NL Agency
Ministry of Economic Affairs, Agriculture and Innovation

Sustainable Biomass

Valorization of palm oil (mill) residues.

Identifying and solving the challenges

>> Focus on energy and climate change

Valorization of palm oil (mill) residues.

Identifying and solving the challenges

Colofon

Date	October 2013
Status	final

This study was carried out in the framework of the Netherlands Programmes Sustainable Biomass by

Name organisation	Wageningen UR, Food & Biobased Research
Contact person	Wolter Elbersen, Koen Meesters and Rob Bakker

Valorization of palm oil (mill) residues. Identifying and solving the challenges
October 2013.

Contact

Netherlands Programmes Sustainable Biomass

Drs. Sietske Boschma and Ir. Kees W. Kwant
NL Agency
NL Energy and Climate Change
Croeselaan 15, 3521 BJ Utrecht
P.O. Box 8242, 3503 RE Utrecht
The Netherlands
Email: Sietske Boschma@agentschapnl.nl
Phone: +31-88-6022458
www.agentschapNL.nl/biomass

Organisation 1

Wageningen UR, Food & Biobased Research
Food & Biobased Research
Bornse Weilanden 9.
6708 WG, Wageningen
The Netherlands
Tel:
E-mail: Wolter.elbersen@wur.nl
www.wageningenur.nl/fbr

Index

Summary and Outlook

This report explains in brief how the palm oil production system is set-up and how by-products of palm oil extraction (Empty Fruit Bunch (EFB), Mesocarp Fibre, Shells and Palm Oil Mill Effluent (POME)) are generated in the Palm oil Mill and what the composition of each stream is. We then show the options for improved energy efficiency and alternative uses for the by-products and additional income generation while reducing the GHG (greenhouse gas) emissions.

Figure A. Palm fruit is processed into oil and by-products (mesocarp) fibre, shell and POME (palm oil mill effluent).

Most current mills are set-up to use as much mesocarp fibre and palm shell as possible to generate steam for sterilization and electricity generation for the mill. Efficient use of energy and biomass fuel is generally not relevant as biomass is abundant and often considered a problematic waste. The empty fruit bunch (EFB) is the least useful for combustion and is therefore generally considered the most problematic waste product (see Figure B).

The demand for biomass to replace fossil fuels has increased worldwide due to increased cost of fossil fuels and climate change concerns. This has led to increased use of (agri)commodities as a fossil fuel replacement. In many cases this has become controversial, due to competition with food or other current uses (fibre, soil amendment, animal feed). As palm oil mill by-products are essentially underutilized this may not be a problem any time soon for palm mill by-products. And this may offer opportunities for improving the palm oil sustainability and generate additional income. This efficient use of mill residues should be one of the issues addressed in more detail by the RSPO, which is developing and implementing sustainability certification in the palm oil industry. We hope that efficient use of palm oil residues will also help to increase yields per hectare instead of expansion into virgin forest lands which is a very problematic sustainability issue for the whole palm oil industry.

Figure B. The Fresh fruit bunch (FFB) is harvested at the plantation and shipped to the mill for immediate processing. The empty fruit bunch (EFB) is the largest byproduct by volume produced at the mill. The EFB is often brought to the plantation to serve as mulch but may also have other applications

In this report we show that under current practice (based on an average productive plantation system) 2.5 tons dry weight per hectare per year of surplus mill residues are available (see summary in Table A). Most of this biomass consist of EFB (1.88 tons dry weight) and shells (0.61 ton dry weight). If the energy efficiency of the mill is increased, and the mill switches to using energy generated from biogas generated by the POME and a fraction of the EFBs, the surplus mill residue available for other uses will increase to 4.23 ton per ha per year. The available biomass consists of 1,27 tons EFB, 1.95 tons fibre and 1.03 tons of shells. The shells and fibre should have more potential for making added value compounds than EFB due to the lower moisture content, and lower nutrient content.

In Table B a short overview of potential applications of mill by-products is given together with an estimate of their suitability for conversion processes. Compared to EFBs, fibre and especially shells may have attractive characteristics for conversion into tradable commodities such as torrefied pellets and pyrolysis oil. Other products that should be considered are fibre products and lignocellulosic sugars for second generation fuels and chemicals and many other products. Apart from biomass becoming available for other uses there is also an estimated reduction of GHG emissions of 4.5 tons CO_2eq per ha per year, which would add up to 68 million tons CO_2eq per year for the total oil palm industry.

Table A. Current availability of biomass for alternative uses in palm oil processing mills and the availability under improved conditions (based on 15.4 50 million ha in 2010).

	Surplus biomass		Total worldwide	Avoided GHG emission[2]	Total avoided GHG emissions
	Ton dw/ha	GJ[1]/ ha	PJ	Ton CO_2eq per ha	Million ton CO_2eq
Current practice	2.5	48	740	0	0
Improved efficiency and anaerobic digestion	4.23	80	1250	4.5	68

[1]Higher Heating Value. [2]The estimated avoided GHG emissions are related to CH_4 and N_2O, the potential GHG emission savings due to fossil fuel replacement depends on the type of application and is not included here.

Apart from palm mill by-products, the oil palm also produces oil palm fronds (leaves) which are now left to mulch in the field. With a productivity of 11 tons per ha per year (almost 2.5 tons per ton of palm oil in productive plantations). The maximum potential is 165 million tons worldwide. Still, using this biomass has much more constraints as the biomass is now used as soil amendment, returning nutrients and carbon to the soil. If fronds are to be used for applications, solution to the cost of collection and replacement of nutrients and carbon should be provided.

Table B. Possible applications for palm oil mill by-products.

Methods / By-product	Composting/ mulching	Combustion	Anaerobic digestion[2]	Pyrolysis oil	Torrefaction	Activated carbon	2e gen. fuels and chemicals	Fibre uses
EFB	Y[1]	P	P	P/Y	P/N	N	Y	Y
POME	Y	N	Y	N	N	N	P/N	N
Fibre	Y	Y	P/N	Y	Y	N	Y	Y
Shell	P	Y	N	Y	Y	Y	P	P/Y

[1]Y = is a good option; P = is a possible option (can be that it has not been evaluated enough or that yields are relatively low); N = not an option. [2]Biogas production followed by generating electricity.

In the end the local technical and economic feasibility will determine if the potential the palm oil residues offer will be taken advantage of. Developing clear policies that give advantage to biofuels made from residues (generated outside of competition with other uses) and long term commitments to source this biomass, will determine if the potential of palm oil mill residues is realised.

Abbreviations

CPO: Crude Palm Oil
EFB: Empty Fruit Bunch
Fibre: Mesocarp Fibre
FFB: Fresh Fruit Bunch
HHV: Higher Heating Value
OPF: Oil Palm Fronds
PKO: Palm Kernel Oil
PKM: Palm Kernel Meal
HHV: Higher Heating Value
LHV: Lower Heating Value

1 Introduction

1.1 Palm oil production worldwide

The African oil palm (*Elaeis guineensis* L.) is the most productive oil crop in the world and it is also the largest oil crop with an annual oil production of 53.3 million tons in 2012/2013 (USDA-FAS, 2013) just before soy.

Crude Palm oil is derived from the mesocarp (pulp) of the fruit of the oil palm tree. Besides crude palm oil, palm kernel oil (PKO) is also derived from the oil palm fruit kernel. Crude palm oil is further refined for use in the commercial food industry. Palm oil, like other vegetable oils, is also used to produce biodiesel.
The major palm oil producing countries include Indonesia, Malaysia, Thailand, Colombia and Nigeria. The largest importers of palm oil are India, China and the EU27. Table 1 gives an overview of production data of oil palm in 2010. Globally, approximately 15.4 million hectares are planted to palm oil, producing approximately 217 million tons of oil palm fruit per year, from which 43.5 million tons of crude palm oil and 5.7 million tons of crude palm kernel oil are generated (2010). Taking an approximate market value of 650 €/ton of crude palm oil only, the world production represents a total economic value of 32 Billion €. However, the economic value of products made on the basis of crude palm oil is even much higher.

Figure 1. The fresh fruit bunch is harvested and the oldest fronds are removed and left to mulch in the plantation.

Oil palm is the most productive oil crop in the world with potential yields of more than 5 tons of oil per ha per year. As can be seen from Table 1, the productivity of oil palm cultivation varies widely, from 3 – 5 ton Fresh Fruit Bunch (FFB) per ha in Africa, to more than 21 ton FFB per ha in Malaysia.

Table 1: Production of palm oil in major palm oil producing countries (source: FAOstat; 2010 production date)

	Area harvested	Fresh Fruit Bunch Production	Productivity	Crude Palm Oil Production	Crude Palm Kernel Oil Production
	ha	ton/y; fresh weight	ton FFB / ha.y	ton CPO/y	ton CKPO/y
Brazil	106,420	1,292,710	12.1	250,000	117,000
Cameroon	76,000	1,575,000	20.7	111,440	37,800
Colombia	165,000	3,100,000	18.8	753,100	78,300
Costa Rica	55,000	141,250	2.6	210,905	15,159
Cote d'ivoire	225,000	1,500,000	6.7	330,000	29,400
DR Congo	179,000	1,163,580	6.5	187,000	24,255
Ecuador	120,000	1,800,000	15.0	289,900	31,700
Ghana	360,000	2,004,300	5.6	120,000	16,000
Guatemala	55,000	1,200,000	21.8	182,000	54,000
Guinea	310,000	830,000	2.7	50,000	4,876
Honduras	100,000	1,556,350	15.6	275,000	32,500
Indonesia	5,370,000	90,000,000	16.8	19,760,000	2,358,000
Malaysia	4,010,000	87,825,000	21.9	16,993,000	2,014,900
Nigeria	3,200,000	8,500,000	2.7	1,350,000	542,800
Papua New Guinea	119,000	1,730,000	14.5	500,000	41,700
Thailand	569,364	8,223,140	14.4	1,287,510	127,500
World	15,410,262	217,925,795	14.1	43,573,469	5,688,559

Figure 2. The fresh fruit bunches are transported to the mill for processing within 24 hrs.

1.2 Why use palm oil mill residues?

Palm oil mill residues have been identified as one of the most interesting biomass feedstocks for the biobased economy, because they appear to be underutilized, they are available as "a point source" at the processing mill, and they have a low value (at the mill). As explained in the next chapter at least one ton of lignocellulosic biomass is potentially available per ton of palm oil, at the processing mill. This results in a largely underutilized biomass potential of more than 50 million tons worldwide. In the plantation, fronds are also produced as a residue (see Figure 1). Although the total amount of fronds are estimated as well, fronds are not a focus of this report as they are generated at the plantation, not the oil mill. During processing at the palm oil refinery, by-products, such as free fatty acids and spent bleaching earth are produced. These are also outside the scope of this report, as they are of comparatively small volume.

The potential of at least 50 million (dry) tons of palm oil mill residues is a considerable amount of biomass even in view of the very large amounts of biomass that are required to fulfill the biomass demands worldwide. The economic value represented by this amount of residues is estimated to be at least 3.4 Billion €. The largest demand for (lignocellulosic) biomass in the coming years is likely to come from the EU. Based on the National Renewable Energy Action Plans (NREAPs) of the 27 EU countries a total biomass demand of 650 million tons (dry weight) has been estimated. The estimated need for importing lignocellulosic biomass, was estimated between 50 and 150 tons by 2020 in the EU 27 (Elbersen et al. 2011).

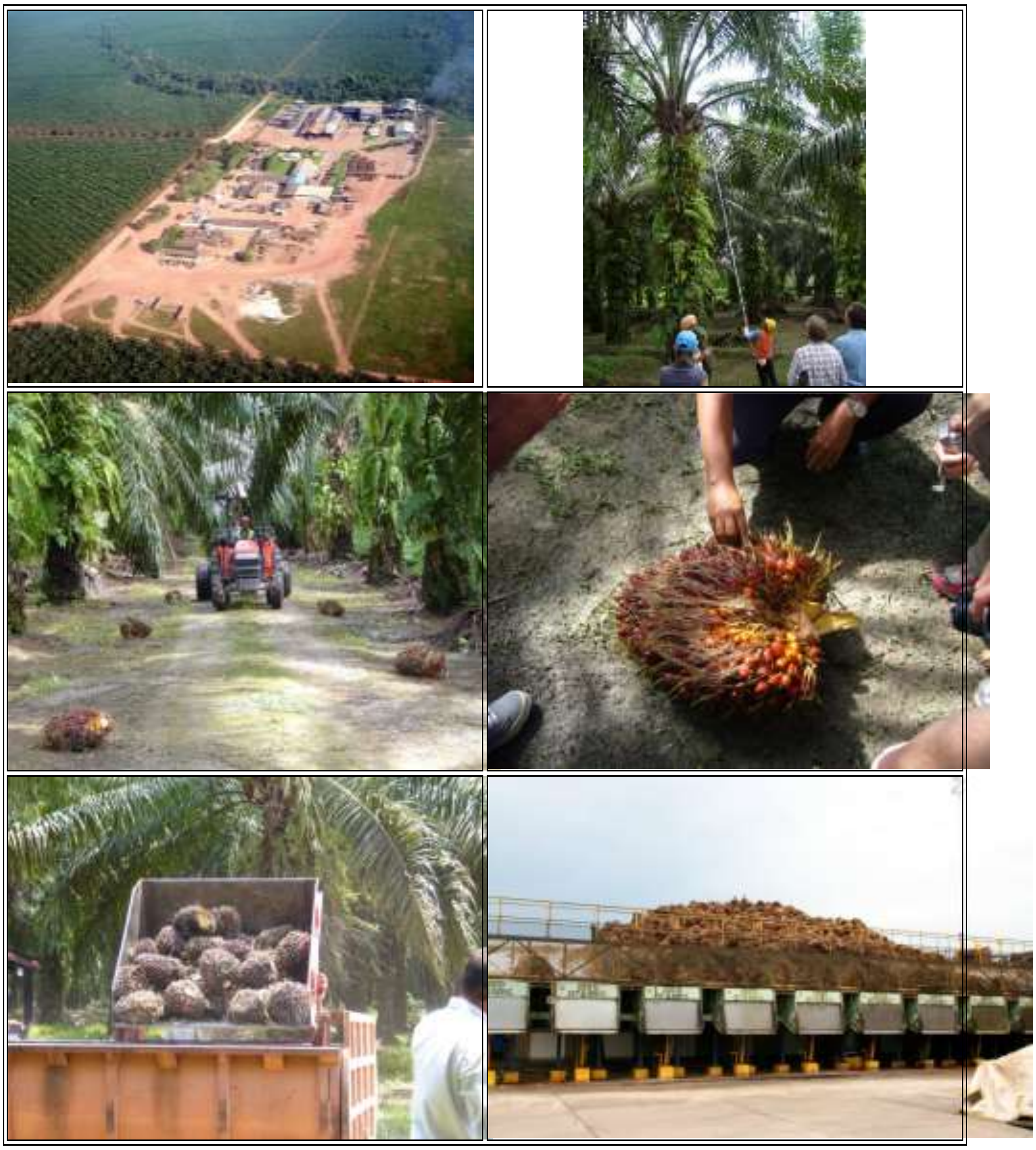
Much of the lignocellulosic biomass is thought to be imported in the form of (wood) pellets, which is an easily tradable commodity. Based on different studies the demand for wood pellets alone is expected to be between 20 and 50 million tons by 2020 in the EU 27 (Cocci et al. 2011). The same study expects a wood pellet demand in East Asia (mainly Japan, South Korea and China) to range between 5 and 10 million tons by 2020.

At this moment international trade in palm oil shells, mainly for co-firing, is already taking place. Co-firing in powder coal facilities may be problematic due to the hardness of palm shell which is difficult to grind.
Locally, empty fruit bunches (EFB) are also used for energy generation (outside of the mill), for example in Thailand. Other uses of by-products (mainly EFB) are being developed and explored (see chapter 3).

One of the compelling reasons for using palm oil mill residues is that these residues are largely underutilized at this moment. As is explained in Chapter 2 and 3, adaptations in the mill set-up can make by-products available without compromising current uses for these by-products. Therefore using these by-products for energy applications (and other non-food uses) should not have undesirable indirect side-effects. This indirect effect of using biomass for non-food uses has in recent years become a concern, mainly when speaking about first generation biofuels (biodiesel and ethanol) which are produced from crops that can also be used for food. This may lead to increased food prices and decreased food security and it may also lead to indirect land use change (iLUC) as more land is needed for agriculture. This in turn may lead to loss of forests and grasslands and large greenhouse gas (GHG) emissions (Searchinger 2008). This can actually completely undo the GHG benefits of using biomass instead of fossil fuels. The iLUC risks are low or close to zero for bioenergy and biofuel feedstocks which do not require land for their production (Fritsche et al, 2010). Underutilised residues such as palm mill by-products are not in competition with other uses. At the source they still have a low-to-zero economic value. Still, they could be used for soil fertilization and maintaining soil organic carbon. A methodology to assess this is currently in development (Ecofys et al. 2012).

Even though a large potential exists to supply palm oil mill residues, many constraints exist as well, which currently limit the possibilities of mobilizing this resource. This short study compiles the facts about palm oil residues, explains what constraints exist to using these residues and discusses possible solutions.

Figure 3. A typical oil palm extraction mill is situated close to the palm oil plantation, fresh fruit bunch is harvested and transported to the mill for processing. The oldest fronds (leaves) are also removed (pictures at Agro Palma S.A. Brazil; Dabon, Colombia; and Malaysia).



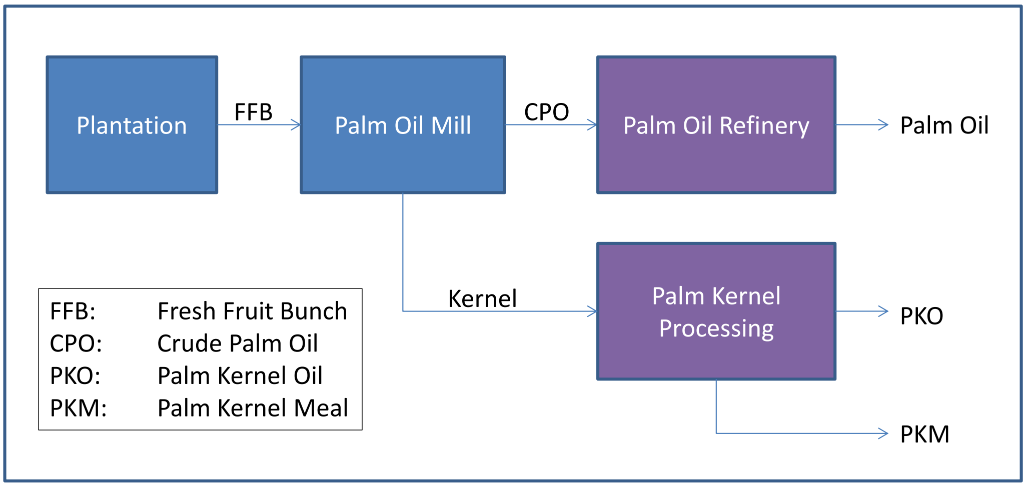
2 Chapter 2

2.1 Palm oil production system

Figure 4 presents a schematic of the palm oil production system. Oil palm trees are grown at the oil palm plantation, where fresh fruit bunches (FFB) are harvested from the trees. Fresh fruit bunches are then transported to the Palm Oil Mill. Palm oil mills are usually situated near the plantation, as the Fresh Fruit Bunches need to be processed quickly - within 24 hours - after harvest. A typical mill will process 30 tons of FFB (fresh weight) per hour, although larger mills exist as well.

At the mill, the main products that are produced from FFB are Crude Palm Oil (CPO) and Palm Kernels. Crude Palm Oil is usually transported elsewhere for further refinery. The kernels are usually processed elsewhere into Palm Kernel Oil (PKO) and Palm Kernel Meal (PKM). The main by-products and by-products of the Plantation and Palm Oil mill are further described in this report. The Palm Oil Refinery and Palm Kernel processing also produce by-products, but these are outside the scope of this study.

Figure 4: General schematic of the Palm Oil Production System (main products only). The by-products are presented in Figure 5.



2.2 Oil Palm Plantation

Oil Palm plants are first grown in a nursery. After growing in the nursery for approximately 1 year, the plants are re-planted in the plantation. After 3 years in the field, the first fruit bunches are harvested. Harvesting is done year-round. During harvesting, oil palm fronds (leaves of the oil palm) are removed to facilitate the harvest of FFB. After approximately 25 years, the productivity of the trees gradually decreases, and the trees are cut down and replanted. Removing cut trees produces two additional by-products of the Oil Palm Plantation: trunks, and roots.
Table 2 gives an overview of total production of fresh fruit bunches, and the three main by-products at the plantation. The data are based on a productivity of 21.4 ton FFB/ha which is typical for plantations in Malaysia. Under these conditions a productive palm plantation produces some 30 tons dry weight of total biomass per year. For productivity in other countries, refer to Table 1 in Chapter 1. Data show that almost one third (9.2 tons dry weight) of the biomass is contained in the main product (FFB), more than 1/3 (11 tons dry weight) is contained in the leaves (fronds), and another 1/3 is contained in the trunks and roots combined In other words, of the total of 30.6 tons of dry weight biomass. 9.2 tons of dry weight in the form of FFB is exported to the processing mill for processing.
Table 2 gives an estimation of the main nutrients contained in the products and by-products, based on literature reviews by Corley and Tinker, (2003) and Elbersen et al (2005). These data are also presented in Table 3 as fraction of total nutrients, and show that about one third of total nitrogen, nearly half of phosphate, and one fifth of potassium are removed from the plantation by harvest of Fresh Fruit Bunches (FFB). In addition, the data show that oil palm fronds contain by far the highest amount of nutrients from all field by-products, including trunks and roots.

Table 2. Productivity and nutrient content of main product and by-products from the oil palm plantation (per hectare per year).

	Biomass Production		Nutrients				
	Fresh weight	Dry weight	N	P	K	Mg	Ca
	--------- ton/ha.yr ----------		-------------------------- kg/ha.yr ----------------------------				
Fronds	36.7	11.0	80.5	6.1	141.9	18.6	38.8
Trunks (average over 25 years)	9.2	4.6	25.7	2.5	74.4	6.9	14.2
Roots	19.4	5.8	18.6	1.6	46.6	4.8	2.8
Fresh Fruit Bunch (FFB)	21.4	9.2	57.0	8.3	71.7	14.7	15.6
Total	86.7	30.6	181.8	18.4	334.5	45.0	71.5

Table 3. Biomass productivity of oil palm and nutrient distribution over the biomass components.

	Biomass Production		Nutrients				
	Fresh weight	Dry weight	N	P	K	Mg	Ca
Fronds	42%	36%	44%	33%	42%	41%	54%
Trunks	11%	15%	14%	13%	22%	15%	20%
Roots	22%	19%	10%	9%	14%	11%	4%
Fresh Fruit (FFB)	25%	30%	31%	45%	21%	33%	22%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

The removal of FFB from the plantation is inevitable for the production of palm oil. The field by-products (fronds) are generally not removed. If the fronds were removed from the plantation some form of replenishment of soil carbon and nutrients would be required.

Oil Palm Fronds have a high water content of approximately 70% (see Table 2). Therefore the leaves are prone to fast deterioration. Oil Palm Fronds are very bulky and therefore transport and further handling is expensive. At the same time, the Oil Palm Fronds have a high nutrient content (relative to their dry matter content) causing relatively high additional costs for replenishment of nutrients (see Table 2 and 3).

Roots are difficult to harvest and have a high water (70%) and will always be contaminated with soil. Transport and further handling is expensive. Therefore, the use of roots should be a relatively unattractive proposition.

The trunks need to be removed after 25 years of production to make replanting possible. Whereas Oil Palm Fronds would need to be collected throughout the year, the trunks can be harvested and collected all at once after 25 years. Therefore harvest of trunks is much cheaper. Trunks have a lower water content (<50%) and a higher loading density on the truck. For all of these reasons, the trunks are the first by-products that could be removed from the plantation in an economical way yielding 115 tons (dry weight) after 25 years.

The FFB's that are removed from the plantation to the palm oil mill contain considerable amounts of nutrients (Table 2). A significant part of these nutrients can be recycled to the plantation by returning mulched EFB's and ashes from burning of shells and fibres. Also Palm Oil Mill Effluent (POME) sludge may be recycled to the field.

2.3 Energy content of plantation by-products

Table 4 shows that a productive palm plantation produces some 30 tons dry weight of total biomass per year of which 9.2 tons dry weight FFBs are exported to the processing mill for processing. The FFBs contain 43% of the overall energy content of all biomass produced. The fronds (OPF) contain 29% of the energy.

Table 4. Energy contained in palm plantation products and by-products produced per year. (calculated from dry matter assuming 19 GJ/ton Higher Heating Value if no specific information was available).

	Biomass Production		Energy content		
	Fresh weight	Dry weight			
	ton/ha.yr		GJ/ha.yr	GJ/ton FFB	% of total
Fronds	36.7	11	209.4	9.79	29%
Trunks	9.2	4.6	87.3	4.08	12%
Roots	19.4	5.8	110.6	5.17	15%
Fresh Fruit (FFB)	21.4	9.2	312.6	14.61	43%
Total	86.7	30.6	719.9	33.64	100%

2.4 Palm Oil Mill

Byproducts are generated at the palm oil extraction mill, in which crude palm oil (CPO) and kernels are produced from the Fresh Fruit Bunches (FFB).

At the extraction mill, the upstream production process consists of a number of process steps for production of CPO and kernel (Corley et al., 2003):

1. Bunch sterilization with the aid of steam: this loosens the oil-containing fruit from the bunch and inactivates lipid-degrading enzymes as well as micro-organisms that naturally occur in FFB.
2. Bunch stripping, which separates the fruit from the bunch stalk and spikelets. In this process, the byproduct Empty Fruit Bunch (EFB) is produced.
3. Fruit digestion to crush and disrupt the mesocarp(pulp), with the aid of steam.
4. Pressing of the digested fruit to extract the oil from the mesocarp fibre. In this process, two fractions are produced: raw oil and a residue, containing palm oil fibres and nuts.
5. Separating, clarifying and drying the CPO.
6. Separating the nuts from the oil palm fibres. In this process step, the by-product Oil Palm Mesocarp Fibres are produced, or fibres for short.
7. Drying, grading, and cracking of the nuts, producing Palm Oil Kernels and shells.
8. Separating Kernels from the shells. In this process step, the by-product Oil Palm Kernel Shells, or Shells for short, is produced.
9. Kernel drying and storage

As noted earlier, pressing kernels to produce Crude Palm Kernel Oil (CPKPO) is usually done at larger facilities, not at the extraction mill.

Besides the three solid by-products (EFB, fibres, shells), a liquid effluent is produced in the extraction process, commonly referred to as Palm Oil Mill Effluent (POME). POME is generated by combining the following fractions from the extraction process (Corley and Tinker, 2003):

- Condensate from bunch sterilization (0.6 t/t palm oil produced)
- Water phase or sludge from oil clarification centrifuges (up to 2.5 t/t palm oil produced)
- Water from the hydro cyclone used in separation (0.25 t/t palm oil)

In other words, the primary source of liquid effluent or POME is the clarification process, although the amount produced per ton FFB varies greatly, depending on the process used.

A schematic of the flow diagram of palm oil and kernel extraction is shown in Figure 5 and illustrated in Figure 6. Per ton of FFB , approximately 200 kg crude palm oil is produced, and a considerable amount of byproducts, including 220 kg EFB, 135 kg fibres, 55 kg shells, and more than 600 kg of liquid effluents.

Figure 5. Schematic flow diagram for palm oil and kernel extraction. Approximate mass of outputs shown, on wet weight basis (based on Corley et al, 2003). The by-products are shown in the red circles. The palm oil mill effluent (POME) consists of condensate, sludge and waste water.

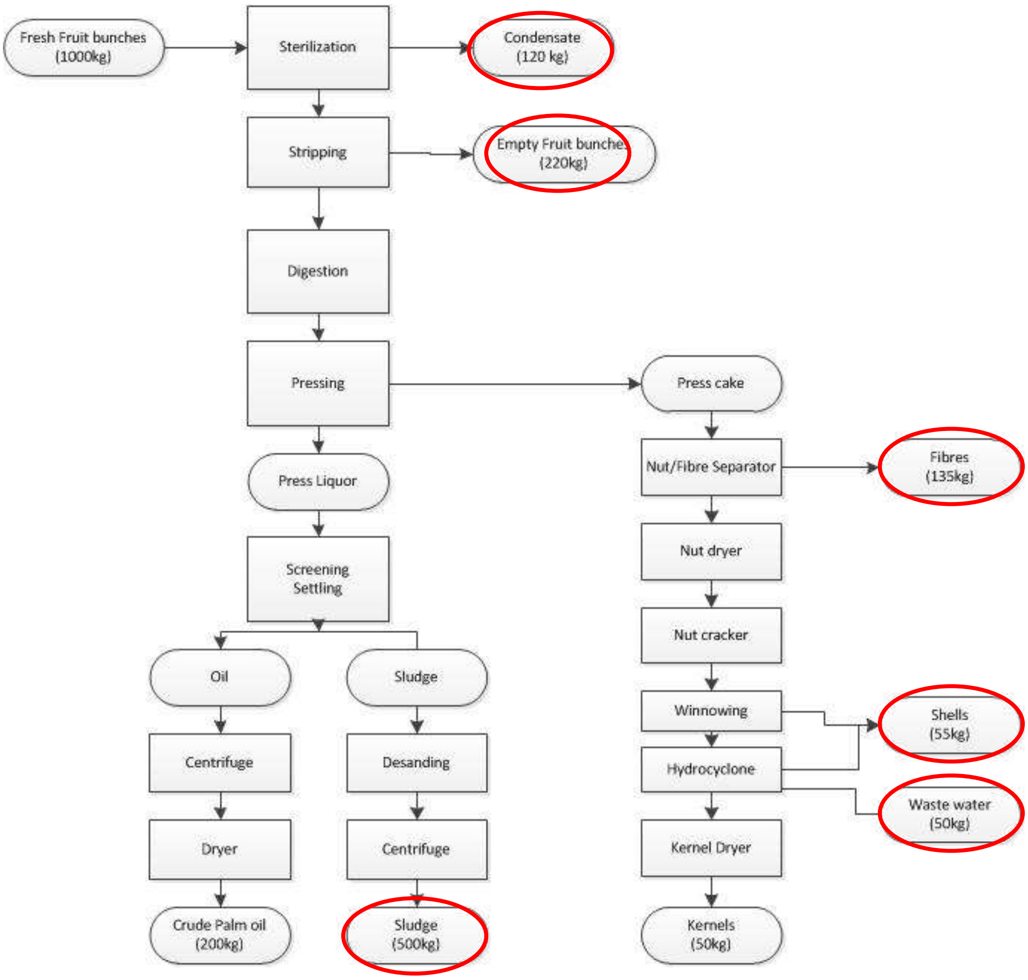


Figure 6. Fresh fruit bunches are transported to the processing mill and sterilized after which the crude palm oil is extracted and byproducts (fibre, shells and empty fruit bunch) are generated.

In Table 5 the volumes of FFB and by-products and their nutrient contents are presented based on different literature sources. The mass balances for dry matter are largely closed. Mass balances for nitrogen, phosphate and magnesium do not completely add up due to the fact that data was used from different sources and the nutrient contents of the different by-products will differ due to growing conditions and fertilisation. The most important aspect may be that compositions of by-products depends on available nutrient levels in the soil of the plantation (fertilisation). Also processing schemes will differ between different mills leading to different qualities of by-products. The separation efficiency may change and hence the composition of by-products changes as well. Particularly the composition of POME is known to be a function of process scheme, process conditions and separation efficiencies.

Table 5. Mass balance of palm oil mill, expressed per ha. Data are based on a productivity of 21.4 Fresh Fruit Bunches (FFB) per ha per year.

	Biomass Production		Nutrients			
	Fresh weight	Dry weight	N	P	K	Mg
	---- ton/ha.yr ----		----------- kg/ha.yr -----------			
Fresh Fruit (FFB)	21.4	9.2	57.0	8.3	71.7	14.7
Steam	*10.9*					
Total in FFB and steam	32.3	9.2	57.0	8.3	71.7	14.7
Crude Palm Oil (CPO)	4.5	4.5	0.0	0.0	0.0	0.0
Kernels	1.2	1.1	10.8	3.8	10.8	1.3
Empty Fruit Bunch (EFB)	4.7	1.9	12.3	1.5	44.6	1.9
Fibres	3.0	1.9	5.6	1.4	23.0	2.0
Shells	1.3	1.0	3.2	0.1	1.5	0.2
Palm Oil Mill Effluent (POME)	17.5	0.7	4.7	1.0	22.1	4.2
Total in products/ by-products	32.3	11.2	36.6	7.8	102.0	9.7

Figure 7. Mill byproducts are stored near the mill. EFB is mainly returned to the plantation and mulched or burned to produce bunch ash. Fibre is mainly used to provide energy for steam generation. In some cases compost is produced from EFB and fibre and ash. (Pictures taken at Agro Palma S.A. Brazil; Daabon, Colombia; and Malaysia).

Table 6. Fraction of mass and nutrients of the main palm oil mill by-products (excluding the palm kernels). Data are based on a productivity of 21.4 Fresh Fruit Bunches per ha per year.

	Biomass Production		Nutrients			
	Fresh weight	Dry weight	N	P	K	Mg
Empty Fruit Bunch (EFB)	15%	17%	34%	20%	44%	20%
Fibres	9%	17%	15%	18%	23%	21%
Shells	4%	9%	9%	1%	1%	2%
Palm Oil Mill Effluent (POME)	54%	6%	13%	13%	22%	43%
Total of all products from oil mill	82%	50%	71%	51%	89%	86%

Data in Table 5 show that per hectare 4.5 tons of oil are produced and a total of 6.6 tons of dry weight by-products is produced (EFB, fibres, shells, and POME). Most biomass (1.9 tons dry weight each) is contained in EFB and fibres. Although Palm Oil Mill Effluent (POME) is the largest by-product by volume (17.5 m^3), in terms of dry weight POME only represents 6% of the total. For nutrient content, most of the nitrogen and potassium are contained in EFB, whereas nutrient concentrations in fibres and POME are largely similar (with exception of magnesium). The least amount of nutrients are contained in the shells, as shown in Table 6.

2.5 Bioenergy balance of palm oil mill

In most palm oil mills today, residues such as fibres and shells are used to generate steam and electricity. In order to investigate current bioenergy use of palm oil mills and identify options for improvement or change, the energy content of the major by-products are presented in Table 7.

Table 7 shows the biomass energy balance of the palm oil mill, based on an assumed energy content (HHV) of 19 GJ/ton on dry weight basis for all by-products. It should be pointed out that the efficiency at which bio-energy can be produced may vary, in particular due to differences in moisture content. The data show that a total of 5 GJ of primary energy are contained in the by-products, calculated per ton of Fresh Fruit Bunch processed by the mill. If a productivity of 21.4 ton FFB/ha is assumed, a total of 105 GJ/ha per year is produced. Most of the energy is contained in EFB and fibres.

Table 7, Biomass energy balance of Palm Oil Mill by-products on a fresh fruit (FFB) basis and hectare. (based on productivity of 21.4 FFB per ha)

	Dry weight	Energy content		Fraction
	ton/ton FFB	GJ/ton FFB	GJ/ha	%
Empty Fruit Bunch (EFB)	0.088	1.672	35.8	34%
Fibres	0.091	1.729	37.0	35%
Shells	0.048	0.912	19.5	18%
Palm Oil Mill Effluent (POME)	0.034	0.637	13.6	13%
Total	0.261	4.950	105.9	100%

2.6 Energy use in palm oil mills and options for improvement

The electricity and steam needed for the extraction mill is generally produced locally from the by-products fibre and in some cases also the shells.
Based on a short literature review (Schmidt, 2010; Sommart and Pipatmanomai, 2011; Vijaja et al, 2008; Yussof, 2006) we estimate that the electricity use is around 17 kW·hr/ton FFB (equal to 0.061 GJe/ton FFB), which is equivalent to 1.3 GJe per ha per year at the earlier stated productivity of 21.4 ton FFB/ha.
The amount of steam consumed is estimated at 0.5 ton/ton FFB (equal to 1.1 GJ/ton FFB). We estimate that in a fully insulated system, only 0.16 ton of steam per ton FFB would be needed. Insulation of the sterilization vessels could therefore greatly improve the heat efficiency of the Palm Oil Mill. Recovery of heat from condensate could further improve the heat efficiency. Improving thermal conversion systems at the mill could also raise the efficiency to produce electricity, although this is not taken into account. Currently, the estimated electric power consumption at the mill is rather low, and improving electric generation efficiency would only make sense if there is a local or regional market for electricity.

Usually steam is produced in a low pressure boiler. This low pressure steam is used to drive a turbine for production of electricity. After that, the steam is used in the process (mainly for the sterilization). The electricity generation efficiency is estimated at 12% (Sommart and Pipatmanomai, 2011) and boiler efficiency at 60%.
Based on the data above, a set of scenarios was developed to show current and potential future improvements to residue use and energy generation and efficiency of use at the palm oil mill. These scenario’s not only help identifying opportunities for increased use of by-products (that are otherwise underutilised, disposed of by dumping, or produce a low-value compost) by the palm oil mill industry, but also can be used to assess to what extent a greater amount of oil palm-derived biomass by-products could be delivered to markets outside the palm oil sector, such as bioenergy production in the country, or for export. For each scenario, the amount of energy needed at the oil palm mill is calculated per ton of fresh fruit (FFB) processed, followed by an estimate of which by-products can produce that energy. From that it is calculated how much by-products can become available for other uses or export (Table 8).

1. Current practice (base case): Approximately 17 kWh of electricity and 0.5 ton steam per ton FFB is required for the palm oil mill (see above). This energy is produced by combustion of fibres as well as shells in low efficiency boilers. The electricity generation efficiency is estimated at 12% (Sommart and Pipatmanomai, 2011) and boiler efficiency at 60%. In total 2.1 GJ of primary energy is needed per ton of fresh fruit. This means that all the fibres as well as 40 % of the shells are used to generated heat and electricity for the mill: 60% of the shells (equivalent to approx. 0.4 GJ per ton FFB) are available for other uses. EFB and POME are not utilised (for energy generation) in this scenario.

2. POME Digestion + Fibres: As in the previous scenario, 17 kWh of electricity and 0.5 ton steam per ton FFB is required for the palm oil mill. In this scenario, POME is used for generation of biogas through anaerobic digestion (which is increasingly practiced by oil palm mills around the world) and the biogas is converted to electricity and heat in a combined heat and power installation (see Figure 8 for an example of biogas generation system). Additional energy needed is provided by combustion of fibre. Assuming a biogas generation potential of 9.87 GJ of total solid for POME and a conversion efficiency of biogas to heat of 90%, the energy produced by POME is equivalent to 0.33 GJ per ton FFB. In this scenario, all shells and EFB are available for other uses or export.

3. POME Digestion + EFB: This scenario is largely similar to the previous scenario (POME Digestion + fibres), except that additional energy needed for the palm oil mill-above energy already provided by biogas from POME, is provided by combustion of EFB, instead of fibres. In this case, all fibres and shells are available for other uses or export

4. Higher Efficiency: In this scenario, measures are taken to reduce the steam required by the Palm Oil Mill, for instance by insulating sterilization vessels which could greatly improve the heat efficiency of the Palm Oil Mill. Furthermore, recovery of heat from condensate could further improve the heat efficiency. The boiler efficiency is generally low (40% loss, 31% loss in off gasses as latent heat and heat of vaporization from the high water content of the fuel)[1] The boiler fuel can have significant water content (depending on the type of biofuel used). This water is evaporated during burning and the heat of evaporation is not recovered (Sommart and Pipatmanomai, 2011). As a result, boiler efficiency increases to 75%, and total steam utilisation is reduced to 0.25 ton of steam per ton. The total energy demand is thereby reduced to 1.00 GJ per ton of FFB. Assuming this demand is met by combustion of fibres (as in the base case), 60% of the fibres are sufficient to supply the palm oil mill of energy, and 40% of fibres and all shells are available for other uses or export.

5. POME Digestion + higher efficiency: in this final scenario, a combination is made of improvements to the efficiency of the palm oil mill (see scenario

[1] Raising the efficiency of the boiler system is primarily directed at improving steam generation (in particular lowering biomass use to raise steam), rather then electricity generation. Improvements could also lead to raising the electric generation efficiency, however this is not taken into account in the scenarios. The main reason is that current electricity use at the mill is relatively low.

4) and utilising biogas from POME digestion. As in the third scenario, EFB provides the remainder of energy. In this case, all of the fibres, shells, as well as approximately 50% of EFB is available for other uses, or export.

Figure 8. Palm oil mill effluent is cooled down before being transferred into the tarp covered biogas reactor. The sludge is used to make compost and the effluent is also returned to the plantation after aerobic treatment. (Pictures taken at Tequendama plantation in Colombia).

In summary, a combination of employing anaerobic digestion of POME with on-site biogas utilisation in CHP's, and relative simple energy savings measures in the form of improving boiler efficiency at the palm oil mill could free up significant quantities of oil palm biomass to be used in other markets, including export.

Savings of the current energy use by more than a factor of 2 or more seems possible, making it possible for biogas from POME (and part of the EFB) to supply the total energy demand of the processing mill. Along the way a significant amount of CH_4 emissions from POME (and possibly EFB) is avoided as will be explained in the next paragraph.

Table 8. Energy demand, bioenergy utilisation and associated biomass availability at palm oil mills, for improvement scenarios and current practice.

		1. Current practice	2. POME Digestion + Fibres	3. POME Digestion + EFB	4. Higher Efficiency only	5. POME Digestion + Efficiency
Electricity use of mill	kWhr/ton FFB	17	17	17	17	17
Electricity use of mill	GJe/ton FFB	0.061	0.061	0.061	0.061	0.061
Steam generation of mill	ton steam/ton FFB	0.5	0.5	0.5	0.25	0.25
Steam generation of mill	GJ/ton FFB	1.1	1.1	1.1	0.55	0.55
Biomass utilisation for electricity gen.	GJ-hhv/ton FFB	0.51	0.51	0.51	0.51	0.51
Biomass utilisation for steam generation	GJ-hhv/ton FFB	1.83	1.83	1.22	0.73	0.61
Total Biomass energy need for mill*	GJ-hhv/ton FFB	2.10	2.10	1.49	1.00	0.88
**** in cases where energy demand is met by biogas; HHB of biogas is used***						
Biomass utilisation by mill						
Empty Fruit Bunch (EFB)	GJ-hhv/ton FFB	0	0	1.16	0	0.54
Fibres	GJ-hhv/ton FFB	1.73	1.77	0	1.00	0.00
Shells	GJ-hhv/ton FFB	0.37	0	0	0.00	0
Palm Oil Mill Effluent (POME)	GJ-hhv/ton FFB	0	0.33	0.33	0	0.33
Biomass available for other use/export						
Empty Fruit Bunch (EFB)	% of total EFB	100%	100%	31%	100%	67%
Fibres	% of total fibres	0%	0%	100%	42%	100%
Shells	% of total shells	60%	100%	100%	100%	100%
Palm Oil Mill Effluent (POME)	% of total POME	100%	0%	0%	100%	0%

2.7 GHG emissions

As all energy used by the palm oil mill is derived from biomass resources, the use of energy does not contribute to the direct emissions of Green House Gasses. However, the main contributors to GHG emission are related to current disposal methods for by-products, in particular natural decomposition (rotting) of POME and EFB.

The EFBs are often left on a large heap. This heap will produce methane and N_2O as a consequence of a spontaneous and largely uncontrolled rotting process.
The methane and N_2O emissions from EFB can be as high as 4.7 ton CO_2eq per ha per year or 0.23 ton CO_2eq per ton FFB or 1.1 ton CO_2eq/ton palm oil (Elbersen et al. 2006, following CDM-SSC-PDD version 2). Other references report an emission that is more than a factor 2 lower (Project design document form (CDM PDD) Version 03.1).

The other better known contributor to the GHG emissions of the palm oil mill originates from the open pond treatment of POME. Schmidt (2010) reports an emission of 11.4 kg $CH_{4\ per}$ ton FFB. This is equal to 34 kg CH_4/ton palm oil (incl. kernel oil) or 816 kg ton CO_2eq per ton of palm oil. This is roughly 1 third of the CO_2 captured in the palm oil. The value from Schmidt is confirmed by other references: A methane potential of 55 kg CH_4 per ton CPO produced, at the mill was calculated from Soni (2007) and a 64% COD reduction at 7 days retention time in anaerobic treatment of POME was reported by Puetpaiboon and Chotwattanasak (2004). This equals 25 kg CH_4 or 575 kg CO_2eq per ton of palm oil. We conclude that overall the GHG emissions from POME and EFB can easily be 1000 kg CO_2eq per ton of palm oil.

Good composting practice strongly reduces GHG emissions from EFB. The Dutch government reports GHG emissions of 0.05 ton CO_2eq per ton of fresh waste for well controlled composting units (AgentschapNL). Thus the potential emission of 0.23 ton CO_2eq/ton FFB or 1 ton CO_2eq/ton EFB could be reduced to only 0.05 ton CO_2eq/ton EFB or 0.01 ton CO_2eq/ton FFB by a well-controlled composting facility.

Controlled anaerobic treatment of POME could also greatly reduce the GHG emissions. Capture of released biogas and burning the biogas in a flare would reduce GHG emissions by 95%. The avoided emissions can be sold as carbon credits in the form of Certified Emission Reductions (CERs) under the Clean Development Mechanism (CDM) of the Kyoto Protocol.

The switch to using biogas form POME (and EFB) to provide energy to the palm oil mill could free up shells and fibres that could then be sold as a sustainable produced biomass for export or local use. In the next chapter, the available mill byproducts are further characterized.

3 Characterisation of application of palm mill by-products

This chapter presents the main characteristics and current and alternative uses of the by-products of the palm oil mill. The availability of the oil palm by-products EFB, shells and fibres is summarised in Table 9 depending on the energy management scenario (as described in Table 8). This table shows that, depending on the scenario for energy production at the oil palm, a small-sized oil palm mill (capacity 30 ton FFB/y) could produce approximately 26.000 to 44.000 tons of biomass (dry weight) divided over the three main by-products: EFBs, fibres en shells.

Table 9. Biomass availability of palm oil production, based on five scenarios based on (also refer to paragraph 2.6 for description of the scenarios.)

	Biomass availability		
1. Current practice	ton dw/ton FFB	Ton dw/ha.yr	ton/mill.yr
Empty Fruit Bunch (EFB)	0.088	1.88	19800
Fibres	0	0	0
Shells	0.029	0.61	6434
total	*0.12*	*2.50*	*26234*
2. POME Digestion + Fibres	ton dw/ton FFB	ton/ha.yr	ton/mill.yr
Empty Fruit Bunch (EFB)	0.088	1.88	19800
Fibres	0.	0	0
Shells	0.048	1.03	10800
total	*0.14*	*2.91*	*30600*
3. POME Digestion + EFB	ton dw/ton FFB	ton/ha.yr	ton/mill.yr
Empty Fruit Bunch (EFB)	0.027	0.58	6115
Fibres	0.091	1.95	20475
Shells	0.048	1.03	10800
total	*0.17*	*3.56*	*37390*
4. Higher Efficiency	ton dw/ton FFB	ton/ha.yr	ton/mill.yr
Empty Fruit Bunch (EFB)	0.088	1.88	19800
Fibres	0.038	0.82	8661
Shells	0.048	1.03	10800
total	*0.17*	*3.73*	*39261*
5. POME digestion + Higher Efficiency	ton dw/ton FFB	ton/ha.yr	ton/mill.yr
Empty Fruit Bunch (EFB)	0.059	1.27	13352
Fibres	0.091	1.95	20475
Shells	0.048	1.03	10800
total	*0.20*	*4.24*	*44627*
Note: availability per mill based on production of 30 ton FFB/h			

3.1 General characteristics of palm oil EFB, fibre and shells

In Table 10 the general composition characteristics of EFBs, mesocarp fibre and shells are summarized. This composition is variable. Especially for the ash content will vary according to soil characteristics and processing. The same goes for other components such as K, N and P. In general the ash content is lowest for shells and highest for EFB and fibre.
The energy content (HHV) is highest for shells and lowest for EFBs. This is mainly explained by the higher lignin content of shells (which has a higher energy content). The potassium content is lowest for shells and highest for EFBs.

Table 10. Typical composition characteristics of palm oil Empty Fruit Bunches (EFB), mesocarp fibre, and shells.

		EFB	Fibre	Shells
Production	ton d.w./ton FFB	0.09	0.09	0.05
Moisture content	% FW	60	17 to 40	10 to 25
Dry matter concentration at collection	% dry weight	40.0	83 to 60	75 to 90
Higher heating value	GJ/ton dw	17.5 to 19.0	19.7	20.5 to 21.5
Lower heating value	GJ/ton dw	6.4	13.0	15.1
Ash concentration	% dw	1.6 to 7.7	3.5 to 8.4	2.7 to 4.4
Biochemical composition				
Cellulose	% dw	38.3	34.5	20.8
Hemicellulose	% dw	35.3	31.8	22.7
Lignin	% dw	22.1	25.7	50.7
Nutrient composition				
N	% dw	0.65 to 0.7	0.29 to 1.4	0.3 to 0.6
P	% dw	0.08	0.07	0.01
K	% dw	2.37	1.18	0.15

References: Dehue, 2006; Harimi et al. 2005; Kelly-Yong et al., 2007; Mohamed et al. 2005; MPOB; Omar et al. 2011.

3.2 Empty Fruit Bunch (EFB)

Current uses

The EFB is sometimes pressed to yield small quantities of oil and reduce transport on stage volume. The high K content makes EFB less suitable than fibre or shells, as a boiler fuel because the high K content will lower ash melting point leading to slag formation and fouling of boilers (see Figure 9).

EFBs have generally been burnt in the open air or in simple burners to generate "bunch ash" which has a value due to its high K and other mineral content (Yusef, 2006). Bunch ash is recycled to the plantation. Air pollution caused by this simple incineration is often undesirable or forbidden. Now EFB are often left on a heap before being returned to the plantation, though generally only to the fields close by the mill (see Figure 7 picture 3). The spontaneous and largely uncontrolled composting may produce methane and N_2O as a consequence. This can generate GHG emissions of up to 4.7 ton CO_2eq/ha.yr (as explained in paragraph 2.7). Especially independent millers do not return the EFB to the field as they do not own the plantations (Dehue, 2006). The value of EFB returned to the field as mulch has been estimated between $2.1 and $3.3 per tonne due to the benefit from replacing fertilizer the costs for transport and spreading (Dehue, 2006). According to Menon et. al (2003) the economic benefit of using EFBs as a fuel for power generation is 3,5 times the benefit of using EFBs as a fertilizer (mulch).

Still, EFB appears to be the most problematic by-product of palm oil mills and a considerable amount of effort is being put into developing alternative uses.

Figure 9. Example of ash agglomeration formed due to a low ash melting point in boilers due to a high alkali (K) content of the ash.

Alternative uses

Thermal conversion

Since EFB is generally regarded as underutilised, readily available biomass, there is a vast literature on alternative uses for EFB. By far the most common use is converting EFB to electricity and heat by thermal conversion, including combustion. In Thailand, stand-alone boilers are in place that are fed with EFB. These installations produce electricity for the public electricity grid. As explained above the low quality characteristics for combustion (high moisture and potassium contents) should pose a problem here. Transport of EFBs is problematic due to the large volume and high moisture content (40%) therefore methods of pretreatment to increase energy content and storability and transportability has been assessed.

Pre-treatment

Besides combustion of EFB as such (e.g. without pre-treatment), pre-treatment technologies for EFB are developed that facilitate combustion, such as shredding (which improves handling of EFB and feeding it into a boiler), torrefaction and pelletization. Producing pellets from EFB is reported to be more costly compared to producing wood pellets. For torrefaction, Aziz et al (2012) reported that EFB, due to its higher hemicellulose content, is almost completely decomposed by torrefaction. Uemura et al (2011) also found that the torrefaction (energy) yield of EFB was only 56% compared to 100 and 97% for shells and fibre respectively. Flash pyrolysis at temperatures from 400 to 600 ºC, to generate gas, char and pyrolysis oil (see table 11) has been tested on EFBs (Abdulla et al, 2010; Islam et al, 1999; Omar et al, 2011). The gas is generally used for the pyrolysis process. Pyrolysis oil can be easily exported for other uses such as energy generation. The production of chemical and second generation biofuels is under development. The char can be used for local heat and electricity production or soil improvement. An added advantage would be that most inorganic compounds are found in the char, thus returning valuable nutrients to the soil.

Table 11. Pyrolysis products (from palm kernel shells) at different temperatures.

Temperature ºC	Pyrolysis Oil	Char	Gases
	---------------------- % of dry weight	------------------------------	
400	42	35	23
450	50	29	21
500	58	26	16
550	53	21	26
600	**41**	**15**	**34**

Source: Islam et al, 1999.

Anaerobic digestion

Some literature sources refer to producing biogas from EFB, by co-digestion with other biomass sources (Nieves et al, 2011; O-Thong et al, 2011). In general, the biogas yield of untreated EFB is low due to its lignocellulosic composition, and a pretreatment is necessary to improve biogas yield from EFB. Nieves et al (2011) report that biogas yield of untreated EFB (0.2 NM3/kg VS) can be doubled after treating it with Sodium hydroxide.

Second generation fuels and chemicals

EFB is also considered as source of fermentable sugars for 2nd generation fermentation processes, to produce biofuel or chemicals as fossil fuel replacement. In this case, EFB will have to undergo chemical and enzymatic pre-treatment to liberate sugars from the lignocellulosic biomass. After this the sugars are converted by fermentation into ethanol (Tan et al, 2010; Han et al, 2011; Lau et al, 2010; and others), or ABE (Ibrahim et al, 2012; and others). Other products include dissolving pulp and furfural.

Materials

EFB could also be used for production of materials, including structural materials (fibre boards). Currently, some EFB produced in Malaysia undergoes shredding and drying, and is exported to other countries. Other material uses include producing Medium Dense Fibreboards (MDF) from EFB, as well as dissolving cellulose. From 5 tons of EFB about one ton of pulp can be produced (Lee and Ofori-Boateng, 2013). Technologies for producing these materials are primarily proven in concept, and not yet implemented at a commercial scale.

Challenges of EFB utilisation

EFB exhibits a high moisture content which, in combination with a low bulk density, poses particular challenges to utilisation. For most applications, some type of pre-processing or pretreatment is needed, and the stability of the material needs to be improved if EFB have to be stored for longer periods. Another relevant question is at which location if also whether the pre-treatment should be done at the mill side, or at the central site.

3.3 (Mesocarp) Fibres

Current uses
Oil palm fibres have a reported moisture content of 17 to 40% (Table 10) making it difficult to store without drying. The fibre is (therefore) used as the primary boiler fuel by oil palm plantations before shells and EFBs. This explains why there has been less research into alternative uses compared to EFbs. However, if energy efficiency of the processing mill is increased and biogas from POME is used for energy generation up to 100% of the palm fibre could become available for alternative uses (see paragraph 2.6 and Table 9).

Alternative uses
Oil palm mesocarp fibres could be used to produce fuel briquettes or pellets. Briquetting is a mechanical treatment to make biomass more uniform via compaction. In some cases, the outer layer of the biomass is carbonised during briquetting in order to improve the combustion characteristics. So far, most technologies have been tested to produce briquettes from either EFB, or shells, or a blend of EFB and shells (MPOB, 2010).

Besides energy conversion, in principal oil palm mesocarp fibre could be as raw materials that are also considered for EFB and shells, including light-weight concrete, fillers, activated carbon, and other materials. As far as known, none of the applications are currently done on a large scale.

As mentioned (in paragraph 3.2) fibres have a better torrefaction yield than EFB. We speculate that pyrolysis oil yield may also be higher for fibre than for EFB due to lower ash contents. Other uses that have been studies even included fodder.

Challenges
Fibres have a comparatively high water content and also contain a considerable amount of nutrients. Still, the moisture and nutrient content is generally lower than for EFBs while the energy and lignin content should generally be higher. As fibres are the main boiler fuel, fibre should only become available if energy efficiency and alternative energy generation source is available.

3.4 Palm Kernel Shells (PKS)

Current uses

The primary use of shells is as a boiler fuel supplementing the fibre which is used as primary fuel. The remaining shells are often disposed of in the field or burned. In recent years PKS are sold as fuel around the world. Besides selling shells in bulk, there are companies that produce fuel briquettes from shells (MPOB, 2010) which may include partial carbonisation of the material to improve the combustion characteristics. As a raw material for fuel briquettes, palm shells are reported to have the same calorific characteristics as coconut shells. The smaller size compared to coconut shells makes it easier to carbonise for mass production, and its resulting palm shell charcoal can be pressed into a heat efficient biofuel briquette. To what extent oil palm shell briquettes are produced on a large scale, is not known.

Alternative uses

Although the literature on using oil palm shells (and fibres) is not as extensive as EFB, common research directions of using shells, besides energy, are to use it as raw material for light-weight concrete, fillers, activated carbon, and other materials. As far as known, none of the applications are currently done on a large scale. Since shells are dry and suitable for thermal conversion, technologies that further improve the combustion characteristics and increase the energy density, such as torrefaction, could be relevant for oil palm shells. Furthermore, palm oil shells are studied as feedstock for fast pyrolysis. To what extent shells are a source of fermentable sugars is not known, however the (reported) high lignin content in palm kernel shells indicates that shells are less suitable as raw material for fermentation.

Challenges/opportunities

The shells have a high dry matter content (>80% dry matter). Therefore the shells are generally considered a good fuel for the boilers as it generates low ash amounts and the low K and Cl content will lead to less ash agglomeration. These properties are also ideal for production of biomass for export. Aziz et al (2012) reported a high lignin content for shells, which affects torrefaction characteristics positively (as the material is not easily degraded compared to EFB and fibres).
As described in paragaraph 3.2 pyrolysis oil production has been produced successfully. Giving yields of more than 50%.

Economics

On the internet, prices of 55 to 70$ /ton of shells (FOB) are quoted.

3.5 Palm Oil Mill Effluent (POME)

Palm Oil Mill Effluent volume and composition will vary heavily upon FFB composition, process scheme, actual processing conditions and separation efficiencies. Three different streams add to the Palm Oil Mill Effluent: (1) Sterilizer condensate, (2) Clarification wastewater and (3) Hydrocyclone wastewater. The POME flow could be reduced by heat efficiency improvements during sterilization.

Better heat efficiency will lead to lower usage of steam and hence to lower condensate flow rates. POME has been identified as one of the major sources of aquatic pollution in Malaysia (Yeoh, 2004). As described in paragraph 2.6 emissions of greenhouse gasses can be equal to. Also odour and eutrophication can be a problem if proper disposal is not implemented. Biogas production through anaerobic digestion for energy production in a CHP (combined heat and power) system is the main alternative use for POME. As described in paragraph 2.6 and 2.7 this will be nearly enough to provide steam and electricity for the processing mill, if energy efficiency measures are implemented.

3.6 Technology providers and potential buyers of oil palm residues

Following is an initial list of service providers, providers of technologies to add value to oil palm residues, and companies that would have potential interest in importing biomass residues to the Netherlands. The list is not conclusive, and inclusion in this list does not indicate any endorsement of these companies.

Host, Biogast, BTG, DSM, Newfoss, BioMCN, Abengoa, Essent, Nuon/Vattenfall, Eon, and members of the Dutch Bioenergy Platform (refer to http://www.platformbioenergie.nl/nl/ab.php): Archimedes Solutions, Biomassbrokers, Cirmac International, Degin Duurzame Energie, EcoSon, Eneco, Energon, GDF SUEZ Energie Nederland, GF Energy, GMB BioEnergie Zutphen, Grontmij Energie, HVC K.S.B. Nederland, Ludan Renewable Energy, NUON Power Generation, Partners for Innovation, Rabobank, Raedthuys Groep, SEnS Capital Sparkling Projects, Tri-O-Gen Tubro Filter-, Lucht- en Verbrandingstechniek Twence Unica Ecopower.

4 References

Abdulla N., H. Gerhauser, F. Sulaiman. 2010. Fast pyrolysis of empty fruit bunches. Fuel 89 (2010) 2166–2169.

AgentschapNL, no year, Lachgasemissie bij professionele compostering en vergisting, www.rwsleefomgeving.NL.

Ani, F.N., and R. Zailani. 2000. Characterisation of pyrolysis oil and char from oil palm shells, Vol 1 (Ed. A.V.Bridgwater and D.G.B.Boocock), pp. 425-432.

Aziz, M.A. et al, 2012. A study on Torrefaction of Oil Palm Biomass, Journal of Applied Sciences 12(11): 1130-1135.

Baharuddin et al., 2010. Effects of palm oil mill effluent (POME) anaerobic sludge from 500 m3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process, African journal of biotechnology, Vol. 9 (16) - pp 2427 – 2436.

Chin, no year, Palm Kernel Cake (PKC) as a supplement for fattening and dairy cattle in Malaysia.

Chotwattanasak, J. and U. Puetpaiboon. 2011. Full Scale Anaerobic Digester for Treating Palm Oil Mill Wastewater. Journal of Sustainable Energy & Environment 2 (2011) 133-136.

Cocchi M, et al., 2011. Global wood pellet industry market and trade study. IEA Bioenergy Task 40 "Sustainable Bioenergy Trade". Available at: http://bioenergytrade.org/downloads/t40-global-wood-pellet-market-study_final.pdf

Corley R.H.V., Tinker P.B., 2003. The oil palm, Fourth edition, Published by Blackwell Science

Dehue, Bart. 2006. Palm Oil and its By-Products as a Renewable Energy Source. Potential, Sustainability and Governance. MSc. Thesis Wageningen University, July 2006.

Ecofys, EPFL, WWF International (2012). Low Indirect Impact Biofuel (LIIB) Methodology. Version 0. July 2012. Partially funded by the Dutch Ministry of Foreign Affairs via the Global Sustainable Biomass programme, coordinated by NL Agency.

Elbersen, H.W. J. Zhang and J. Verhagen. 2006. Study into the use of palm oil by-products while increasing the sustainability of palm oil production. The Netherlands.

Elbersen, H.W., J.E.G. van Dam, R.R. Bakker, R.R. 2005. Oil palm by-products as a biomass source: availability and sustainability. Paris, France, 14th European biomass conference & exhibition: biomass for energy, industry and climate protection.

Fritsche U.R., R.E.H. Sims and A. Monti. 2010. Direct and indirect land-use competition issues for energy crops and their sustainable production – an overview. Biofuels Bioprod Bioref 4:692–704.

Han, M.H., Y. Kim, S.W. Kim, G-W Choi. 2011. High efficiency bioethanol production from OPEFB using pilot pretreatment reactor. Journal of Chemical Technology and Biotechnology. 2011; 86: 1527-1534.

Harimi M., M.M.H. Megat Ahmad, S.M. Sapuan, Azni Idriset. 2005. Numerical analysis of emission component from incineration of palm oil wastes. Biomass and Bioenergy 28 (2005) 339–345.

Islam, N.N., Zailani, R. and Ani, F.N. 1999. Pyrolytic oil from fluidized bed pyrolysis of oil palm shell and its characterization. Renewable Energy 1999, 17:73-84.

Ibrahim, M.F., S.A. Aziz, M.N.A. Razak, L.Y. Phang, M.A. Hassan. 2012. Oil palm empty fruit bunch as alternative substrate for acetone-butanol-ethanol production by Clostridium butyricum EB6. Applied Biochemistry and Biotechnology (166): 1615-1625.

Lau M.J., M.W. Lau, C. Gunawan, and B.E. Dale. Ammonia fibre expansion (AFEX) pretreatment, enzymatic hydrolysis, and fermentation on empty palm fruit Bunch fibre (EPFBF) for cellulosic ethanol production. Applied Biochemistry and Biotechnology (162). 1847-1857.

Lang L.Y. 2007. Treatability of palm oil mill effluent (POME) using black liquor in an anaerobic treatment process, Thesis MSc.

Keat Teong Lee K.T. and C. Ofori-Boateng. 2013. Chapter 5. Utilisation of Palm Oil Wastes for Biofuel and Other Value-Added Bio-Products: A Holistic Approach to Sustainable Waste Management for the Palm Oil Industry. In Advances in Biofuels. 53-87. Springer.

Menon, N.A., Rahman, Z. A. and Bakar N.A 2003. Empty Fruit Bunches Evaluation: Mulch in Plantation vs. Fuel for Electricity Generation. Oil Palm Industry Economic Journal. 2003 V.3(2):15~20.

MPOB, 2010. Briquetting of EFB and Shells ……….. http://palmoilis.mpob.gov.my/publications/TOT/TT-456.pdf

Nieves et al. 2011. Industrial Crops and Products Volume 34, Issue 1, July 2011, Pages 1097–1101

Omar R., A. Idris, R. Yunus, K. Khalid, M.I. Aida Isma. 2011. Characterization of empty fruit bunch for microwave-assisted pyrolysis. Fuel 90 (2011) 1536–1544.

O-Thong S, K. Boe, I. Angelidaki. 2012. Thermophilic anaerobic co-digestion of oil palm empty fruit bunches with palm oil mill effluent for efficient biogas production. Applied Energy 2012; 93: 648-654.

Puetpaiboon U. and J. Chotwattanasak, 2004. Anaerobic Treatment of Palm Oil Mill Wastewater under Mesophilic Condition. Proceeding 10th World Congress on Anaerobic Digestion 2004, Montreal, Canada, August 29-September 3, 2004.

Schmidt J.H. 2010. Comparative life cycle assessment of rapeseed oil and palm oil, International Journal Life Cycle Assessment 15 183-197

Searchinger T, R. Heimlich, R. Houghton, F, Dong et al. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change, Science 319:1238–1240.

Sumiani Y. 2006. Renewable energy from palm oil-innovation on effective utilization of waste, Journal of cleaner production 14, 87-93

Sompong O-T, C. Mamimin, P. Prasertsan, 2011. Effect of temperature and initial pH on biohydrogen production from palm oil mill effluent: long-term evaluation and microbial community analysis, Electronic Journal of Biotechnology ISSN 0717 3458

Sommart K. and Pipatmanomai S., 2011. Assessment and improvement of energy utilization in crude palm oil mill, 2011 International conference on chemistry and chemical process IPCBEE vol 10

Soni S. W. 2007. Energy generation opportunities from palm oil mills in Indonesia, Presentation at Fourth biomass-Asia workshop.

Uemura Y., W.N. Omar, T. Tsutsui, S. Yusup. 2011. Torrefaction of oil palm wastes. Fuel 90 (2011) 2585–2591.

Vijaya S., A.N. Ma, Y.M. Choo, N.S. Nik Meriam. 2008. Journal of oil palm research Vol 10 June 2009 p 484-494

Yeoh B.G. 2004. A Technical and Economic Analysis of Heat and Power Generation from Biomethanation of Palm Oil Mill Effluent. In Electricity Supply Industry in Transition: Issues and Prospect for Asia 14-16 January 2004.

Yojiro K. and A. Ishizaki. 1990. Chemical composition of palm fiber and its feasibility as cellulosic raw material for sugar production, Agric. Biol. Clem. 54 (5), 1183-1187.

Yusoff, S. 2006. Renewable energy from palm oil – innovation on effective utilization of waste. Journal of Cleaner Production, Volume 14, Issue 1, 2006, Pages 87-93.

Kelly-Yong, T. L., K. T. Lee, A. R. Mohamed, S. Bhatia. 2007. Potential of hydrogen from oil palm biomass as a source of renewable energy worldwide. Energy Policy 35 (2007) 5692–5701.