (accessed 21 September 2009).
- [28] Mahlia TMI, Abdulmuin MZ, Alamsyah TMI, Mukhlis D. An Alternative Energy Source from Palm Waste Industry For Malaysia and Indonesia, *Energy Conversion and Management* 2001; 42, 2109 – 18.
- [29] Prasertsan, S. and Prasertsan, P. Biomass Residues from Palm Oil Mills in Thailand: An Overview on Quantity and Potential Usage, *Biomass and Bioenergy* 1996; 11, 5:387 – 95.
- [30] Yusoff S. Renewable Energy from Palm Oil - Innovation on Effective Utilization of Waste. *Journal of Cleaner Production* 2006; 14:87-93.
- [31] Husain Z, Zainal ZA, Abdullah MZ. Analysis of Biomass-Residue-Based Cogeneration System in Palm Oil Mills. *Biomass and Bioenergy* 2003; 24:117–24.
- [32] Ahmad AL, Ismail S, Bhatia S. Water Recycling from Palm Oil Mill Effluent (POME) using Membrane Technology. *Desalination* 2003; 157:87-95.
- [33] Hoi Why Kong, Koh Mok Poh. Newsletter of Wood and Non-Wood Products Utilization Branch (FOPW) of the FAO Forest Products Division, Issue No 9 December 2001. <<http://www.fao.org/DOCREP/003/y3198E/y3198e00.htm>> (accessed 19 September 2002).
- [34] Kong HY. Current status of biomass utilization in Malaysia. *Forest Research Institute Malaysia*; 2000. p. 1–15.

- [35] Goh CS, Tan KT, Lee KT, Bhatia S. Bio-Ethanol From Lignocellulose: Status, Perspectives and Challenges in Malaysia. *Bioresource Technology* 2010;101(July (13)):4834–41.
- [36] Hussain Z, Zainac Z, Abdullah Z. () 'Briquetting of Palm Fibre and Shell from The Processing of Palm Nuts to Palm Oil. *Biomass and Bioenergy* 2002; 22, 6:505-509.
- [37] Yeoh HH. The Potential Of Producing Liquid Fuel From Oil Palm Wastes. M.Sc. thesis. Universiti Sains Malaysia, Penang, Malaysia; 1999.
- [38] Lim B. The New Straits Times 2000. Thursday, December 28, 2000.
- [39] Hamdan AB, Tarmizi AM, Mohad D, Tayeb. Empty Fruit Bunch Mulching and Nitrogen Fertilizer Amendment: The Result Effect On Oil Palm Performance And Soil Properties, *PORIM Bulletin* 1998, Palm Oil Reserch Institute of Malaysia.
- [40] Zain AZ, Koh Mok Poh, Mohd. Yusoff MN, Khoo Kean Choon, Mohd. Nasir N. Commercial Utilization of Oil Palm Empty Fruit Bunches, in *Processing of the Third National Seminar on Utilisation of Oil Palm Tree and Other Palms*, Forest Research Institute Malaysia, Kuala Lumpur; 1994.
- [41] Abu Hassan O, Ishida M. Status of Utilization of Selected Fibrous Crop Residues and Animal Performance with Emphasis on Processing of Oil Palm Fronds (OPF) For Ruminant Feed in Malaysia. *Tropical Agriculture Research Center TARS No.25*. Ministry of Agriculture, Forestry and Fisheries, Tsukuba, Japan; 1992.
- [42] Takigawa A, Oshio S, Mohd. Jaafar Daud, Abu Hassan Osman. Processing and Utilization of Palm By-product for Ruminant, *MARDI-TARC Collaborative Study*; 1990.
- [43] Khozirah Shaari, Khoo Kean Choon () Introduction. In Khozirah Shaari, Khoo K.C, Abdul Razak Mohd. Ali (eds.) *Oil Palm Stem Utilisation 1991: Review of Research*, FRIM Research Pamphlet No. 107, Kepong, Forest Research Institute Malaysia; 1991.
- [44] Husin M, Ramli R, Mokhtar A, Hassan WHW, Hassan K, Mamat R, Aziz AA. Research and Development of Oil Palm Biomass Utilization in Wood-based Industries. *Palm Oil Developments* 2002, 36:1-5.
- [45] Menon, N.R., Rahman, Z.A. and Bakar, N.A. Empty Fruit Bunches Evaluation: Mulch in Plantation vs. Fuel for Electricity Generation. *Oil Palm Industry Economic Journal* 2003; 3(2):15-20.
- [46] Jaafar MZ, Kheng WH, Kamaruddin N. Greener Energy Solutions for A Sustainable Future: Issues and Challenges for Malaysia, *Energy Policy* 2003; 31(11):1061-72.
- [47] Fakhru'l-Razi A, Noor MJMM. Treatment of Palm Oil Mill Effluent (POME) with the Membrane Anaerobic System (MAS), *Water Science and Technology* 1999; 39, 10-11:159-63.
- [48] Chin KK, Lee SW, Mohammad HH. A Study of Palm Oil Mill Effluent Treatment Using a Pond System, *Water Science and Treatment* 1996; 34, 11:119-23.
- [49] Ani FN, Islam MN. Liquid Oil from Fluidised Bed Pyrolysis of Rice Husk Waste and Its Characterisation, *RERIC International Energy Journal* 1998; 20, 1:55-65.
- [50] Lua AC, Guo J. Preparation And Characterisation of Chars from Oil Palm Waste, *Carbon* 1998; 36, 11:1663-70.

- [51] Lim KO. Production of Solid Biofuels from Biowastes, in Proceedings of The Second International Energy Conference, Kuala Lumpur, Energy from Biomass Residues, Forest Research Institute Malaysia; 1992.
- [52] Chew TY, Yeoh BG. Palm Oil Effluent As A Source of Bioenergy, in Proceedings National Symposium on Oil Palm By-Products for Agro-Based Industries, Kuala Lumpur; 1985.
- [53] Akmar PF, Elham P. Ethanol Fermentation from Oil Palm Trunk Hydrolyzate, in Oil Palm Trunk and Other Palmwood Utilization, Proceeding of a National Seminar, Kuala Lumpur, Malaysia; 1991
- [54] Mohammad AW, Yeong WT, Md Jahim J, Anuar, N. Palm Oil Mill Effluent (POME) Treatment and Bioresource Recovery Using Ultrafiltration Membrane: Effect of Pressure One Membrane Fouling, *Biochemical Engineering Journal* 2008; 35(3):309-17.
- [55] Ma AN. A Novel Treatment for Palm Oil Mill Effluent, *Palm Oil Research Institute of Malaysia (PORIM)* 1995; 29:201-12.
- [56] Hwang TK, Ong SM, Seow CC, Tan HK. Chemical Composition of Palm Oil Mill Effluent, *Planter* 1978;54:749-56.
- [57] Habib MAB, Yusoff FM, Phang SM, Ang KJ, Mohamed S. Nutritional Values of Chironomid Larvae Grown in Palm Oil Mill Effluent and Alga Culture. *Aquaculture* 1997; 158:95-105.
- [58] Agamuthu P, Tan EL. Digestion of Dried Palm Oil Mill Effluent by *Cellulomonas* Species. *Microbios Letters* 1985; 30: 109-13.
- [59] Gurmit S, Lim Kim H, Teo L, David Lee, K. Oil Palm and the Environment a Malaysian Perspective, *Malaysian Oil Palm Growers Council* 1999; vol.1, p. 253.
- [60] 'Palm biomass power plants in Malaysia'. Biopact article. Sunday, August 06, 2006. <<http://biopact.com>>, (accessed 23 September 2009).
- [61] 'The world's most productive ethanol crop is oil palm'. Biopact article. June 21<sup>st</sup>, 2006. <<http://biopact.com>>, (accessed 23 September 2009).
- [62] Esther OU. Anaerobic Digestion of Palm Oil Mill Effluent and Its Utilization as Fertilizer for Environmental Protection. *Renewable Energy* 1997; 10(213): 291-4.
- [63] Fakhru'l-Razi, Yassin AAA, Lyuke SE, Ngan MA, Morimoto M. Bio-hydrogen Synthesis from Wastewater by Anaerobic Fermentation Using Microflora. *International Journal of Green Energy* 2005; 2: 387-96.
- [64] 'Bumibiopower Methane Extraction and Power Generation'. Project report by Mitsubishi Securities Clean Energy Finance Committee. (January 2004). <[http://dnv.com/certification/.../PDD\\_BumibiopowerBiomass\\_2004-03-19.pdf](http://dnv.com/certification/.../PDD_BumibiopowerBiomass_2004-03-19.pdf)> (accessed 5 August 2009).
- [65] Wikipedia. The free encyclopedia: pyrolysis oil. <<http://en.wikipedia.org/wiki/Bio-oil>> (accessed 23 April 2011).
- [66] Bridgwater AV, Peacocke GVC. Fast Pyrolysis Processes for Biomass. *Sustainable and Renewable Energy Reviews* 2000; 4(1):1 – 73.
- [67] Chiaramonti D, Oasmaa A, Solantausta Y. Power Generation using Fast Pyrolysis Liquids from Biomass. *Renewable and Sustainable Energy Reviews* 2007; 11(6): 1056-86.

- [68] Bridgwater AV, Meier D, Radlein D. An Overview of Fast Pyrolysis of Biomass. *Organic Geochemistry* 1999; 30(12):1479-93.
- [69] 'Bumibiopower Biomass Power Plant Project Malaysia'. Project Design Document for Small-Scale SDM Activity, Version 02, March 2006.  
<[http://www.dnv.com/certification/climatechange/Upload/PDD\\_Bumibiopower%20Biomass\\_2004-03-19.pdf](http://www.dnv.com/certification/climatechange/Upload/PDD_Bumibiopower%20Biomass_2004-03-19.pdf)> (accessed 23 December 2007).
- [70] Nurul Islam M, Zailani R, Ani FN. Pyrolytic Oil from Fluidised Bed Pyrolysis of Oil Palm Shell and Its Characterisation, *Renewable Energy* 1999; 17, 1:73-84.
- [71] Kawser MDJ, Farid NA. Thermochemical Processing of Rubber Waste to Liquid Fuel, *Journal of Plastics, Rubber and Composites Processing and Applications* 2000; 29(2):100-4.
- [72] Ani FN, Islam MN. Liquid Oil from Fluidised Bed Pyrolysis of Rice Husk Waste and its Characterisation, *RERIC International Energy Journal* 1998; 20(1):55-65.
- [73] Ani FN, Islam MN. Pyrolytic Recycling of Agro-Industrial Solid Wastes in Malaysia. *Journal of the Institute of Energy* 1998; 71: 55-8.
- [74] Abnisa F, Wan Daud WMA, Husin WNW, Sahu JN. Utilisation Possibilities of Palm Shell as a Source Of Biomass Energy In Malaysia By Producing Bio-Oil In Pyrolysis Process. *Biomass and Bioenergy* 2011; 35:1863-72.
- [75] Abdullah N. An Assessment of Pyrolysis for Processing Empty Fruit Bunches. PhD thesis, Aston University, Birmingham, UK; 2005.
- [76] Sukiran MA, Chin CM, Abu Bakar NK. Bio-oils from Pyrolysis of Oil Palm Empty Fruit Bunches. *American Journal of Applied Sciences* 2009; 6(5): 869-75.
- [77] Kawser MDJ, Farid Nasir A. Oil Palm Shell as a Source of Phenol. *Journal of Oil Palm Research* 2000; 12(1): 86-94.
- [78] 'Genting Group Unveils Malaysia's First Commercially Produced Bio-oil Using Breakthrough Technology'. Report by Genting Group, Press Release, 21<sup>st</sup> August, 2005.
- [79] Venderbosch RH, Gansekoeloe E, Florijn JF, Assink D. Pyrolysis of Oil Palm Residue in Malaysia. BTG Biomass Technology Group BV, Ng HY, Genting Bio-oil BHD.  
<<http://www.pyne.co.uk/docs/PyNe%20Section1.pdf;2005>>, (accessed 3 April 2011).
- [80] BTG-BTL website. Biomass To Liquid:Pyrolysis Oil-The Sustainable Alternative.  
<<http://www.btg-btl.com/index2.php>> (accessed 2 April 2011).
- [81] Poster A. Malaysia Palm Oil Council. Palm Oil Industry- a Learning Experient. 2006.  
<<http://www.mpoc.org.y/>>, (accessed January 2009).
- [82] 'Long Term Benefit from Oil Palm Biomass'. Bernama, The Malaysian National News Agency. Press Release 16<sup>th</sup> August, 2001.
- [83] Husin M, Ramli R, Mokhtar A, Wan Hassan WH, Hassan K, Ropandi, M, Abdul Aziz A. Research and Development of Oil Palm Biomass in Wood Based Industries. *Malaysian Palm Oil Board Bulletin. Palm Oil Development* 36. 2005.
- [84] Sumanthi, S., Chai, S.P. and Mohamed, A.R. Utilization of Oil Palm as a Source of Renewable Energy in Malaysia. *Renewable and Sustainable Energy Reviews* 2008; 12(9): 2404-21.
- [85] Malaysian Timber Council (MTC). Kuala Lumpur, Malaysia (1992-2004).  
<<http://www.mtc.com.my/news/pr33.htm>>, (accessed 7 January 2009).

- [86] Wood Based Industry. Report by Malaysia Industrial Development Authority (MIDA). [http://www.mida.gov.my/en\\_v2/index.php?page=wood-based-industry](http://www.mida.gov.my/en_v2/index.php?page=wood-based-industry); (accessed 7 April 2011).
- [87] MIDA e-News: Agro-Bio Fibre expands production, ties up with FRIM on HDF. Report by Malaysia Industrial Development Authority (MIDA). [http://www.mida.gov.my/en\\_v2/index.php?mact=News,cntnt01,detail,0&cntnt01articl eid=234&cntnt01returnid=388](http://www.mida.gov.my/en_v2/index.php?mact=News,cntnt01,detail,0&cntnt01articl eid=234&cntnt01returnid=388); (accessed 7 April 2011).
- [88] Ministry of Plantation Industries and Commodities. Speech by Y.B. Dato' Seri Lim Keng Yaik in the Opening Ceremony of the Seminar on Oil Palm Biomass: Opportunities for Commercialization (2001). [www.kppk.gov.my/index .php?option=com\\_content&task=view&id=86&Itemid=46-53k](http://www.kppk.gov.my/index.php?option=com_content&task=view&id=86&Itemid=46-53k); (accessed 9 September 2009).
- [89] Shuit SH, Tan KT, Lee KT, Kamaruddin AH. Oil Palm Biomass as a Sustainable Energy Source: Malaysian Case Study, *Energy* 2009; 34(9): 1225-35.
- [90] Hassan OA, Ishida M, Shukri Mohd I, Tajuddin ZA. Oil Palm Fronds as a Roughage Feed Source For Ruminants in Malaysia FFTC for the Asia and Pacific Region 1994. <http://www.agnet.org/library/eb/420/;1994>; (accessed 6 September 2009).
- [91] 'Oil Palm Frond Based Ruminant Pellet'. (2008). Report by MARDI, <http://www.mardi.my/main.php?Content=home&FolderID=157&CurLocation=131>; (accessed 7 September 2009).
- [92] Zainudin NF, Lee KT, Kamaruddin AH, Bhatia S, Mohamed AR. Study of Adsorbent Prepared From Oil Palm Ash (OPA) for Flue Gas Desulphurization. *Separation and Purification Technology* 2005; 45:50-60.
- [93] Mohamed AR, Zainudin NF, Lee KT, Kamaruddin AH. Reactivity of Adsorbent Prepared From Oil Palm Ash (OPA) for Flue Gas Desulphurization : Effect of SO<sub>2</sub> Concentration and Reaction Temperature. *Studies in Surface Science and Catalysis* 2006; 159:449-52.
- [94] Nomanbhay SM, Palanisamy K. Removal of Heavy Metal from Industrial Wastewater Using Chitosan Coated Oil Palm Shell Charcoal. *Electronic Journal of Biotechnology* 2005; 8(April 15):44-53.
- [95] Nasrin AB, Ma AN, Choo YM, Mohamad S, Rohaya MH, Azali A, et al. Oil Palm Biomass as Potential Substitution Raw Materials for Commercial Biomass Briquettes Production. *American Journal of Applied Science* 2008; 5(3):179-83.
- [96] Hoi Why Kong. Wood and Charcoal Briquetting in Malaysia. In: *Proceedings of International Workshop on Biomass Briquetting*, (eds P.D.Grover and S.K Mishra). 1995. pp 68-74. FAO Regional Wood Energy Development Programme. 1995.
- [97] Ahmad M, Wan Daud W, Aroua M. Adsorption Kinetics of Various Gases In Carbon Molecular Sieves (CMS) Produced From Palm Shell. *Colloids and Surfaces A* 2008; 312:131-5.
- [98] Tan J. Ani F, Carbon Molecular Sieves Produced From Oil Palm Shell for Air Separation. *Separation and Purification Technology* 2004; 35: 47-54.
- [99] Ahmad M, Wan Daud W. Aroua M. Synthesis of Carbon Molecular Sieves from Palm Shell by Carbon Vapor Deposition. *Journal of Porous Matter* 2007; 14: 393-9.

- [100] Adinata D, Wan Daud W, Aroua M. Production of Carbon Molecular Sieves From Palm Shell Based Activated Carbon by Pore Sizes Modification With Benzene For Methane Selective Separation. *Fuel Process Technology* 2007; 88: 599-605.
- [101] Daud W, Ahmad M, Aroua M. Carbon Molecular Sieves from Palm Shell: Effect of the Benzene Deposition Times On Gas Separation Properties. *Separation and Purification Technology* 2007;57: 289-93.
- [102] Wikipedia. The free encyclopedia: Activated Carbon. <[http://en.wikipedia.org/wiki/Activated\\_carbon#cite\\_note-0](http://en.wikipedia.org/wiki/Activated_carbon#cite_note-0)>, (accessed 3 April 2011).
- [103] Hameed BH, Tan IAW, Ahmad AL. Preparation of Oil Palm Empty Fruit Bunch-Based Activated Carbon For Removal Of 2,4,6-Trichlorophenol: Optimization using Response Surface Methodology. *Journal of Hazardous Materials* 2009, 164; 2-3:1316-24.
- [104] Berita. Biochar Malaysia: UPM-NASMECH Effect of Producing EFB Biochar : World's First. 7 January 2010. <<http://biocharmalaysia.blogspot.com/2010/01/upm-nasmech-effort-of-producing-efb.html>>, (accessed 4 April 2011).
- [105] Keck Seng (M) Berhad. Biogas utilization. 2001. <[http://www.biogen.org.my/bris/BioGen/Tech/\(b\)Project/technology\(b\)2.pdf](http://www.biogen.org.my/bris/BioGen/Tech/(b)Project/technology(b)2.pdf)>, (accessed 4 April 2011).
- [106] Ludin NA, MBakri MA, Hashim M, Sawilla B, Menon NR, Mokhtar H. Palm Oil Biomass For Electricity Generation In Malaysia. Pusat Tenaga Malaysia, Malaysia Palm Oil Board, SIRIM Berhad. 2004. <[http://www.biogen.org.my/bris/BioGen/Tech/\(d\)Documents/technology\(d\)7.pdf](http://www.biogen.org.my/bris/BioGen/Tech/(d)Documents/technology(d)7.pdf)>, (accessed 5 April 2011).
- [107] Dit M. Palm Kernel Shell (PKS) Is More than Biomass for Alternative Fuel after 2005. Proceedings of Chemistry and Technology Conference. 2007. <[cdm.unfccc.int/Projects/DB/DNV-CUK1182238337.59/ReviewInitialComments/6MHGPZIM56119DT6NGL30G9OGNTIOK](http://cdm.unfccc.int/Projects/DB/DNV-CUK1182238337.59/ReviewInitialComments/6MHGPZIM56119DT6NGL30G9OGNTIOK)>, (accessed 3 April 2011).
- [108] Barbir F. Transition to Renewable Energy Systems with Hydrogen as an Energy Carrier. *Energy* 2009;34:308–12.
- [109] Azali A, Nasrin AB, Choo YM, Adam NM, Sapuan SM. Development of Gasification System Fuelled With Oil Palm Fibres and Shells. *American Journal of Applied Science* 2005:72–5.
- [110] Kelly-Yong TL, Lee KT, Mohamed AR, Bhatia S. Potential of Hydrogen From Oil Palm Biomass as a Source Of Renewable Energy Worldwide. *Energy Policy* 2007; 35:5692–701.
- [111] Neef HJ. International Overview of Hydrogen and Fuel Cell Research. *Energy* 2009; 34: 327–33.