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A CASE STUDY ON PALM EMPTY FRUIT BUNCH AS ENERGY FEEDSTOCK

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ABSTRACT

Abundant sources of oil palm based biomass provide an impetus for the sustainable generation of bio-ethanol. Previously used as fuel to generate steam at the mills, the waste inflicts a severe impact towards the protection of the environment. Conversion of bioethanol from biomass, especially from empty fruit bunches (EFBs) offers a simple yet effective treatment of waste from the palm industry. One of these options is the bio-conversion of lignocelluloses to bioethanol using acid hydrolysis and fermentation. EFB is one of the candidates for renewable energy to fulfil the requirement of clean carbon emission. The development of lignocellulosic-bioethanol as an alternative energy provides an opportunity and incentive to generate some Carbon Emission Reduction (CERs) credits.

1.0 Background of the Palm Oil Industry

The Malaysian palm oil industry is at the forefront of technology and production in both plantation [upstream] and oleo-chemical [downstream] products for the global markets. With a planted area of 4.48 million hectares, it generates 17.73 million tons of palm oil annually through a combined processing capacity of 92.49 million tons by 406 mills and 52 refineries (Malaysia Palm Oil Board 2009). With export earnings of RM 65.2 billions, plantation firms are attracted to further seek huge land banks for expansion. Malaysia produces about 41% of the world's supply of palm oil, second to Indonesia at 44.8% (19.3 million tons). Malaysia also accounts for the highest percentage of global vegetable oils and fats trade in the year 2008. Malaysia and Indonesia palm oil mills share a similarity on combustion of oil palm crop residues like fibres and shells (DeVries 2008) with a combined market share of more than 90% of global palm oil production or half of the world oil and fats trade. From these perspectives, it is well justified to explore the Malaysian palm oil industry's wastes as a case study for fossil fuels replacement as an alternative source of bio-fuel energy like bio-diesel, bio-ethanol, bio-methanol and bio-hydrogen (Lam *et al* 2008). Oil palm planting would rise by 4 to 6 million ha by the year 2030 raising oil production from 28 million tons/year to 50 million tons/year (Focus on Surfactants, 2006). Besides producing oils and fats, there are continuous interests concerning oil palm waste as renewable energy (Sumathi *et al* 2008). The APEC 2008 report suggested that economies with a high resource like Malaysia has the potential to develop second generation bio-diesel feedstock (Milbrandt & Overend, 2008). The oil palm is a well-known plant for its other sources of renewable energy with a huge quantity of biomass by-products developed to produce value added methane gas, bio-plastic, organic acids, bio-compost, plywood, activated carbon and animal feedstock (Sumathi *et al* 2008). Expanding demand for alternative energy like bio-diesel has created greater consideration for oil palm waste because of the 'food for fuel' issue. UNDP (2007) reported that between 2006-2030, global primary energy demand is projected to increase at an annual rate of 1.6% with 70% demand coming from developing countries like China which alone will account for 30%. Based on this assumption, bio-ethanol can be a good primary energy generating huge potential for EFB as biomass energy feedstock.

2.0 Methods
This paper will be using a case study approach on the Malaysian Oil Palm Industry using recent secondary data and archival records. A review on the oil palm process in relation to EFB sources, ethanol yield and current environmental issues will be illustrated. Selected data from research publications by plantation journals is used to compare and describe the potential of EFB as biomass energy, its viability and why it should be promoted as a source of renewable energy.

3.0 Overview of Oil Palm Industry
Indigenous to Africa, the oil palm (Elaeis guineensis Jacq.) has been domesticated from the wilderness and transformed to become a plantation-based industry (Yusoff 2006), growing well in wet and humid places like Malaysia (Abu Hassan *et al* 1994, Basiron 2007). Oil palm is a perennial tree crop, which is cultivated extensively in the humid tropical land. For efficient productivity, average planting cycle of a palm tree is about 25 years. The oil palm plantations in Malaysia are planted with a density of 148 palm tree per hectare. One stand of oil palm tree occupies 0.0068 ha of land. Each palm yields about 150 kg of fresh fruit bunches (FFBs) per year (Yusoff 2006). The reddish colour fruit grows in large bunches; each weighing about 10–40 kg. Surrounded by the soft pulp, inside of each fruit seed is the palm kernel. The oil extracted from the pulp is edible while kernel oil is used mainly in soap-manufacturing industries. Oil palm fruit is usually harvested after 3 years from planting with the maximum yield achieved by the 12–13th year, and then the yield continuously declines until the end of the 25th year (Yong *et al* 2007).

4.0 Environmental Problems in the Palm Oil Industry
The oil palm fruit generates two components of products namely crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO is obtained from the mesocarp and CPKO is obtained from the endosperm (kernel). During the extraction process, it generates by-products and wastes known as EFBs, palm oil mill effluent (POME), sterilizer condensate, palm fibre and palm kernel shell (Yusoff 2006). The CPO processing is entirely physical and mechanical and does not require any chemical as a processing aid. The oil, by-products and residues originate from the FFB. However, the processing environment raises a number of pollution problems such as high noise level from the machines, high water consumption, generation of high organic content of wastewater, generation of large quantities of solid waste and air pollution as shown in Figure 1 (Chavalparit *et al* 2006).

Figure 1 Emission Associated with the Crude Palm Oil Production and Characteristics of POME (Source: Chavalparit *et al*, 2006), Sumathi *et al*, 2008)

Process	Air emission	Waste water	Solid waste	POME characteristics			
				Parameter	mg/L	Element	mg/L
Loading ramp	-	Oil contaminated W/W	-	Oil & grease	4,000-6,000	Potas sium	2270
Steriliza tion	Steam blow	High organic W/W	-	Biochemical oxygen demand	25,000	Magne sium	615

	down						
Bunch stripping	-	-	EFB	Chemical oxygen demand	50,000	Calcium	439
Oil extraction	-	-	Fibre, shell	Total solid	40,000	Phos phorous	180
Oil clarification	-	High organic W/W	Decanter cake	Suspended solids	18,000	Iron	46.5
Oil purification	Vapour	High organic W/W	-	Total volatile solids	34,000	Boron	7.6
Steam generation	Black smoke	-	Ash	Total nitrogen	750	Zinc	2.3
				Ammonicals nitrogen	35	Manga nese	2.0
						Copper	0.89

The palm oil industry is striving towards quality and environmental conservation through a 'sustainable development and cleaner technology' approach through the requirements of Environmental Quality Act (EQA) and the specific regulations governing the management of CPO mills. The present practices in CPO mill are still insufficient for full compliance of regulatory requirements in terms of combustion, fly ash and energy conservation (Yusoff, 2006) because the annual production volume exceeds the conversion process. The surplus biomass (Figure 2) ends up being discarded in open areas or burnt; generating pollutant gases (Yong *et al*, 2007).

Figure 2 Biomass per Hectare of Oil Palm (Source: Yusoff, 2006)

MT of fresh and dry weight EFB, shell, fibre and effluent per ha/year after milling 1 ha of mater oil palms		
	Fresh wt (mt/ha/year)	Dry wt (mt/ha/year)
FFB	20.8	10.60
EFB at 22% of FFB	4.42	1.55
Fibre 13.5% of FFB	2.71	1.63
Shell 5.5% of FFB	1.10	1.10
i) Sterilizer condensate 12% FFB	2.41	0.12
ii) Clarification sludge 50% of FFB	10.04	0.50
iii) Hydrocyclone washing 5% FFB	1.00	0.05
Total POME	13.45	0.67

Malaysia and Indonesia (Mahlia *et al*, 2001), accounting for 86% of global palm oil production, contribute 1.5% of the annual rate of deforestation of tropical rainforests (Fagione *et al*, 2008). The conundrum sets an environmental urgency for the processed wastes to be use as an alternative energy feedstock. Oil palm is a multipurpose plantation but it is also a prolific producer of biomass (Kelly Yong *et al*, 2007) and the projected growth in cultivation raises massive environmental concerns. The supply of oil palm biomass and its processing by-products are found to be 7 times that of of natural timber (Basiron and Chan, 2004). A tropical country like Malaysia has an enormous supply of biomass resources generated from photosynthetic activities throughout the year such as trunks, fronds and from the oil extraction process such as the mesocarp fiber (MF) (9.66 million tons), shell (5.2million tons), EFB (17.08million tons) and POME. It was estimated that more than 50 million tons of total biomass were generated by the palm oil industry in the year 2005 and is expected to continuously increase in proportion to the world demand of edible oils (Hassan *et al*, 2004). Generally, palm oil forms about 10% of the whole palm tree, while the other 90% remains as biomass that is full of fiber and cellulose used to generate steam for power generation in palm oil mills. Palm biomass is generally composed of lignin, cellulose and hemicelluloses (Thiam & Bhatia 2008). Growing interest in alternative energy provides great potential for such use as renewable energy. However, there are concerns with regards to the enormous potential vegetable waste (Bio-Centrum-DTU, 2008) in the form of dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids. Decomposition is a problem when the wastes are disposed within limited open spaces and in catchment ponds. The option of incinerating EFB is restricted by Department of Environment (DOE) within the confines of EQA (Yusoff, 2006).

5.0 Empty Fruit Bunch as Biomass Renewable Energy

There are 406 palm mills in Malaysia catering to the milling of oil palm fruits produced by 4.48 million hectares of plantations. The focus of this study is to address issues related to the supply chain of EFB as a ready feedstock for energy production. EcoIdeal & Mensilin (2006) observes, "palm oil mill waste in the form of biomass residue such as EFB can be a potential renewable energy producer in Malaysia". It is estimated that each year Malaysia produces about 30 million tonnes of oil palm biomass that includes trunks, fronds, and EFB" (Bio-Centrum-DTU, 2008). The EFBs constitute 9% of the total oil palm industry's 90 million tons of renewable biomass leftover after extraction at oil mills (Gutierrez *et al*, 2007). Harnessing it as industrial energy feedstock (through combustion or as ethanol potential), may promote replacement of fossil fuel for industrial use and consequently address the issue of waste management since the density of EFB makes it uneconomical to transport, store and manage. It is the hope of this project to provide an overview of the potential of EFB as a ready feedstock for bio energy production. Biomass refers to living and recently living biological material, which can be used as fuel or energy for industrial production (Sumathi *et al*, 2008). Biomass conversion relates to production of bio-fuels, which includes ethanol, methanol, bio-oil, and bio-diesel as a source of renewable energy. Despite its potential wide use, there is still much to be done to optimize the utilization of biomass for cogeneration in Malaysia (Sumathi *et al*, 2008). Firstly, the biomass can be converted to high-value bio-ethanol using proper technology. Biomass is expected to play a substantial role in the future global energy balance as it can contribute to about 12% of the world's energy supply but more significantly, 40% to 50% of energy in many developing countries (Thiam & Bhatia, 2008). With improved processing efficiency to reduce environmental impacts, the potential and importance of oil palm biomass for the production of bio-ethanol using fermentation processes can be economically realized. This suggestion is augmented by the APEC 2008 report on oil palm as a resource for bio-energy with the most potential.

6.0 Second-generation Bio-fuels Potential from Bio-ethanol

Malaysia devotes 11% of the total land area or 62% of the economy's agricultural land for planting oil palm. Assuming that 20% of palm oil productions are used for bio-fuels, based on a yield of 3.2 million tons of bio-diesel, it can replace 64% of diesel consumption thereby cutting 41% off its crude oil imports (Milbrandt & Overend, 2008). However, it does not solve the problem of biomass waste. The National Energy Research Center (PTM) 2007 reported that 69.32 million tons of biomass residues are generated annually, translating to 9.7 hm3 of ethanol or 4.6 million tons of gasoline equivalent (Milbrandt &

Overend, 2008). This would represent 60% of current gasoline consumption thereby displacing 59% of crude oil imports. To realize this potential, there is an obvious need to transform the residue into a more-valuable end product (Yong *et al*, 2007) by converting EFB into biomass energy feedstock. Each year, oil palm mills generate 15.8 million tons of EFB and 9.6 million tons of MF. The EFB, MF and shells are collected daily from the pressing of sterilized fruits. These can be transformed into three types of biomass energies: i.e. bio-products, bio-fuels, and bio-power (Yusoff, 2006). The total energy from pressed shell and fibre of a palm tree is 14GJ. However, EFB with a heat value of about 1950 kcal/kg at 50% moisture has to be shredded and dehydrated to a moisture content below 50% to make it more combustible (Yusoff, 2006). EFB are commonly incinerated for its ash which makes a very good fertiliser/soil conditioner but the high moisture (>60%) causes it to emit 'white smoke' (Yusoff, 2006). EFB is a solid residue produced in the highest amount as a by-product in palm oil processing shown in figure 3 (Gutierrez *et al*, 2009). The lignocellulosic biomass (cellulose, hemi cellulose and lignin) contained in EFB can be used for ethanol production (Rahman *et al*, 2007). EFB is also a potential source of xylose for production of xylitol, a high value product. The increasing interest in the use of lignocellulosic waste for bioconversion to bio-fuels and chemicals is attributable to low cost, renewalibity and the widespread sources of sugars. Biomass was the world's first fuel and source of energy, but when coal became widely available, followed by bio oil and natural gas, its use declined. Nevertheless, the importance of biomass energy in developing countries today is indisputable. (Hussain *et al*, 2006).

7.0 Empty Fruit Bunch for Bioconversion to Bio-ethanol

Utilization of bio-fuels worldwide is commonly dependent on either a politically decided economic measure to reduce sales prices, or the commitment of environmentally concerned consumers that are willing to pay higher prices for renewable fuel. However in Malaysia, the existing price structures for fuels are influenced by the fossil fuel-subsidizing policy, which makes bio-fuels even less competitive although it is technically realistic to introduce 10% - 20% bio-diesel (B10) and 5% bioethanol (E5) to fuels in the existing engine technology. The launching of the National Bio-fuel Policy in March 2006 by the Malaysian Government hastened the use of bio-fuel in line with the existing Five-Fuel Diversification Policy to mitigate effects of crude oil escalations and commitment to renewable resources (NIRAS, 2006) such as ethanol for motor vehicles. Ethanol (CH3CH2OH) is an oxygenated fuel that contains 35% oxygen which helps to reduce particulate and NOx emissions during combustion while significantly reducing environmental pollution (Thiam & Bathia, 2008). Bio-ethanol, an eco-friendly fuel made from plant biomass, is an alternative to conventional gasoline. Ethanol is produced by utilizing sugar-containing feedstock such as renewable biomass energy through a fermentation process and can be a potential source of sustainable transportation fuel. Economically, EFB can be used as a resource for conversion to bio-ethanol since production is 6.1 million tons dry EFB and forecasted to increase to 7.6 million tons dry EFB by 2025 (Bio-Centrum, 2008). The Danish Technical University had conducted tests on EFB in Malaysia for the production of cellulose-ethanol (Bio-Centrum, 2008) and found it suitable for ethanol production with an estimated yield of 39% (388 liters ethanol, on 1 t dry raw material). Other palm biomass like trunks having the highest ethanol yield of 451 l/ton dry matter while fronds have the lowest ethanol yield of 377 l/ton shown in Figures 3a, b & c.

Figure 3a: Ethanol Yields from EFB, Trunks and Fronds (Source NIRAS, 2006)

Biomass	EFB	Trunks	Fronds
Glucose g / g Dry Matter	0.43	0.65	0.47
Xylose g / g Dry Matter	0.26	0.12	0.24
Ethanol L / ton Dry Matter	388	451	377

Figure 3b: EFB Production and Estimated Production (100% Dry Matter) (Source: NIRAS, 2006)

	2004	2005 *
PLANTING *(Hectares)*		
Area	3,875,327	4,049,201
PRODUCTION *(Ton)*		
Crude Palm Oil	13,976,182	14,961,658
EFB, dry **	5,019,006	5,323,138
PRICES *(RM / Ton)*		
Fresh Fruit Bunches (1% OER)	17.26	14.55
YIELDS *(Ton / Hectare)*		
EFB @ 33% DM **	3.92	3.98
Note * Preliminary figures as at 11 January 2006. ** Calculations made on following: FFB contain 21,1 % EFB; @ 67% moisture		

Figure 3c: Potential Ethanol and Forecasted EFB Production by MPOB based on 22% EFB to FFB and Moisture at 65% (Sources: MPOB & NIRAS, 2006)

Year	Projected EFB production million tons dry matter / year	Potential Bioethanol production million per l / year	GJ * / year * Energy content in ethanol: 22 MJ / litre	Potential Bioethanol ktoe / year
2005	6.14	2,382	54,793,360	1,863
2015	7.59	2,945	67,733,160	2,303
2025	7.66	2,972	68,357,840	2,324

EFB constitutes more than 20% of the fresh fruit weight. EFB, a fibrous and relatively wet material (moisture content about 65 to 70 %) comprising lignocelluloses (cellulose, hemi-cellulose, lignin), is difficult to degrade for ethanol production so pretreatment and hydrolysis steps are required in order to obtain the fermentable sugars. To understand the technology associated with bio-ethanol using EFB, we have to understand types of extraction methods available to convert the energy. There are several methods to produce bio-ethanol from cellulose and hemicelluloses (branched polymers of xylose, arabinose, galactose, mannose, and glucose, of which xylose is the largest to form micro fibrils) by pre-treating with acids and enzymatic fermentation through Saccaromyces cerevisae (Hadyan, 2006; Bio-Centrum, 2008) for glucose/sucrose conversion. Simultaneously with the treatment, hemi cellulose is partially hydrolyzed forming pentoses (mainly xylose) and hexoses (including glucose) (Cheng *et al*, 2007). The key to ethanol productivity is the breeding of superior yeast strains. Critical consideration required for efficient bio-ethanol production are, tolerance to high temperature (reactor operates at 190ºC), acidity, cooling costs, increasing saccharification (sugar transformation) and fermentation yield (Sugiyama *et al*, 2008). The total energy obtainable from oil palm wastes can be higher than 20% of country's transportation energy requirements if the pentosan hemi cellulose content can be converted to ethanol, (Sugiyama *et al*, 2008).

8.0 Bio-ethanol Extraction Methodology

There are two sets of approach to obtain bio-ethanol. The first step is to hydrolyze EFB in high temperature by pre-treating with sodium hydroxide and diluted sulfuric acid (0.4%-0. 7%) to break the lignin (complex polymer of phenyl propane units) seal into sucrose sugar (Hadyan, 2006; Cheng *et al*, 2007). The second is to set the fermentation with an enzyme called invertase (Saccaromyces cerevisae), which acts as a catalyst in anaerobic condition at different concentration of yeast. Saccharomyces, cerevisiae is a common microorganism (ordinary baking yeast) is efficient in converting sugars into ethanol and able to ferment mannose as well (Cheng *et al*, 2007). Alternative yeasts like Pichia stipitis, Candida shehatae and Pachysolen tannophilus can be utilized but these microorganisms have lower efficiency in ethanol production and reduced tolerance (Gutierrez *et al*, 2007). The inoculums concentration had no effect on the final ethanol concentration but the duration of fermentation decreased when yeast concentration is increased (Hadyan, 2006). However, yeast "Saccharomyces cerevisiae cannot ferment the xylose because it lacks both a xylose-assimilation pathway and adequate levels of key pentose phosphate pathway enzymes". Depending on the microorganism and the fermentation condition, Yeoh & Lim (2000) reported three types of xylose fermentation processes with verifying ethanol yields of 30% to 50% of initial xylose weight. Gutierrez *et al* (2007) support research findings that EFB has been successful in producing glucose and xylose. There are numerous studies over the years trying to increase yield of ethanol at different concentration of glucose and Saccaromyces cerevisae from EFB through pyrolysis and fermentation or hydrolysis, respectively (Cheng *et al*, 2007).

9.0 Ethanol Concentration

Ethanol concentrations refer to the purity and yield as a basis of economic measure on its viability in terms of process or methods refers as technology. Numerous tests were done (still is) to increase glucose concentration to elevate ethanol concentration such as Hadyan (2006) research using 15mg/ml of glucose to extract only 13.8 % ethanol (w/w). The concentration was improved to 39% in 2007 by a Denmark Technical University researcher (Bio-Centrum, 2007). A subsequent improvement by Gutierrez *et al*, (2007, 2009) to 42% using process integration of biomass-to-ethanol conversion known as simultaneous saccharification and fermentation (SSF). A further improvement by Cardona & Sanchez (2007) using simultaneous saccharification and co-fermentation (SSCF) where engineered microorganisms Zymomonas mobilis is used to hydrolyze cellulases and to ferment hexoses and pentoses in the same unit with an ethanol concentration of about 6% by weight and further distilled to 42% (Gutierrez *et al*, 2007). Thiam & Bhatia (2008) stated numerous efforts have been reported to develop commercially viable thermo chemical-to-ethanol processes yielding up to 50-80% ethanol using synthesis gas-to-ethanol processes but yet to be cost effective. Despite technological improvement, production of cellulose-ethanol has been very costly in terms of multi stage process. This could be the reason why many plants have been either currently at testing, demonstration, or at pilot plant stage respectively.

10.0 Direct Bioconversion Process with Compatible Mixed Culture

One cost effective method is direct bioconversion that eliminates the need for a lengthy process but the yield is less satisfactory. Kabashi *et al* (2007) had proposed direct bioconversion (single-step) of EFBs as alternative process using compatible mixed culture of lignocellulolytic fungi and yeast to increase the yield of ethanol production. The EFB were stored at 4 ºC then dried for grinding into particles of 100 - 500 µm in size before decomposition by 4 fungals at 37 °C (Phanerocheate chrysosporium, Trichoderma harzianum, Mucor hiemalis and Aspergillus niger (SS-103) and 1 yeast strain (S. cerevisiae) was incubated at 25 ºC for 24 hours. Figures 4a & b, indicated that the highest ethanol production (14.2%, v/v) was observed by TH-SC combination whereas the lowest was 6.4 % (v/v) in AN-SC combination (Kabbashi *et al*, 2007).

11.0 Wet Explosion

Bio-Centrum-DTU (2008) develops a more promising commercial extraction with 39% through wet explosion. The approach to ethanol extraction is to subject EFB to ammonia freeze explosion (AFEX) cellulosic pre-treatment to be enzyme-compliant to a theoretical potential of 98%. AFEXs suggest lower waste generation cost and high cellulose digestibility, high hemi-cellulose sugar recovery, low capital and energy cost, low lignin degradation, and recoverable process chemicals (Bio-Centrum, 2008). Instead of acid dilution, this method uses alkaline- based methods to solubilize a larger fraction of lignin leaving hemi-cellulose in an insoluble form. The AFEX reduces the requirements for enzyme (cellulase) and disrupts lignocellulose but removes neither hemi-cellulose nor lignin. The 'Celluclast' endo- glucanasses enzymes supplied by Novozymes is then used to hydrolyse cellulose to glucose (Bio-Centrum, 2008). Cellulose is a polysaccharide with a high molecular weight bound covalently by hundreds or thousands of monomeric units. The glucose monomers are bound together with β-1, 4 orientations in the cellulose polymer. The compound houses a disaccharide of two β-1, 4 bonded glucoses known as cellubiose (Bio-Centrum, 2008). A comparative ethanol potential for the biomasses (EFB, trunks and fronds) with the highest content of fermentable sugars was calculated with yields of 0.5 g ethanol /g glucose and 0.35 g ethanol /g xylose. Using a density of 0.789 g/ml, the calculations show ethanol yields of 388 L ethanol /dry EFB summarised in Figure 5.

Figure 4a: Compatibility of Mixed Culture on PDA Plates (Kabbashi *et al*, 2007)

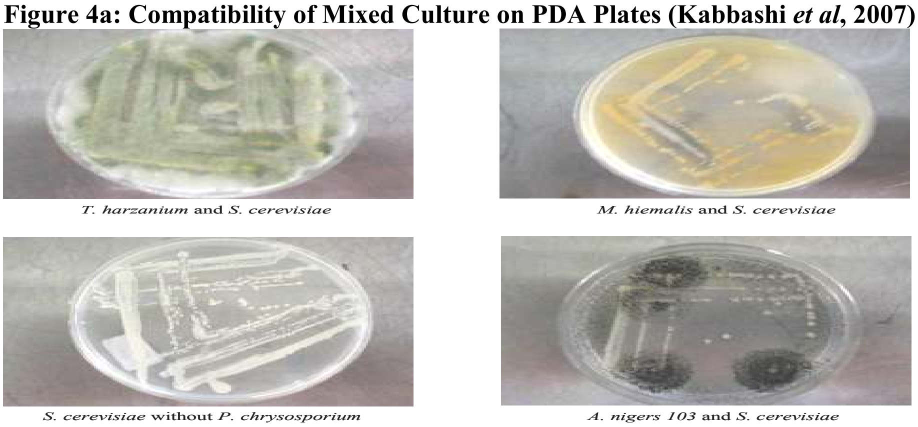

Figure 4b: Production of Ethanol (% v/v) with Different Mixed Culture (Kabbashi *et al*, 2007)

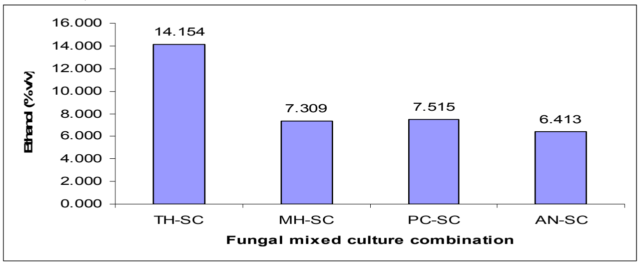

Figure 5: Calculation of Ethanol Yield (Source: Adapted from Bio-Centrum-DTU, 2006)

Biomass	EFB	Trunks	Funds
Glucose g /g Dry Matter	0.43	0.65	0.47
Xylose g /g Dry Matter	0.26	0.12	0.24
Ethanol L/ton Dry Matter	388	451	377

	tons EFB dry								
Year	Industry	EFB available for ethanol	Combine Heat Power	Utilized EFB	Total resource	Bio-ethanol liters	Plants	Gasoline utilization liters / year	Replacement
2005	45.042	-	77.215	122.258	4.825.967	-			
2006	81.076	80.433	107.458	-	-	31.207.920		7.044.000.000	0.4%
2010	225.212	402.164	228.429	-	-	156.039.602		8.965.000.000	1.7%
2015	405.381	804.328	379.643	1.589.352	6.312.365	312.079.204		11.431.000.000	2.7%
2020	566.247	804.328	569.464	-	-	312.079.204		14.596.000.000	2.1%
2025	727.112	804.328	759.285	2.290.726	6.794.962	312.079.204			

The Bio Centrum-DTU wet explosion process suggests promising results in terms of:

1. High sugar yield;
2. High percentage of fermentable sugars in EFB

Hidayah *et al* (2008) suggested that fermentation parameters such as acidity (PH), temperature, and nitrogen source (Ammonia sulfate, urea, yeast extract and bacteriological peptone) play a role in the productivity of endoglucanase production using carboxymethylcellulose (CMC) as the carbon source. It was observed that the productivity of the Bacterium Pumilus EB3 enzyme increased two fold when two g/l of yeast extract was used as the organic nitrogen supplement as compared to the non-supplemented medium. EFB has the potential of acting as a substrate in cellulase production to ferment ethanol (Hidayah *et al*, 2008).

12.0 Conclusion

The Malaysian oil palm industry generates huge quantities of lignocelluloses resources throughout the year that are consistent in quality and quantities. Present anaerobic and aerobic processes to treat the effluent may produce suitable microbes to aid fermentation therefore a systematic microbiological selection for culturing is required. Numerous ongoing research has indicated improvements in ethanol yields to transform EFB to bio-ethanol although prospect of commercialization is slow in coming due to ineffective cost structures. The recent experiments to increase ethanol yield have been encouraging at a reasonably economical level to sustain continuous use of EFB as biomass feedstock. Recent bio-ethanol experiments to extend yield productivity and purity are summarized in Figure 6. We are getting closer to the realization of commercial production, if not at least very close to the timeline for a demonstration facility.

Figure 6 Continuum of Bio-ethanol Experiments Using EFB

Year	Researcher/ Company	Methods/Process	Ethanol Yield
2006	Hadyan	Hydrolysis and enzymatic fermentation through Saccaromyces cerevisae	13.8%
2007	BioCentrum DTU	Ammonia freeze explosion cellulosic pre-treatment	39%
2007	Cardon & Sanchez	simultaneous saccharification and cofermentation (SSCF) using engineered microorganisms Zymomonas mobilis	42%
2007	Gutierrez *et al*	Process integration conversion using simultaneous saccharification and fermentation (SSF)	42%
2007	Kabashi *et al*	Direct bioconversion mixed culture	14.2%
2008	Thiam & Bhatia	Thermo-chemical using synthesis gas-to-ethanol	50%
2008	Hidayah *et al*	Endoglucanase productivity by carboxymethylcelluslose (CMC) as carbon source & Bacterium Pumilus EB3	NA
2008	Pure Vision USA	Biofractionation to purify cellulose	NA
2008	Jinando Japan	Two step enzymatic saccharification and fermentation bioconversion	NA

While the abundance of EFB cellulose and emerging technology provides a viable option for ethanol production complemented by escalating price of the conventional high sugars/carbohydrates feedstock, more needs to be done to overcome barriers of supply that involves a series of stakeholders as echoed by Eco-Ideal & Mensilin (2006). The following parties identified below could play a critical role in maximizing advantage of the biomass waste:

- Oil palm plantations & processing mills-supplies of EFB
- Other transporters of EFB (e.g. brokers, waste companies, users etc.)
- Fuel Processing Equipment Suppliers & Operators, boiler equipment suppliers

The viability of lignocelluloses raw materials should be concentrated at specific localities where there are certain mills, crushers and estates in order to ensure a continuous supply of economically priced raw feedstock. The varied utilization of palm biomass has always been a concern for commercial users because of the suppliers' refusal to commit to long-term arrangements. Malaysia can be a pioneer in lignocellulose's-ethanol technology using EFB as a resource by integrating a bio-ethanol plant near palm oil mills. This new industry can generate various spin-offs beneficial to the country (Chow, 2005). Independent palm oil processing mills would be expected to be the main contributors of EFB as they do not have plantation to decompose the EFB residues generated from their mills. (Eco-Ideal & Mensilin, 2006). The development of a bio-ethanol demonstration plant has to overcome barriers related to the supply chain. This can be done through educational campaigns on the benefits of a renewable energy industry. Some key issues that need to be disseminated are, the technology, acceptance of EFB as renewable fuel, and access to supply. This was reflected in the Eco-Ideal Mensilin (2006) demonstration project where all stakeholders' negative perceptions were mapped out as barriers of supply in designing an approach for regulatory implementation. Finally, from the regulatory perspective, the government has to eradicate tilting favours to the 'old energy' companies by favouring new approaches on 'waste to energy' concepts so that private renewable energy initiatives could take shape in Malaysia. Currently Malaysia does not have broad and clear-cut incentives for pursuing renewable energy seriously at the federal level. The state government has no say on the energy sector, which is monopolized by a sole power generation company owned by the federal government. There are some palm oil mills licensed for localized power generation by incinerating biomass but their obligations are to divert surplus energy back to the national power grid. Consequently, the consumers do not have a role to play nor do they benefit from any renewable energy initiatives.

REFERENCES

Basiron, Y., Simeh, M.D. (2005). "Vision 2020-The Palm Oil Phenomenon." *Oil Palm Industry Economic Journal* **5**: 1-10.

Basiron, Y., Chan, K.W. (2004). "The Oil Palm and Its Sustainability." *Journal of Oil Palm Research* **16**: 1-10.

BioCentrum-DTU. (2008). Ethanol Potential for Empty Fruit Bunches Pre-treated by Wet-Explosion. A report prepared under the Malaysian - Danish Environmental Cooperation Programme Renewable Energy and Energy Efficiency Component, Denmark's Technical University.

Chavalparit, O., Rulkens, W.H., Mol, A.P.J., Khaodhair, S. (2006). "Options for Environmental Sustainability of the Crude Palm Oil Industry in Thailand through Enhancement of Industrial Ecosystems." *Environment Development and Sustainability* **8**: 271-287.

Cheng, C. K., Hani, H.H., Ismail, K.S.K. (2007). *Bioethanol Glucose Biomass Fermentation: Palm Oil Biomass Energy Alcohol as Fuel*. Oil Palm 1st Conference on Sustainable Materials (IcoSM) 9th-12th June, 2007. Universiti Malaysia Perlis: 69-72.

Chow, M. C. (2005). *An Assessment of Potential and Availability of Palm Biomass for Bioconversion to Bioethanol*. A report prepared under the Malaysian-Danish Environment Cooperation Programme Renewable Energy and Energy Efficiency Component, Malaysia Energy Centre (PTM).

De Vries, S. C. (2008). "The Bio-fuel Debate and Fossil Energy Use in Palm Oil Production: A Critique of Reijnders and Huibregts 2007." *Journal of Cleaner Production* **16**: 1926-1927.

Eco-Ideal Consulting Sdn. Bhd, M. H. S. B. (2006). Barrier Analysis for the Supply Chain of Palm Oil Processing Biomass (Empty Fruit Bunch) as Renewable Fuel. A report prepared under the Malaysian - Danish Environmental Cooperation Programme Renewable Energy and Energy Efficiency Component.

Fagione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P. (2008) Land Clearing and the Biofuel Carbon Debt. *Scienceexpress* Volume, **1** DOI: 10.1126/science.1152747

Gutierrez, L. F., Sanchez, O.J., Cardona, C.A. (2007). *Integrated Production of Biodiesel from Palm Oil using In Situ Produced Bioethanol*. Proceedings of European Congress of Chemical Engineering (ECCE-6), Copenhagen.

Gutierrez, L. F., Sanchez, O.J., Cardona, C.A. (2009). "Process Integration Possibilities for Biodiesel Production from Palm Oil using Ethanol obtained from Palm Lignocellulosic Residues Oil Palm Industry." *Bioresource Technology* **100**: 1227-1237.

Hadyan, H. (2006). Bioethanol Production from EFB of Oil Palm, KUKTEM.

Hidayah, A. M. A., H., Umi Kalsom, M.S., Norhafizah, A., Farinazleen, M.G. and Shirai, Y. (2008). "Production of Bacterial Endoglucanase from Pretreated Oil Palm Empty Fruit Bunch by Bacillus Pumilus EB3." *Journal of Bioscience and Bioengineering*, The Society for Biotechnology, Japan. **106**(3): 231-236.

Hussain, A., Aini, FN., Darus, AN., Mokhtar, H., Azam, S., Mustafa, A. (2006). "Thermochemical Behavior of Empty Fruit Bunches and Oil Palm Shell Waste in A Circulating Fluidized-Bed Combustor (CFBC)." *Journal of Oil Palm Research* **18** (June): 210-218.

Kabbashi, A. N., Md. Zahangir Alam., M. Faharurrazi Tompang (2007). "Direct Bioconversion of Oil Palm Empty Fruit Bunches for Bioethanol Production by Solid State Bioconversion " *IIUM Engineering Journal* **8**(2).

Lam, M. K., Tan, K.T., Lee, K.T., Mohamed, A.R. (2008) Malaysian Palm Oil: Surviving the Food versus Fuel Dispute for A Sustainable Future. *Renewable and Sustainable Energy Reviews* **Volume,** DOI: doi:10.1016/j.rser.

Mahlia, T. M. I., Abdulmuin, M.Z.,Alamsyah, T.M.I., Mukhlishien, D. (2001). "An Alternative Energy Source from Palm Wastes Industry for Malaysia and Indonesia." *Energy Conversion and Management* **42**: 2109-2118.

MPOB. "*Malaysia Palm Oil Board"* Retrieved November 13, 2008, from www.mpob.gov.my.

Milbrandt, A., Overend, R.P. (2008). *Survey of Biomass Resource Assessments and Assessment Capabilities* in APEC Economies. APEC Energy Working Group.

NIRAS (2006). *Bio-fuels for the Malaysian Transport Sector*. A report prepared under the Malaysian-Danish Environmental Cooperation Programme: Renewable Energy and Energy Efficiency Component.

Rahman, S. H. A., Choudhury, J.P., Ahmad, A.L., Kamaruddin, A.H. (2007). "Optimization Studies on Acid Hydrolysis of Oil Palm Empty Fruit Bunch Fiber for Production of Xylose." *Bioresource Technology* **98**: 554-559.

Rahman, S. H. A., Choudhury, J.P., Ahmad, A.L. (2006). "Production of Xylose from Oil Palm Fruit Bunch Fiber Using Sulfuric Acid." *Biochemical Engineering Journal* **30**: 97-103.

RFA (2008). *Changing The Climate: Ethanol Industry Outlook 2008*, Renewable Association.

Sugiyama, M., Suthee, B., Auesukaree, C., Asavarak, T., Kaneko, Y., Boonchird, C., & Harashima, S. (2008). *Yeast Carbon Neutral Biotechnology, High Temperature and Acid Tolerant Strain for High Level Bioethanol Production*. Thailand-Japan Joint Symposium on Biotechnology by Efficient Utilization of Thai Biosciences, Thailand.

Sumathi, S., Chai, S.P., Mohamed, A.R. (2008). "Oil Palm As A Source of Renewable Energy in Malaysia." *Renewable & Sustainable Energy Reviews* **12**: 2404-2421.

Thiam, L. C., Bhatia, S. (2008). "Catalytic Processes Towards the Production of Biofuels in a Palm Oil and Oil Palm Biomass-based Biorefinery." *Bioresource Technology* **99**: 7911–7922.

UNDP (2007). *Malaysia Generating Renewable Energy From Palm Oil Wastes*. Malaysia Report, United Nations Development Programme, Malaysia.

Yeoh, H. H. L., K.O. (2000). "Production of Fuel Ethanol From Oil Palm Wastes." *International Energy Journal* **1**(2): 89-95.

Yong-Kelly, T. L., Lee K.T., Mohamed, A.R., Subhash Bhatia. (2007). "Potential of Hydrogen From Oil Palm Biomass As A Source of Renewable Energy Worldwide."*Energy Policy* **35**: 5692-5701.

Yusoff, S. (2006). "Renewable Energy From Palm Oil – Innovation of Effective Utilization of Waste*." Journal of Cleaner Production* **14**: 87-93.