



Contents lists available at ScienceDirect

## Journal of Cleaner Production

journal homepage: [www.elsevier.com/locate/jclepro](http://www.elsevier.com/locate/jclepro)

# Sustainable and integrated palm oil biorefinery concept with value-addition of biomass and zero emission system

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## ARTICLE INFO

## Article history:

Received 4 April 2014

Received in revised form

31 October 2014

Accepted 8 December 2014

Available online xxx

## Keywords:

Biorefinery

Oil palm biomass

Sustainability

Zero emission

## ABSTRACT

The problem of biomass residues and effluent from the palm oil milling process has become a big concern for the industry, the public and the environment. Furthermore, the modern palm oil mill can no longer rely solely on traditional crude palm oil and palm kernel products for profit generation. In order to remain truly sustainable in the future, we propose the solid biomass residues and liquid effluent to be managed and utilized via a biorefinery concept to generate new value-added products, in-line with zero emission system. Modern and efficient boiler and turbine systems utilizing biomass and biogas captured from the anaerobic effluent treatment can provide the steam and electricity required for the palm oil mill operations. The solid biomass residues can be channeled towards the production of value-added products such as biofertiliser, biochar, biofuels and biomaterials. The liquid final discharge can be further treated to meet river water quality, making it suitable to be recycled - hence achieving zero emission. Such an integrated approach will not only solve the issue of proper biomass disposal and effluent treatment, but also more importantly create a win-win-win situation for profit, people and planet - the three pillars of sustainability.

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## 1. Introduction

The main traditional products of the palm oil mill process are crude palm oil (CPO) and palm kernel (PK). In obtaining these valuable commodities, large quantities of solid and liquid biomass by-products are generated daily in the form of empty fruit bunch (EFB), mesocarp fiber (MF), palm kernel shell (PKS) and palm oil mill effluent (POME). Empty fruit bunches are mainly sent to the plantations for mulching, while MF and part of the PKS are used as boiler fuel to generate steam and electricity to power the mill's operations. The palm biomass residues are inefficiently burnt in order to reduce the problem of biomass treatment and disposal (Baharuddin et al., 2010). On the other hand, POME is biologically treated via a series of extensive lagoons or tanks just to meet the

discharge standards prior to discharge to the watercourses (Othman et al., 2014). These biomass by-products, once viewed as 'waste' materials, are now highly valued biomass with the potential of generating green businesses in their own right. The current trend in oil palm biomass management is for the biomass to be used in the most efficient and sustainable way possible to reap maximum benefits in terms of profit, people and planet – the 3 pillars of sustainability. This means that no waste product must be discharged from the mill, i.e. zero emission, whereby all of the excess biomass are either converted into useful by-products or recycled for the mill's use. This paper evaluates and proposes an integrated palm oil biorefinery concept, with biomass resource utilization within a zero emission system in a palm oil mill as a way forward for the future sustainability of the palm oil industry.

## 2. Basis of the palm oil biorefinery concept

In order to effectively utilize the biomass resources at the mill, the amount of potential excess biomass and energy at the mill was

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determined by comparing the current system against an efficient fuel strategy system. By capturing the biogas from anaerobic POME digestion for conversion to electrical energy, the power requirement for producing the value-added products from the excess biomass could be met, coupled with reduced emission of the greenhouse gases to the environment (Agensi Inovasi Malaysia, 2011). The excess energy and biomass resources are thus made available for producing value-added bioproducts within the biorefinery. The POME final discharge is further treated to achieve river water quality, which makes it possible for it to be recycled for the mill's use, instead of discharging to the river. The indicator for sustainability would be new financial revenue streams being generated (profit), new jobs created (people), and reduced pollution being released into the atmosphere (planet). All in all, therefore a truly sustainable and integrated zero emission system for the palm oil mill can be realised.

### 3. Current biomass utilization

Table 1 shows the current biomass and energy utilization at a typical palm oil mill processing 300,000 tonnes of fresh fruit bunches (FFB) annually. Currently, all palm oil mills are self-sufficient in terms of energy and steam. There is no apparent need for changing the current process, since by burning all of the MF and part of the PKS, the mill tackles both issues of fuel requirement and disposal of these biomass. However, this is far from the best practice possible as a number of improvements could be made for more sustainable and efficient utilization of these biomass resources. Within the current system, for every tonne of FFB processed, 200 kg of CPO and 50 kg of PK are produced (Lam and Lee, 2011). These are the high value commodities which drive the palm oil industry today. However, to process each tonne of FFB, 1 tonne of fresh river water is pumped up from the river or holding pond (Othman et al., 2014). High-pressure steam is generated by burning all of the MF and part of the PKS in the conventional low-efficiency boilers. The steam is first passed through the turbines, generating electricity to power the mill's operations. The low-pressure steam is then used to cook the FFB in the sterilisers. About 230 kg of EFB is generated after the FFB sterilisation process, which is partly sent back to the plantations for mulching (Baharuddin et al., 2010; Lam and Lee, 2011). Approximately 700 kg of POME is generated (UNFCCC, 2008) in the mill which is pumped into extensive lagoons or tanks for treatment just to meet the discharge standards prior to discharge into a nearby river or watercourse. This anaerobic treatment yields biogas containing methane, a greenhouse gas, which is released uselessly into the atmosphere (Yacob et al., 2005). The current deficit in terms of

sustainability would be the untapped potential of creating a new green industry and financial revenue streams from the excess biomass and energy (profit), untapped potential of creating new job employments for the local community and human capacity building (people), as well as the current release of approximately 37,251 tonnes of CO<sub>2</sub>e annually (Yoshizaki et al., 2012) into the atmosphere as a result of the anaerobic treatment of POME (planet).

### 4. Proposed sustainable and integrated palm oil biorefinery concept

The sustainable and integrated palm oil biorefinery concept proposed is shown in Fig. 1. In the biorefinery, a total solution is proposed which allows the current production of CPO and PK to be maintained, but concurrently utilizes all of the by-products generated into value-added materials, i.e. towards a zero emission system. As shown in Table 2, the first pre-requisite is to install an efficient boiler and turbine system. This would immediately result in less MF fuel being used and reduce the gaseous pollution. The PKS is no longer necessary as boiler fuel, making it totally in excess. With a modern boiler and turbine system efficiency of 85%, only 42% of the total MF would be required as boiler fuel to generate steam required for the sterilisers (Table 2), with the remaining 58% available as substrate for conversion to higher value-added products. The potential steam generated would satisfy the minimum demand of 400 kg steam per tonne FFB (Yoshizaki et al., 2012).

As for the POME treatment, closed anaerobic digesters should be installed to enable efficient degradation of POME as well as biogas or methane capture for electricity conversion. This methane would be a source of energy to power the mill's operations. Biogas energy alone would be more than sufficient to cater for the total electrical energy required for both mill demand and any new biomass business, since about 3 MW electricity could be produced from the biogas generated by anaerobic digestion of POME supplemented with EFB (UNFCCC, 2008; Ali et al., 2012). With further appropriate treatment such as with biochar or activated carbon, the polished POME final discharge with river water quality could be recycled to the mill to be reused as boiler feed water (Othman et al., 2014). Excess biomass, steam, heat and energy are now available for conversion into a range of desired bioproducts such as bioethanol, biobutanol, biohydrogen, bioplastics, biodiesel, biovanillin, biocomposite, bioadsorbent, biocompost and biochar (Coats et al., 2008; Sanchez and Cardona, 2008; Kaparaju et al., 2009; de Souza et al., 2010; Ismail et al., 2010; Rebitanim et al., 2013).

In terms of profit, if a biomass business – biocomposite for example – were to be implemented using excess MF alone with RM 10 million capital expenditure, annual labour and maintenance

**Table 1**  
Current biomass and energy scenario in a typical palm oil mill.

Item	Details	Amount	Reference
FFB processing capacity	Annual capacity	300,000 t/y	Yoshizaki et al., 2012
	Hourly capacity	54 t/h	UNFCCC, 2008
OPMF burnt as boiler fuel ( $M_f$ )	54 t/h $\times$ 0.157 $\times$ 1	8.478 t/h	Yoshizaki et al., 2012
		8478 kg/h	
OPMF calorific value ( $CV_f$ )	–	19,068 kJ/kg	Nasrin et al., 2008
PKS burnt as boiler fuel ( $M_s$ )	54 t/h $\times$ 0.05 $\times$ 0.5	1.35 t/h	Yoshizaki et al., 2012
		1350 kg/h	
PKS calorific value ( $CV_s$ )	–	20,108 kJ/kg	Nasrin et al., 2008
Potential energy conversion	$E = M_f CV_f + M_s CV_s$	188,804,304 kJ/h	Mahlia et al., 2001
Electricity demand	17 kWh/t FFB $\times$ 54 t/h FFB	918 kW	Yoshizaki et al., 2012
Steam demand	30 kg/kW $\times$ 918 kW	27,540 kg/h	Mahlia et al., 2001
	400 kg/t FFB $\times$ 54 t/h FFB	21,600 kg/h	Yoshizaki et al., 2012
Available energy for steam generation	188,804,304 kJ/h $\times$ 0.68 (Boiler efficiency = 68%)	128,386,927 kJ/h	
Potential steam obtained	128,386,927 kJ/h/2590 kJ/kg (Energy required to generate 1 kg steam = 2590 kJ)	49,570 kg/h > 27,540 kg/h	Mahlia et al., 2001

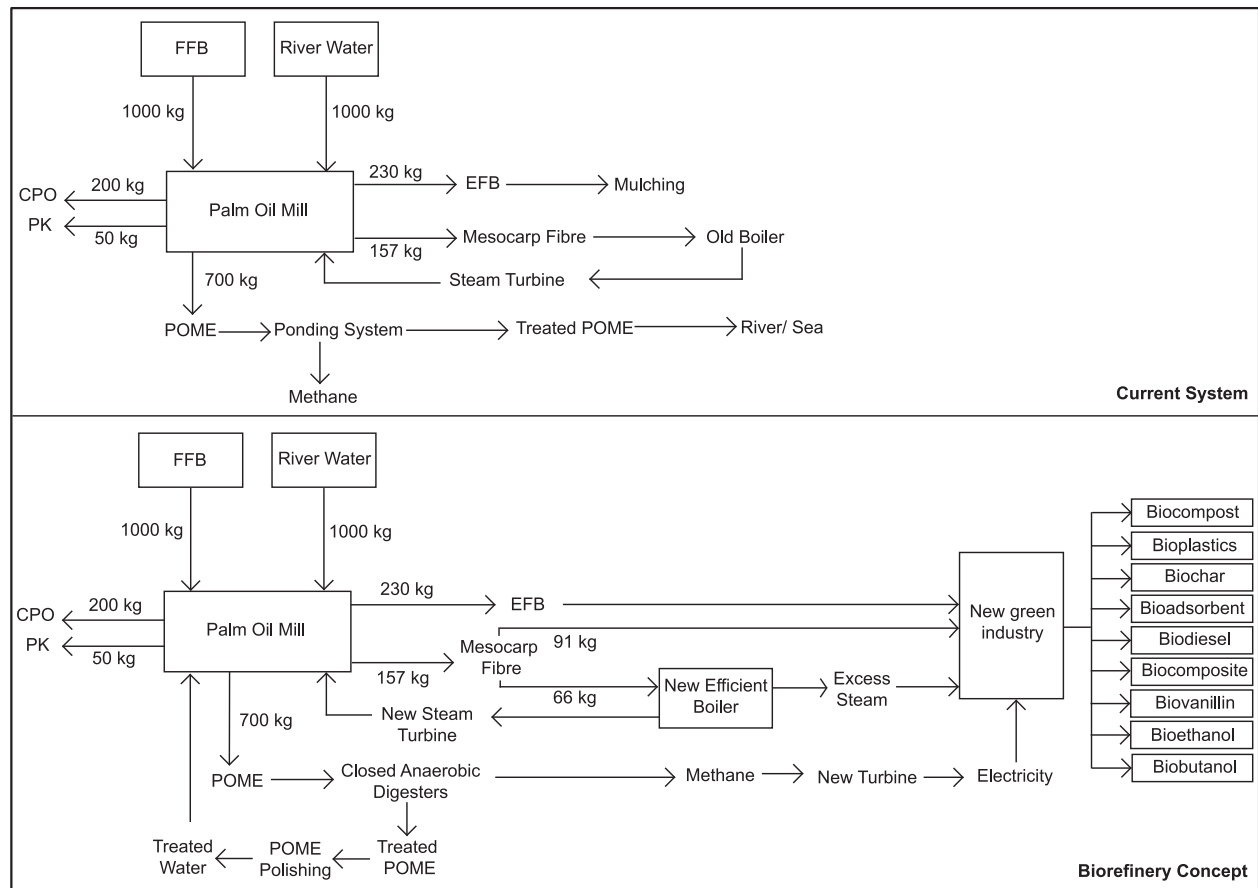


Fig. 1. Proposed sustainable and integrated biorefinery concept with zero emission system.

costs at about RM 1.1 million, raw material cost at RM 54.6 million per year, and 10% profit margin, the expected annual profit would be RM 5.6 million, payback period at 1.8 years and internal rate of return at 55%. The new biomass business is expected to create about 15–20 new job opportunities at any given mill. This would translate into more than 6000–8000 new employment created considering that there are more than 400 palm oil mills operating nationwide. The environmental benefit would be the immediate prevention of harmful greenhouse gas being released into the atmosphere. In addition, POME would be treated properly and recycled back to the mill instead of being discharged to the rivers.

## 5. Discussion

The core business of the palm oil mill is to produce CPO and PK. Presently, the mill already generates substantial revenues from CPO and PK without implementing any sort of efficient biomass utilization technologies. Based on the previous study by our research group (Yoshizaki et al., 2013), integrated biogas and compost technology was found to be the most economically-viable alternative for biomass utilization at the mill. Although biogas and compost technology were appropriate for the mill, our current study found that a shift in approach by adopting a bigger picture scenario as proposed in Fig. 1, could be even more attractive and

Table 2

Proposed biomass and energy utilisation in a typical palm oil mill.

Item	Details	Amount	Reference
FFB processing capacity	Annual capacity Hourly capacity	300,000 t/y 54 t/h	Yoshizaki et al., 2012 UNFCCC, 2008
OPMF burnt as boiler fuel ( $M_f$ )	$54 \text{ t/h} \times 0.157 \times 0.42$ (Only 42% OPMF used)	3.561 t/h 3561 kg/h	Yoshizaki et al., 2012
OPMF calorific value ( $CV_f$ )	—	19,068 kJ/kg	Nasrin et al., 2008
PKS burnt as boiler fuel ( $M_s$ )	—	0	This study
Potential energy conversion from OPMF ( $E_f$ )	$E_f = M_f CV_f$	67,901,148 kJ/h	Mahlia et al., 2001
POME generation	$54 \text{ t/h} \times 0.7$	37.8 t/h	UNFCCC, 2008
Biogas amount	$28 \text{ m}^3 \text{ biogas/t POME} \times 1.6$ (60% increase in biogas with EFB supplementation)	1693.44 m <sup>3</sup> /h	Ali et al., 2012
Potential biogas energy	$1.8 \text{ kWh/m}^3 \text{ biogas}$	3.048 MW	UNFCCC, 2008
Electricity demand	$17 \text{ kWh/t FFB} \times 54 \text{ t/h FFB}$	918 kW	Yoshizaki et al., 2012
Steam demand	$400 \text{ kg/t FFB} \times 54 \text{ t/h FFB}$	21,600 kg/h	Yoshizaki et al., 2012
Total available energy	$E = E_f \times 0.85$ (Boiler efficiency = 85%)	57,715,976 kJ/h	
Potential steam obtained	$57,715,976 \text{ kJ/h} / 2590 \text{ kJ/kg}$ (Energy required to generate 1 kg steam = 2590 kJ)	22,284 kg/h > 21,600 kg/h	Mahlia et al., 2001

sustainable. For example, the city of Kitakyushu in Japan was once one of the most polluted areas in the world during their industrialisation boom in the 1960s ([http://www.city.kitakyushu.lg.jp/english/file\\_0064.html](http://www.city.kitakyushu.lg.jp/english/file_0064.html)). However, as prices of key raw materials particularly oil began to increase sharply and environmental conditions became too severe, the industries in the city was forced to adopt cleaner production technologies to survive ([http://www.city.kitakyushu.lg.jp/english/file\\_0064.html](http://www.city.kitakyushu.lg.jp/english/file_0064.html)). Raw materials and energy were then used in the most efficient ways at every stage of production which yielded more value-added products, reduced waste and pollution to the surrounding environment, as well as increased profit. Nowadays, the industrial city of Kitakyushu is still thriving economically and in harmony with the environment, and was selected as a 'green growth city' and a true role model of sustainable development (OECD, 2013). The end-of-pipe treatment system as practiced with POME in palm oil mills ultimately requires more resources, i.e. cost, labour, land and energy. Thus there is a possibility for improvement via upgrading of each processing stage. From the excess biomass and energy made available, the palm oil industry would have the capability to produce various products to suit market demand and maximize their profits. A study by Zahari et al. (2015) also highlighted this possibility via utilization of oil palm fronds for the production of bioplastics. By producing value-added products such as biocompost, biochar and biodiesel, the industry could even cater for their own internal requirements such as partially offsetting the need for chemical fertilizers, soil conditioners, flocculants, adsorbents and fuel to power their operations.

## 6. Conclusion

We hereby propose a sustainable and integrated biorefinery concept for the palm oil mill, which would produce higher value-added products from the oil palm biomass and enable a true, zero emission solution for the industry. A modern and efficient boiler and turbine system will provide the basic steam and power requirements of the palm oil mill. By adopting the integrated biorefinery concept, a new green downstream industry could be created, yielding new profitable revenue streams for the mills, boosting local economies through creation of new employment opportunities, dramatically reduce the adverse impact towards the environment by reducing pollution and eliminating inefficient biomass disposal methods, maximizing biomass utilization and production of green products, as well as improving the industry's own green image locally and globally. This win-win-win approach would truly enable the palm oil industry to be sustainable in terms of profit, people and planet - the three pillars of sustainability!

## Acknowledgements

The authors gratefully acknowledge the matching research grant provided by the SATREPS-Ministry of Education, Malaysia (Grant No. 6300156), that resulted in this article. The authors also thank Kyushu Institute of Technology (Kyutech), Japan, Universiti Putra Malaysia (UPM), Malaysia, Japan International Cooperation

Agency (JICA) and Japan Science and Technology Agency (JST) for their technical support towards this study.

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