Options for sustainability improvement and biomass use in Malaysia.

Palm oil production chain and biorefineries for non-food use of residues and by-products including other agricultural crops.

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Rapport nr.1080
BO-03-007-005

Colofon

Title	Options for sustainability improvement and biomass use in Malaysia
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AFSG number	984
ISBN-number	
Date of publication	
Confidential	no
LNV Project code	

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Content

1 Executive summary

The Division Biobased Products of the WUR institute A&F was approached by the Dutch Ministry of Agriculture, Nature and Food Quality with a policy support question about the potential of Bio-based economic developments in Malaysia.

Malaysia is one of the major international trade partners of the Netherlands. Annually 4.500 – 5.000 million euro's worth of goods are imported from Malaysia. The Netherlands are Malaysia's most important trading partner within the EU. The volume of agricultural commodities and especially palm oil products are substantial and the use of biobased resources for the generation of energy or biofuel has created a fierce debate on the sustainability of expansion of use of the biomass resources. In the context of the international policy to support the transition towards a biobased economy the potential resources that can be used for production of materials, chemicals and energy needs to be indentified. This report is reviewing the options that the current Malaysian agro-forestry sector may provide for sustainable developments.

The main conclusions are that especially the currently underutilized residues and polluting wastes from the palm oil production have big potential for value addition and technical product development that also could substantially contribute to the reduction of greenhouse gas emissions. Examples can be found in fermentation of residues and effluents to produce bio-gas / ethanol or bioplastics but also fibre boards and building materials. Demonstration on pilot scale of such technologies could create new business and bilateral interactions between Malaysia and The Netherlands.

2 Introduction

2.1 Oil palm and sustainable production

Oil palm belongs to the most productive and the largest vegetable oil commodities in the world (yielding on average almost 6 tons oil per ha/year, up to 8 tons at some plantations in Malaysia), and is together with soybean oil the major edible oil used in food industries. Besides margarines, sauces and frying oil palm oil products are used for manufacturing cosmetic and hygienic products (soaps and shampoos) as well. Palm oil is produced on large scale plantations especially in Malaysia and Indonesia where most of the production (14.8 and 15.0 million tons in 2005, respectively) is found. Prospects of increased demand for palm oil in the coming years due to expected high demand from China and India and for biodiesel as renewable energy source makes investment in new production attractive.

The RSPO (Round table for sustainable palm oil) was established in 2002. RSPO brings together the stakeholders along the production chain including oil palm growers, oil processors and food companies, retailers investors and NGO's. Currently the RSPO comprises over 300 members including 35% of the palm oil producers. For example MVO - the Dutch stakeholder organization in the vegetable oil industries - is a member of RSPO working groups on trade & traceability and communication & claims.

WWF (World Wildlife Fund) has assisted in the formation of the RSPO to develop the sustainability standards for palm oil production. Certified palm oil that is produced sustainably (CSPO) has been on the market since 2008. Valuable tropical rain forest should not have been cleared and social and ecological guarantees are given for the production of CSPO. The WWF and other NGO's concerns are for expanding palm oil plantations, especially in Indonesia (Kalimantan, Sumatra) and other fragile tropical forest areas will take place at the cost of biodiversity and indigenous population (CIFOR, Centre for International Forestry Research). This deforestation is feared to be enhanced when increased demands for the palm oil not only for food application but also for expanding demand for green fuels and biodiesel are at stake.

UNILEVER is the largest single buyer and major end-user of palm oil, which is widely applied in many food products. The company has committed itself to increase the sustainability of their production chains. In this framework the Sustainable Agriculture Initiative has prepared a guide to support sustainable management practices for oil palm production, under supervision of the Sustainable Agriculture Advisory Board (SAAB). They have identified 10 indicators of sustainability which include many aspects from soil fertility and nutrient management to the local socio-economic development and investment in human capital. Consequently, Unilever has recognised its responsibility for the sustainability of their raw materials production, which would include sustainability of waste management. The valorisation of by-products can contribute substantially to improve a sustainable management of the palm oil production chain while creating new jobs and increasing the income of local farming and suppressing the production costs. However, Unilever does not show interest in the energy use of oil palm. The policy statements of the major petrochemical companies (Shell, BP, etc.) to reduce the dependency on fossil carbon sources and reduce the CO_2 production recognize the potential of biomass resources for biofuel production (www.shell.com / www.bp.com) and illustrate the multi-stakeholder engagement.

Palm oil production is one of the major focal points in the partnership programme between Indonesia and the Netherlands, which were agreed after the WSSD (World Summit on Sustainable Development), Johannesburg in 2002. Currently the certified sustainable palm oil (CSPO) on the market does not find the buyers other than for niches. Mainstreaming of the sustainable palm oil and transparency of the production chain is critical for its success.

2.2 Biobased economy and sustainable development

One of the key issues for sustainable development is considered to be the establishment of a bio-based economy. Renewable resources have to play the key role as CO_2 neutral raw material for the transition towards sustainable industrial production to curb depletion of fossil resources. Full exploitation of the potential of biomass as industrial chemical feedstock implies changing scenarios for bio-conversion and accumulation of transport fuels and 'green chemicals'. The expansion of the African oil palm (Elaeis guineensis) as plantation crop especially in Malaysia and Indonesia has taken huge dimensions (respectively 3.4 million ha and 2.8 million ha) and its production has been governed by the demands for plant oil in food industries. However, together with the valued oil products vast amounts of under-utilised residues could provide a valuable feedstock for a more sustainable (chemical) industry. The valorisation of by-products can contribute substantially to improve a sustainable management of the palm oil production chain while creating new jobs and increasing the income of local farming and suppression of the production costs.

The typical large conglomerates of Indonesian or Malaysian companies, have activities in various industrial sectors, among which the agro-industry branch is prominent. The major producers of palm oil and oil palm products may have a production capacity of CPO (crude palm oil) of over half million tons /year. Their policy to operate the plantations and production facilities according the 6R principles for cleaner production, e.g. Refine all production processes, Reduce, Reuse, Recycle, Recover the used raw materials and Retrieve energy, converting unused material into fuel and energy, has led to various measures to improve palm oil production. In this zero-waste context the valorisation of oil rich and lignocellulosic residues is fitting, which are produced in large quantities at both the plantations and processing plants. Commonly not much progress is made in the daily practice of the plantation.

Technical possibilities for improvement of the sustainability of palm oil production have been identified by A&F, based upon discussions with various parties involved in Malaysia and Indonesia. Potential areas of sustainability improvement for the palm oil production chain, were found especially in non-food use of residues.

2.3 Palm oil biomass residues and options for sustainable use

Enhancing the sustainability of the palm oil production chain can be achieved by fully exploiting the abundantly available biomass wastes (shells, fibre, press cake, empty fruit bunches, mill effluent, palm fronts, etc.) as renewable resources in added value products. Currently only part of the waste is used a fuel feedstock in plant operations. The efficiency is, however, still low and more efficient boilers are required. Surplus fibre and shell creates an accumulating problem at the oil production plants and burning practices should be eliminated.

The availability of the various waste streams and the current practice of waste disposal have been quantified and qualified according to their composition and possible usage. Landfill processes and premature composting should be avoided and uncontrolled methane emissions reduced to a minimum. Local employment would be positively affected when new industries could be set up. Manufacturing of novel wood substitute products from plantation and agro-industrial residues will have a slowing impact on the rate of deforestation.

For example, the lignocellulosic fibres from oil palm could provide suitable feedstock for fibre board production. The fronds (10.5 tons per ha per year), and palm trunks (70 tons per ha / 25 yr) are major biomass waste at the estates. The wastes produced at the palm oil mill per ton of palm oil are the empty fruit bunch (EFB 1 ton), mesocarp fibre (0.6 ton) and shells (0.4 ton) (Fig.1). Part of it is consumed as boiler fuel, however especially the EFB is barely used and creates problems for its disposal since burning is no longer allowed.

The summary of technical options for sustainability improvement given below and (partly) elaborated in more detail in next chapters. These examples are technical innovations and not considering the competition with other end uses. For example the palm kernel oil (PKO adds 15% to CPO) mainly finds use in non-food applications (cosmetics and detergents, chemical industry). Lower quality oils and by-products may be used as bio-diesel, when demands for renewable fuel will increase as expected. Similarly, other use for the press cake (palm kernel meal, PKM adds 12% to CPO) may be required, which now largely is consumed in animal feed for meat production.

- **Bio-diesel**

Potentially, the residual oil (in pressing cakes) and free fatty acids could provide a rich source for bio-diesel production, reducing the amount of fossil fuel requirements and greenhouse gas emissions. Improved production efficiency and quality control (fresh fruits processing) also requires optimised use of rejects (too ripe fruits with high FFA), which then could be used for conversion into bio-diesel. The local use of bio-diesel on the plantations could reduce the risk of contamination of palm oil with mineral oil residues.

- **Fermentation to produce Bio-gas and ethanol and bioplastics**

The lignocellulosic and effluent biomass wastes from palm oil production can be converted by digestion as fermentation feedstock to produce ethanol (e.g. second generation biofuel), bio-gas (methane) or other components that can be used as 'green chemicals' (e.g. lactic acid, hydroxyalkanoids, etc). Demands on fermentation feedstock composition, conversion efficiency and microbial cocktails, product extraction and residue handling are relevant aspects to assess the feasibility for palm oil fermentation.

- **Bio-oil - pyrolysis**

Much of the lignocellulosic residues can be converted by controlled pyrolyis into bio-oil or liquid smoke, which is a complex mixture of degradation products rich in furans, phenolic compounds and aliphatic organic components (acids, aldehydes, ketones, etc.). This pyrolysis oil may be used for energy plants but its components may find value added application as substitute for resins, adhesives and coating. Currently promising applications for this oil are being developed (WUR, A&F / BTG) as resin in fibre board, wood glue or coating.

- **Charcoal and bio-char**

The palm oil nutshells will provide a good source for the production of charcoal, that could substitute the activated carbon produced from wood or peat. It is however required to enhance the technology preventing air pollution by noxious vapours and gasses and wasting of the heat released. Biochar is gaining new interest as efficient method to achieve carbon sequestration and reduce the impact of agricultural waste on greenhouse gas emissions and improve soil quality.

- **Fibres for paper pulp and building boards**

It has been demonstrated that the lignocellulosic wastes from oil palm production may yield a excellent fibre for paper pulp production. However, to compete with the existing large scale paper pulp production from wood (forest resources) it has been shown difficult to penetrate the pulp market, because of the relatively high requirement of processing chemicals and the different runnability on the paper machines. As a resource for building boards however, the palm oil residues could satisfy the large demands on the fibre feedstock. The EFB, fronts and trunks provide an abundant and good source for the production of particle boards or medium density boards (MDF). Utilizing the bio-oil resin as adhesive could safe on the need for petrochemical resins.

- **Binderless boards**

The lignocellulosic fibres of EFB and palm fronds is similar to coconut husk fibre in their lignin rich composition and specific properties. The production of board material would be an attractive option to find new value added outlets. It has been demonstrated to be a suitable raw material for MDF production and also it has been reported that binderless high density products can be produced from oil palm residues.

> In the framework of a CFC/FAO funded R&D project it has been demonstrated at A&F that excellent HDF boards can be produced, without the addition of a synthetic binder resin from milled coir husk, a comparable raw material with palm oil residues EFB and palm fronds, that have properties that approach wood based boards. A similar approach is proposed for the palm oil residues in which the intrinsic lignin adhesive present in the fibre material is used for cross-linking of the cellulosic fibres.

- **Dissolving pulp from lignocellulosics**

Abundantly available lignocellulosic residues can be used in various conventional and novel pulping and biorefinery processes to produce a range of raw materials for fibre board and papermaking purposes or purified cellulose. The market for cellulosic fibre and cellulose derivatives however is highly competitive and investments in new pulping plants are high. The options for biorefining processes and manufacturing dissolving cellulose from EFB are currently under investigation at WUR and seem promising for implementation in the near future.

2.4 Proposed strategy

To assess the most successful approach for sustainable product development for palm oil residues, the current situation with waste disposal and occurring bottlenecks at the estates and oil mills, needs to be quantified and evaluated. The potential raw material supplies need to be in concert with the capacity of a conversion technology and market size of products. The most competing outlet for the different residues needs to be worked out for its techno-economic feasibility.

The various lignocellulosic residues and byproducts and oil rich residues are to be tested and proven suitable for conversion into one of the value added components. The effect of storage and processing conditions on raw material quality need to be known.

Test products (demonstrators) are to be prepared on laboratory scale and the technical preconditions for production of marketable items will be established.

Demonstration at pilot scale production will generate the necessary information for the technical feasibility and projections for productivity on industrial scale. The results will form the basis for assessment of the economic feasibility and for investments in full scale production facilities.

The ecological impact of the proposed technologies need to be quantified and compared to the current situation of waste management and needs to bring the technical, socilal and environmental advantage for improving the sustainability of palm oil production.

3 Biomass residues from the palm oil production

3.1 Introduction oil crops markets

Plant oils are obtained from the oil rich seeds of many crops. With the growing demand for bio-diesel the production and supplies of plant oils is expected to grow. Rape seed (Canola) production especially for bio-diesel production has expanded substantially in the past decade (EU, Canada). The largest production of edible oils and cooking oils are obtained from soybeans, oil palm seeds, sunflower seeds, peanuts and olives. The various oilseeds differ in oil content and composition of the fatty acids. The variability is due to species (genotype) and growing conditions. Industrial or speciality oil seeds containing special fatty acids (unsaturated, short chain, oxidized fatty acids) such as linseed, and castor beans, safflower and mustard are specifically grown for non-food application (coatings, lubricants, pharmaceutical use). New oil crops such as *Crambe*, and *Jatropha* are studied for new (non-food) application of their oil seeds. The amount of oil per seed may vary from 2-3 % in grains to ca 50% in peanuts. In absolute quantity oil crops are produced in relatively smaller amounts, but in acreage still these are substantial. The oil from the seeds are extracted by crushing, pressing and extraction, leaving a protein rich press cake, commonly used as livestock feed. The primary residues such as leaves and stalks commonly are left in the field at harvest and do not have a high added value, other than mulch / soil improver or cattle feed. The residues obtained at the oil mill (secondary residues such as press cake, seed hulls, olive stones, etc.) may find value addition in animal feed or as fuel for plant operations.

3.2 Palm Oil for fuel

Oil palm is one of the most productive oil crops. The expansion of oil palm plantations in recent years, especially in Indonesia and Malaysia, in the wake of uprooting and burning of forests has alarmed the NGO's. Discussions on sustainable production of oil palm products have therefore been initiated. The use of palm oil as bio-diesel is gaining more importance. In the Netherlands the use of palm oil as bio-fuel for electricity generation has resulted in fierce debate. In 2005 Electrabel (Nijmengen) proposed to use palm oil for co-firing the coal-fired power station. The proposed plans for building of electricity plants by BioX in Vlissingen, Delfzijl en Rijnmond / Maasvlakte (2006) of 50 MW capacity each was rejected because this would be too polluting (NOx emissions ten times higher than a gas fuelled plant) despite previously issued environmental permissions. The subsidies for "green energy" would not be spent wisely and be non-efficiently used. Greenpeace has opposed the use of more palm oil for energy purposes because of the expected dramatic impact of additional deforestation on Kalimantan and Sumatra (Indonesia) and all the consequences for loss of biodiversity and degradation of (peat) land. Also in Belgium the use of palm oil to generate electricity by BioX Energy Belgium in a new electricity plant in the harbour of Antwerp was declined (2008). The argument to use palm oil as green energy source was based on the fact that the CO_2 emitted is not bringing additional CO_2 in the air because this was taken out of the air by the plant when the oil fruits were grown. The efficiency of such use of food grade oils can be argued. Also Essent used 400.000 tons of palm oil in 2006 for co-firing in gas-fired power plants, but this was stopped because of concerns of NGO's). In commission of Essent a Commission (Blok 2007) investigated the sourcing of sustainable palm oil. The Dutch Cramer criteria were benchmarked against the RSPO sustainability criteria (Cramer 2007; Dehue, Ecofys) and the practical compliance of the chain of custody to those criteria were concluded difficult to verify because traceability is hard to obtain.

The use of palm oil for production of bio-diesel can have substantially lower GHG emissions than conventional diesel. But the use of bio-diesel is considered not sustainable, when food grade oil is used and competition will result in higher prices of food products and further deforestation. Lower grades of oil and recycled food oils, including the residual oil (in pressing cakes) and free fatty acids could provide a rich source for bio-diesel production. Biodiesel production from plant oils or animal fat involves conversion into fatty acid methyl esters (FAME) by trans-esterification reactions with methanol (commonly from mineral origin). In this process the glycerol is liberated as a by-product. The biodiesel (or B100) is often blended in a mixture with diesel fuel, for example for 5% (B5).

BP announced to cooperate with Indonesian companies (MARTEK Biosciences Co.) to produce biodiesel from sugar through microbial fermentation to tailored lipids (suitable for jet-fuel). This would reduce the pressure on food oil.

The Malaysian government has announced the national biofuel policy (2005) to reduce the imports of petrochemical fuels and to promote demand for palm oil as a major national resource. The B5 biodiesel use is locally encouraged through incentives and export markets for biofuel are strongly promoted (www.emergingmarkets.com/biodiesel). Large biodiesel plants are being build currently world wide (projected scale up to 800.000 MT/yr). Several large and smaller companies are supplying biodiesel from Malaysia under different brand names (Mission Biofuels / Golden Hope / Carotina / Kulim / Cognis / SuriaChem / Tein Tein / Vertichem / Idsys etc.). Malaysia has approved the manufacturing of biodiesel from palm oil up to 8 million tons per year. The biodiesel production has not yet reached this volume. The B5 mandate (e.g. 5% mixing of biodiesel) for Malaysia would only require 3% of the Malaysian Palm oil production.

3.3 Oil palm by-products

In the palm oil production chain large quantities of biomass by-products (up to almost 5x the weight of oil production) are produced which are hardly used for adding value to the production chain (Elbersen et al. 2005). Calculated based on a total palm oil production of 25 million ton CPO (Oil world annual, 2002) per year, 70-80 million ton of field residues are produced and at the oil mill another 30-50 million ton of biomass (Table 1). Malaysia and Indonesia are by far the largest producers, with the highest productivity per hectare. The productivity of CPO in 2008 has shown a record high level of 42 million tons. In comparison the African productivity per hectare is substantially lower (Table 2, FAO statistics).

Enhancing the sustainability of the palm oil production chain can be achieved by fully exploiting the abundantly available biomass wastes (Fig. 1: shells, fibre, press cake, empty fruit bunches, palm fronts, etc.) as renewable resources in added value products. Currently only part of the waste is used a fuel feedstock in plant operations. The efficiency of utilisation is, however, still low and more efficient boilers are required. Surplus fibre and shell creates an accumulating problem at the oil production plants and burning practices should be eliminated. The availability of the various waste streams and the current practice of waste disposal has been quantified and qualified according to their composition and possible usage (Table 3). To support a bio-based economy landfill processes and composting should be avoided and uncontrolled methane emissions reduced to a minimum. Local employment would be positively affected when new industries could be set up that can process now discarded biomass residues. Manufacturing of novel wood substitute products and competing use of alternative cellulose sources from plantation and agro-industrial residues will have a slowing impact on the rate of deforestation (Van Dam, 2006a,b).

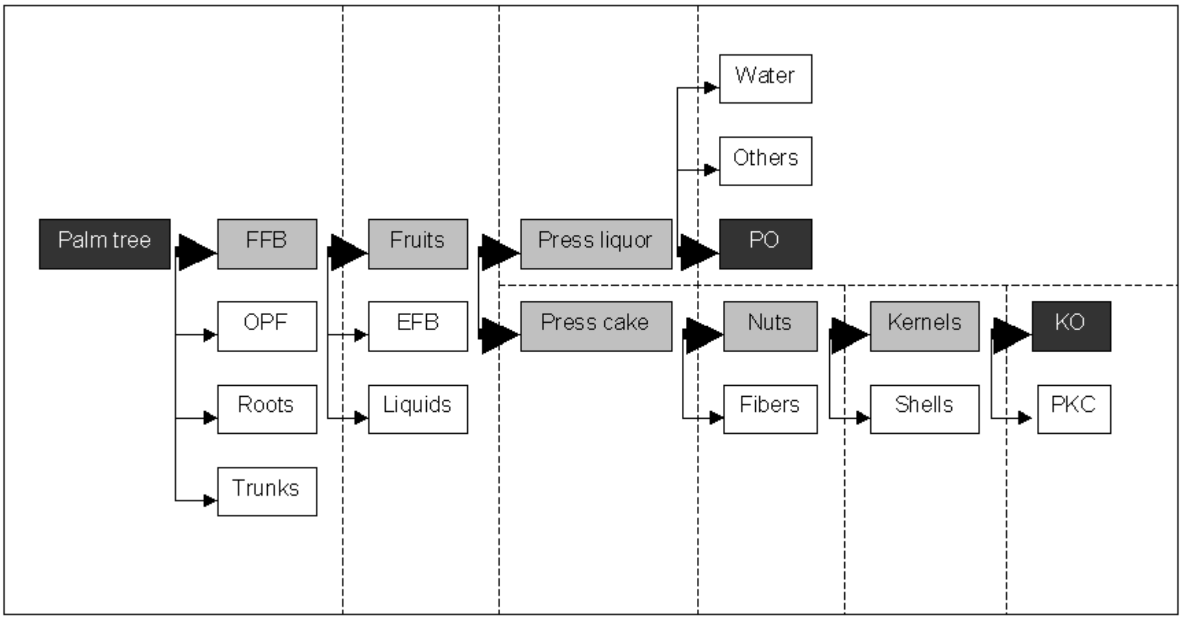

Figure 1 Overview of the chain in which grey boxes dictate intermediate products, black boxes are start and end products and the white boxes are side products referred to as by products. In which FFB are fresh fruit bunches, OPF are oil palm fronds, EFB are empty fruit bunches, PO is palm oil, KO is kernel oil and PKC is palm kernel cake.

3.3.1 Composition and availability of the Oil Palm biomass residues

The availability and composition of the different biomass residues of Oil palm production was examined to determine which of the wastes is most suitable for different bio-refinery processes (Adelwahab-Abraha et al., 2004; W. de Vries, 2005; Elbersen et al., 2005; B. Dehue, 2006). Dry weight figures were estimated for the annually liberated amounts of biomass in Oil palm production (Table 1) based on literature data and extrapolation of statistical productivity data (Table 2, FAO statistics, 2006; Oil world annual, 2006). The data show that the potential substrates for bio-refinery processes are produced in very large amounts.

The utilisation rates of the residues produced at the plantation and of the shells and fibres are reported to be high, while utilisation of POME and EFB is much lower (Table 3). Although some residues have a higher utilisation rate, this gives no indication about the efficiency of utilisation. The plantation residues are left at the site and left to decompose to release organic carbon and the contained nutrients as soil improvement.

Table 1 - Annual productivity of palm oil products and biomass by-products at field and mill level (estimated from 2002 worldwide production data).

Biomass	Where available	Dry matter (DM) per ton of crude palm oil	Worldwide production million tons DM/yr. #	Production tons/ha/yr.
Crude Palm Oil	Mill	1	25	3.50
Kernel Oil	Mill	0.1-0.15	2.5	0.35
Oil Palm Fronds	Field	1.65-2.0	41.5	5,70
Roots	Field, every 20/30 years	0.87	22	3,01
Trunks	Field, every 20/30 years	0.4-0.67	10-17	2,32
Empty Fruit Bunches	Mill	0.32-0.42	8-10	1,11
Fibre	Mill	0.32-0.5	8-12	1,11
Shells	Mill	0.13-0.4	3-10	0,45
Palm Oil Mill Effluent	Mill	0.35-1.0	9-25	1,21
Palm Kernel Cake	Mill	0.06	1.5	0,21
Total products	Mill	1.1	28	
Total by-products	Field, Mill	4.1-5.8	80-130	

Calculated on a total palm oil production of 25 million ton CPO on 7.3 million ha (Oil World annual, 2002)

Table 2 – Major Palm Oil producing countries (FAO, 2006)

Country	*Area Harv (Ha)*	*Production (ton)*
1 Malaysia	3.375.000	59.546.000
2 Nigeria	3.180.000	8.500.000
3 Indonesia	2.790.000	46.800.000
4 Guinea	310.000	830.000
5 Thailand	263.040	4.002.000
6 Congo. Dem Rep	250.000	1.150.000
7 Colombia	145.026	2.600.000
8 Ecuador	145.000	1.505.000
9 Côte d'Ivoire	141.000	1.400.000
10 Ghana	115.000	1.100.000

The current and potential uses of palm oil by-products is listed in table 3. The list shows that currently most by-products are used (disposed off) within the system for mulching / fertiliser and for energy production at the mill. Currently only part of the total secondary by-products is used as a fuel feedstock in plant operations. Particularly, the shells and fibres are released at the mill in the oil extraction process and are used as fuel for heating of the boilers, providing steam for self-sufficient plant operation. Most palm oil mills operate old cogeneration plants using less efficient low pressure boilers (Cogen3, 2004). Surplus of shells may find use in nearby industries (e.g. cement industries) or in road construction. The extra power that is generated can be exported to the national grid, when the local infrastructural conditions alow so. Often due to the remote location of the palm estates these lack the connection to grid. Apparently, the utilisation of POME and EFB is more difficult and the benefits are not considered to outweigh the investment costs for alternative use. POME and EFB are the source of environmental problems, caused by high emissions of methane and pollution of the surroundings. An important remark is that the utilisation rates in countries other than Malaysia are probably lower, because Malaysia has the most advanced palm oil production system. Especially the EFB is barely used and creates problems for its disposal since open field/pile burning is often (officially) no longer allowed. Palm oil mill effluent (POME) is also hardly used and creates an accumulation problem at the oil production mills. Anaerobic digestion in ponds at the oil mill site is causing serious pollution and the emitted methane gas (CH_4) is a very potent greenhouse gas.

Table 3 - Level of utilisation of palm oil biomass residues in Malaysia (1998)

Biomass	Quantity produced (million tons)	Quantity utilised (million tons)	Utilised (%)	Method of utilisation
OPF	27.20	25.83	95	Mulch
Trunks and fronds at replanting	1.38	1.10	80	Mulch
Fibre	3.56	3.20	90	Fuel
Shell	2.41	2.17	90	Fuel
POME	1.43	0.50	35	Nutrient source and organic fertiliser
EFB	3.38	2.20	65	Mulch & bunch ash
Total	39.36	35.00	89	

Source: Gurmit, 1999

One argument for not putting effort in using the biomass residues is that the nutrient content (minerals such as K, N, and P) of the residues that remain in the field does not require compensation. To analyse whether or not certain residues are suitable for bioconversion processes, the chemical composition of the different biomass residues were reviewed. The nutrient composition of the various residues was reported in an evaluation of the production chain in Malaysia and Ghana (Adelwahab-Abraha et al., 2004). Additional information was obtained from several publications in open literature. The composition of the different residues is listed in Table 5. As can be seen from this table, the information is still limited. Some additional characteristics of POME were reported (Ahmad et al., 2003) and, although the characteristics vary between different mills and over time, these data can be used as an indication (Table 4).

Table 4 - Composition of biomass residues from the palm oil production chain.

Product	H_2O	N	P	K	Mg	Ca	Composition
	--%-	---------------------% DM--------------------					
OPF	69.9	0.73	0.06	1.29	0.17	0.35	47.5% cellulose; 9.3% hemicellulose; 16.4% lignin[1] Crude fibre 45%; protein 5.8%
Roots	-	0.32	0.03	0.80	0.08	0.05	-
Trunks	50	0.56	0.05	1.62	0.15	0.31	45% cellulose; 25% hemicellulose; 18% lignin[1]
EFB	58	0.80	0.06	0.24	0.18	-	45-50% cellulose; 25-35% hemicellulose; 25-35% lignin[2]
Fibre	17	2.30	0.01	0.20	0.04	-	65% cellulose; 19% lignin[3]
Shells	20	-	-	-	-	-	-
POME	>70	0.11*	0.005*	0.02*	0.02*	-	95-96% (w/v) water; 0.6-0.7% (v/v) oil; 4-5% (w/v) total solids including 2-4% suspended solids[4]
PKC	33	2	2	0.30	0.30	0.25	8.3% oil, 17.5% crude fibre;14.5-19.6% protein[5]

- = not available, * on % of water basis, # Total palm oil production was 25,235 million ton on 7,3 million ha giving an average palm oil yield of 3,457 ton per ha in 2002 (Oil world annual, 2002); [1] Crop guide, Brehmer (unpublished), [2] Deraman, 1993, [4] Sreekala et al., 1997, [5] www.gpfeeds.co.uk/analysis/palmkern.htm

Table 5 - Characteristics of the palm oil mill effluent determined by Ma (2000).

Parameter/element	Concentration*
pH	4.7
Oil and grease	4
Biochemical oxygen demand (BOD)	25
Chemical oxygen demand (COD)	50
Total solids	40.5
Suspended solids	18
Total volatile solids	34

* All parameters in g/L except pH; Source: Ahmad et al., 2003

The most interesting residues for developing new products are the OPF, trunks, EFB and POME, considering their current low efficient use, the abundant available amounts of the residues and the problems resulting from current practice. The OPF is left at the plantation after harvest of the fruit bunches. They are bulky and dispersed available and require installation of collection and storage centres. The residues at the mill are accumulating in large quantities and especially EFB and POME are causing serious disposal problems. The high discharge temperature and low pH of POME make it an environment in which fermentation processes can occur quickly. Methane emission from the POME ponds are a major concern. Shells and fibres are currently used as fuel for oil mill operations, making them a less suitable substrate, because using the shells and fibres for fermentation processes would mean that other fuels would have to be used instead to generate the power for plant operation. This could be fossil fuels or the methane gas that is released in the POME fermentation.

An average modern palm oil mill with 200.000 tons per annum or ca 600 tons per day CPO capacity provides about 200 - 250 tons of EFB/per day together with surplus of steam and heat for plant operations. There is about 35-40% cellulose contained in EFB and calculated based on a conservative yield of 25% pulp a capacity for a pulping installation would require 50 tons per day output capacity or 15.000 – 20.000 tons per annum.

3.3.2 Nutrient and carbon recycling

Current utilisation of the biomass residues largely consists of recycling it back to the plantation for decomposition to mulch. Only at integrated oil mills linked to palm oil plantations this is possible. Independent mills need alternative ways for disposal. This recycling of residues is considered one of the important criteria for the sustainable production of palm oil by the RSPO, because this results in improvement of soil quality and a lower need for fertilisers (www.sustainable-palmoil.org). By returning residues to the plantation nutrients and organic matter are recycled. The application of residues for the production of energy or manufacturing of other products is therefore not considered as sustainable by the RSPO.

If biomass residues are considered to be used to produce other products, a balance has to be found between extra costs that have to be made to ensure soil quality and the benefits that would result from the use of these residues. Not all the biomass should be removed to prevent a decline of organic matter. As a rough estimation, 25-50% of the biomass residues can be used for other processes without causing a serious decrease in organic matter. One of the recommendations of the RSPO is to grow vegetables as ground cover on plantations to increase the soil structure. When plants with highly branched roots are used the effect on soil structure is even higher. Another option would be to use *Leguminosae* as ground cover as these plants fixate nitrogen from the air, reducing the amount of N-fertiliser needed. Carbon recycling is not necessary on peat lands because the meters-thick layer of peat is a sufficient carbon source.

3.3.3 Biomass feedstock for biorefinery

It is hard to get substantiated and quantified data on the current use of by-products in oil palm production and especially on the efficiency of such use. Only in Malaysia, where palm oil is a major crop, attempts are made to find new uses for the secondary by-products. The current utilisation rate as mulch or fuel and efficiency of such uses can be discussed. Literature clearly shows that biomass utilisation is not optimised and that there is a demand for other uses.

- *Oil Palm Fronds and Trunks*

The lignocellulosic fibres from oil palm could provide suitable feedstock for alternative uses such as fibre board production and wood substitute products. The fronds (10.5 tons per ha per year), and palm trunks (70 tons per ha / 25 yr) are major biomass waste at the estates. Currently no substantial use for these other than mulch have been introduced. The composition of fronts and trunks (table 4) is similar to many other structural woody plant materials and could make extraction of fibres and cellulose possible, when its production could compete in quality and price with established lignocellulose sources.

- *Empty fruit bunch, fibre and shells*

The residues produced at the palm oil mill per ton of palm oil are the empty fruit bunch (EFB 1 ton), mesocarp fibre (0.6 ton) and shells (PKS 0.4 ton) (table 1). Most of the fibre and part of the shells are currently consumed as boiler fuel in inefficient boilers. However, especially the EFB is barely used and creates problems for its disposal since burning in the field is no longer allowed.

Currently most fibre and PKS is used as fuel for the milling process. The amount of energy that is needed for the milling process, both heat and electricity can be combined with information on the efficiency of heat and power cogeneration at the mill. This gives insight into the amount of fibre and PKS needed for the milling process and the amount of fibre and PKS available for alternative applications.

Most palm oil mills operate low pressure boilers (20-25 bar, 220-250 ºC) with a low overall efficiency (Husain 2003). The electricity needed for the milling process was reported to be only about 14 kWh_e per ton FFB (Chlavrapit, 2005, Bronzeoak, 1999) while also the double requirement of 30 kWh_e per ton FFB is mentioned (Husain, 2002). More importantly, about 425-500 kg of steam is needed for each ton of FFB (Bronzeoak 1999, Chalvrapit 2005). The energy requirements for both heat and electricity are given in table 6. The electricity requirement is only 4-8.5 % of the total energy requirement for the milling process (De Hue 2006).

Table 6 Energy requirement for processing 1 ton of FFB.

	14 KWh / tonne FFB	30 KWh / tonne FFB
Energy requirement for 475 kg steam at 20 bar (MJ)	1275	1275
Energy requirement for electricity (MJ)	50	108
Total energy requirement / tonne FFB (MJ)	**1326**	**1383**
Electricity to heat ratio	4.0%	8.5%

The efficiency at which the mill uses its by-products was investigated (Bronzeoak, 1999). The mill uses all its fibre and 50% of its PKS for the milling process. All the fibre plus half the PKS of one ton FFB together contain 2143 MJ[1]. With estimated 1350 MJ needed for the steam and electricity generation, this adds up to a total cogeneration efficiency of 63.0%. This is very close to the 65.6% overall cogeneration efficiency which Husain finds (Husain 2003, Dehue, 2006). It can therefore be concluded that palm oil mills operate at roughly 65% cogeneration efficiency at which roughly all fibre and half the amount of PKS is needed for the milling process. This leaves half the amount of PKS, roughly 4.5 million ton dry mass, available for alternative uses. Interviews with several players in the Malaysian palm oil industry indicated that the numbers for available PKS considered conservative. Part of the shells are currently utilised as fuel in near by industries and as bottom layer in road pavement.

The mesocarp fibre and EFB are seldom sold as fuel as they are less suitable for storage and too bulky to transport. Traditionally EFB was burnt in simple incinerators as a means of disposal and the ash recycled to the plantation as fertiliser. However, because of the air pollution caused by this simple incineration, this is now forbidden in Malaysia. The alternative is returning the EFB to the fields as mulch. This could cut back fertilizer use and improve the soil structure. However, the amount of EFB is only enough to cover 20% of the total plantation (Bronzeoak 1999; Menon 2003) while transport and even distribution associated with this practice make it unpopular with most mill owners: the available transport capacity is often needed for harvest activities and cannot be sacrificed for transporting and distributing mulch to the field. It is suggested that for these reasons EFB is

[1] *Energy content (MJ) in by-products from one ton of FFB:*

	Mass (Kg)	Moisture %	LHV MJ/Kg)	Energy (MJ)
EFB (currently not used)	230	60	6.4	1472
Fibre	130	30	13	1690
Shell	60	20	15.1	906
All Fibre + 50% Shell				2143

often not returned to the field and forms a real waste problem with methane emitting from the piles of EFB (Husain 2002; Harimi 2005; Menon 2003; Prasertsan 1996). Observations at various palm oil mills in Malaysia reveal that especially independent millers do not return the EFB to the field as they do not own the plantations (Van Dam and Dehue, personal communication 2006).

Several studies have estimated the value of EFB when returned as mulch ranging between $2.1 - $3.3 per ton of EFB (Bronzeoak 1999; Menon 2003). These values include the benefits from replacing fertilizer, increasing the FFB yield per ha due to improve soil conditions, minus the costs made for transport and spreading. The potential value of EFB as a source of fuel for electricity generation (Menon, 2003) at an unsubsidised electricity price of 0.17 RM (0.04 eurocents) is roughly 3.5 times higher than the value of EFB as mulch.
There is a new development for utilisation of EFB as energy source. EFB is converted into pyrolysis oil (Venderbosch et al. 2007) which is co-fired in natural gas fired power plants. Here, a pyrolysis efficiency of 70% is assumed with no additional energy inputs required for drying. Furthermore an efficiency of 40% for electricity generation is assumed.

In table 7 the main by-products are listed that are generated on palm oil plantations (primary or field by-products) and at the mill (secondary by-products) relative to the CPO (Crude Palm Oil) produced. Figures show that the potential amount of biomass is very large with an estimated global production of 30 to 50 million tons at the mill and 70 to 80 million tons in the field. These figures are conservative dry weight estimates. Most of this material is found in Malaysia which accounts for almost 50% of world palm oil production and in Indonesia which accounts for almost 1/3 of world palm oil production.

Table 7 - Productivity of Palm oil by-products

	ton / ha /y	current /*possible* use	remarks
OPF	5.7	Mulch, *pulp, fibre,* feed	Distributed over plantation
Roots	3.0	Mulch	Too much available at once Uprooting disturbs the soil
Trunks	2.3	Mulch, *fibre board*	Too much available at once at remote sites
EFB	1.1	Mulch, fuel, bunch ash, *fibre board, pulp, paper*	Less well suited as fuel
Fibre	1.1	Fuel for mill, *fibre board*	
Shells	0.5	Fuel for mill, activated carbon, briquette *particle board*	Silicate forms scale when burned
POME	1.2	Methane, fertilizer, feed, *soap*	Methane emission, river pollution are a problem
PCK	0.2	Feed, fertilizer	Feed potential not fully used

4 Other biomass resources

The 9th Malaysian Plan (W.K. Hoi and M.P. Koh, FRIM, 2008) has emphasized the biomass energy production very strongly. Besides the dominant issues on Oil Palm use (biodiesel) the technologies for production of briquettes and charcoal for solid fuel manufacturing has received attention. These residues could also be used for direct combustion in industries (palm oil, rubber, brick manufacturing, cement). Other biomass residues (forestry and saw mill residues, wood waste, rubber wood, crop residues from rice and sugar cane, animal waste, municipal solid waste) combined amount ca 15% of the total more than 70 million tons of biomass collected in Malaysia each year. Oil palm production accounts for 85% of the collected biomass. Incentives to better use these resources are limited and is poorly organized. Formulation of a CDM approval structure and criteria for CDM could help to stimulate renewable energy production. The current crop production in Malaysia is dominated bythe area planted with Oil Palm (44%), followed by rubber plantations (31%), cocoa (7%), rice (13%) and coconut (6%). Only a part of the residual biomass is utilised as fuel in industrial processes such as drying (timber / rubber) or manufacturing of bricks.

4.1 Jatropha

Like in many tropical countries (India Pakistan, Indonesia, Thailand, Philippines, etc.) trials for *Jatropha curcas* production have been initiated also in Malaysia (Datuk Peter Chin Fah Kui, 2008). It is not yet in a commercialization stage but field trials are conducted at several locations (Brunei, Sabah). *Jatropha* has been selected as high promising oil seed crop for bio-diesel production. It has the advantage of producing seeds with up to 40% of a non-edible oil, that does not compete with food oil production. It is pest resistant and it is claimed that it can grow on marginal lands and has a high drought resistance (at least 600 mm rain per year required for seed production). The expansion of *Jatropha* production is advertised by SLDB (Sabah Land Development Board) as a poverty reduction program. The earning of farmers is calculated as RM 1500 per month for 6 acres *Jatropha*. However, in other countries the resistance of small holder farmers to produce non-edible crops like *Jatropha* is high. The residues of the shrub cannot be fed to the animals as these are toxic. Research for better use of by-products is on-going (also at WUR and RUG in cooperation with Indonesian partners).

4.2 Sugar cane

Sugar cane has been grown in Malaysia since the 19th century but production in Malaysia is relatively small and declining especially since the expansion of the Oil palm area. Sugar cane is not among the top 20 commodities (see Appendix) for Malaysia. The yellow variety is most popular and commonly used to provide fresh juice drinks. Sugar cane is studied for intercropping in Oil Palm production. The cane is grown in between the immature young palms to provide additional income to the farmers (MPOB information series TT 352, June 2007).

The planted area (between 15-24.000 ha) with a production of 1.0-1.1 million tons. The domestic consumption is much higher and more than 90% of Malaysian sugar for refinery is imported (Brazil Thailand and Australia). http://www.fao.org/docrep/005/x0513e/x0513e22.htm 1997).

The most important by-products from sugar cane production are molasses (ca 50% sugar, 40.000 tons per year) (suitable for ethanol production) and bagasse (2.5 million tons), the lignocellulosic residue left after sugar extraction. Other residues (filter cake, effluents) either are fed to the animals or returned to the field and used as fertilizer.

4.3 Rubber

The annual production of rubber in Malaysia amounts ca 1.2- 1.5 million tons on 1.7-1.8 Million ha of rubber estates. Next to palm oil it is the major agricultural commodity of economic interest (see appendix). The majority of the natural rubber is exported to China. An average rubber factory produces 20 tons of rubber per day and also 400 m^3 of effluent waste water (process water and latex residues), which is discharged mostly without treatment. Rubber wood residues are a major byproduct from the natural rubber production. The large volume of residues (11 million m^3), which have no or very little economic value are a major disposal problem. Technologies to make particle boards from rubber wood have been reported to yield good products.

4.4 Rice

Malaysia is growing rice on average 600.000 ha, producing ca 2 million tons of rice annually. Malaysia is self supporting for 65%. The remaining 35% is imported. Rice straw (850.000 tons)* and rice husk (470.000 tons or 3.5 milion m^3) are discharged by landfill or open air burning. Only 2% of the rice husk is used for energy production. As a fuel it is considered less suitable because of its high silica content, which is causing scaling in the burners. Options for use of rice residues in manufacturing of building products (fibre cement boards / particle boards) have been reported from various countries.

* (this value should be higher for 2 million tons of rice at least 2.5-3.0 million tons of straw should be liberated)

4.5 Cocoa

Local production of cocoa beans occupies 380.000 ha, with a local yield of beans of 30.000 tons (FAO 2007). But Malaysia, now the 4th largest cocoa processing country with 258.000 tons capacity per year (2005; or 7.5 % of the total world production), has the ambition to become the leading cocoa processor. The total grinding capacity for 2010 is projected to grow to 360.000 tons per annum. In the production of cocoa beans the shells are collected and traded as organic fertilizer or mulch or as ingredient in animal feed.

4.6 Coconuts

Malaysia used to produce substantial volumes of coconut oil (per year ca 90.000 tons). Farming of coconut trees in Malaysia is neglected and declining over the years because of the strong focus of the government on Oil Palm production in Malaysia. In 1995 the production was still more than one million tons per year (FAO stat), while this was reduced to just a little more than of half this volume in 2007. Coconuts are grown on 180.000 ha farm land, but are often not plantation crops but dispersedly grown by small holder farmers. Not much attention is paid to the development of this commodity. The nutrient rich coconut water (ca 136 litres / 1000 nuts) is also rich in sugars that could be used for ethanol and acetic production. These are now commonly discharged in the oil mills and not used for fermentation. Other residues such as shell and husk are not of commercial interest in Malaysia. In other coconut producing countries (Sri lanka, India, Philippines, Indonesia etc.) the use and exports of the coconut husk for fibre or horticultural substrate production is common practice. The shells yield a good charcoal.

4.7 Other

Coffee an fruits such as pineapple and banana are produced by the Malaysian farmers on substantial scales (FAO stat 2007). Residues from farming and food processing industries are not collected for value addition. The fibres that can be obtained from pineapple or banana are of good quality but do not find commercial use. The coffee beans yield husks and coffee pulp, which is used to produce compost and soil improvers (mulch). Higher value addition is of interest.

For most of the lignocellulosic residues mentioned here the technology for manufacturing of briquettes or charcoal have been reported. (K.M. Poh, 2005).

5 Conclusions

The use of palm oil as source for renewable energy is not per definition sustainable. Enhanced bio-diesel consumption will result in expansion of the production and cause further decline of biodiversity.

Utilisation of the ligno-cellulosic by-products of Palm oil production could increase the sustainability of Palm oil. Conversion technologies for production of wood substitutes (fibre boards and panels) could reduce the rate of deforestation.

It is estimated that up to 50% of the by-products of palm oil production in Malaysia and Indonesia could become available for biomass utilisation and energy export (corresponding roughly to 40-50 million tons dry weight biomass). Because of the low density of the residues local on-site pre-treatment of the biomass would be required for conversion to biomass with sufficient energy density (or commercial value) for economic transportation.

The developments in Malaysia with respect to palm oil by-products utilisation are much more advanced as compared to Indonesia, where deforestation and establishment of new palm oil plantations still occurs at an alarming rate.

A detailed study into the net mass balance and potential biomass production from the palm oil chain and the possibilities of finding added value for these products in a biobased economy is essential for developing economically, socially and environmentally sustainable palm oil systems.

Enhancing the sustainability of the palm oil production chain can be achieved by fully exploiting the abundantly available biomass wastes (shells, fibre, press cake, empty fruit bunches, palm fronts, etc.) as renewable resources in added value products. Thus increasing the sustainability of the palm oil chain and producing significant amounts of biomass for production of renewable energy and products.

The recognition that utilising by-products for added value is beneficial to the sustainability of palm oil production is essential for certifying the sustainability of the palm oil biomass energy and products.

Multi-stakeholder involvement is required for addressing the sustainability of the food oil supply chain. This would also include outsider (non-food) industries involved in energy and fibre products marketing.

EFB and POME are the two major biomass fraction that require development of better conversion methodology

Carbon trade and CDM could become major driving factors for development of sustainable biomass feedstock supply.

Other crops than oil palm play a minor role in Malaysia, but still the residues from rice, rubber, cacao production (etc) could be converted for value addition by various biorefinery processes to yield a large number of 'green' products such as fibre to manufacture particle boards or cellulose, pulp and paper, briquettes for fuel, pyrolysis oil, ethanol by fermentation of carbohydrate rich residues or biogas from anaerobic digestion of effluents.

Demonstration at pilot scale production of selected technologies will generate the necessary information for the technical feasibility and projections for productivity on industrial scale. The results will form the basis for assessment of the economic feasibility and for investments in full scale production facilities.

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7 APPENDIX

FAO Statistics of crop production in Malaysia 2007

Rank	Commodity	Production (Int $1000)	Flag	Production (MT)	Flag
1	Palm oil	4790632		15823200	
2	Indigenous Chicken Meat	1157255		992142	Fc
3	Natural rubber	643441		1199600	
4	Palm kernels	535395		4097000	*
5	Rice, paddy	450010		2197700	
6	Hen eggs, in shell	349691		465000	F
7	Indigenous Pigmeat	194208		191781	Fc
8	Indigenous Duck Meat	162404		124757	Fc
9	Pepper (Piper spp.)	87692		19000	F
10	Bananas	75530		530000	F
11	Pineapples	69620		360000	F
12	Coconuts	52455		580000	*
13	Vegetables fresh nes	46912		250000	F
14	Oilseeds, Nes	43947		150000	F
15	Coffee, green	32702		40000	F
16	Cassava	29436		430000	F
17	Indigenous Cattle Meat	28474		13767	Fc
18	Fruit, tropical fresh nes	26325		230000	F
19	Tobacco, unmanufactured	25525		14000	F
20	Cocoa beans	23105		30000	

