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# Case study: Preliminary assessment of integrated palm biomass biorefinery for bioethanol production utilizing non-food sugars from oil palm frond petiole

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ABSTRACT

In this case study, a preliminary assessment on the bioethanol production from oil palm frond (OPF) petiole sugars within an integrated palm biomass biorefinery was carried out. Based on the case study of 4 neighbouring palm oil mills, approximately 55,600 t/y of fermentable sugars could be obtained from OPF petiole. The integrated biorefinery will be located at one of the 4 mills. The mill has potential excess energy comprising 3.64 GW h/y of electricity and 177,000 t/y of steam which are sufficient to run the biorefinery. With 33.9 million litres/y of bioethanol production, the specific production cost of bioethanol is estimated at $ 0.52/l bioethanol, compared to $ 0.31–0.34/l bioethanol produced from sugarcane and $ 0.49–0.60/l bioethanol from other lignocellulosics. The net energy ratio of 7.48 for bioethanol production from OPF provides a promising alternative for OPF utilization as a non-food sugar feedstock.


## 1. Introduction

Oil palm frond (OPF) is the most abundant oil palm biomass produced at oil palm plantations compared to other biomass. It was reported that over 50 million tonnes of OPF was generated annually in Malaysia [1], which are available throughout the year as the fronds are regularly cut during the harvesting of fresh fruit bunches (FFB). The OPF consists of the petiole which is the basal part of the branch and many long leaflets on either side of the branch. The top two-thirds of the frond which is the leafy part contain 66% of the nutrients, whilst the petiole is rich in cellulosic materials and sugars at 60% and 66%, respectively [2,3]. The nitrogen content is high in the leafy part as compared to the petiole [4], suggesting the suitability of the leafy part as a natural fertiliser for the oil palm, whereas the petiole part can be exploited for the production of biofuels and biobased chemicals [2]. A previous report illustrated the economic viability of renewable sugars from OPF as fermentation feedstock for the production of the bioplastic poly(3-hydroxybutyrate), (P(3HB)) within an integrated palm biomass biorefinery [5]. Meanwhile, OPF juice was proven as an alternative fermentation substrate for the production of bioethanol [6,7]. In another research, a process optimization of an ultrasonic-assisted organosolv/liquid oxidative pretreatment (SOP) of OPF was able to recover cellulose, bioethanol and biochemicals (i.e. phenolic compounds) simultaneously in a biorefinery concept [8]. However, the main obstacles for exploiting the OPF are logistics i.e. collection and transportation of the biomass out of the plantations.

Therefore, this paper proposes a mechanism for utilizing the OPF in an efficient manner. The OPF petiole can be easily collected and transported together with the harvested FFB and transported to the nearest palm oil processing mill. Only the petiole part of the OPF will be collected as it contains more fermentable sugars compared to the leafy part. About half of the fresh OPF petiole (by weight) can be converted to OPF juice by simple pressing, thus providing a big potential as fermentation medium. The juice was found to be rich in sugars at 78.42 g/l, with 73% glucose, 25% sucrose and 2% fructose [3]. On the other hand, the OPF pressed fibre gave about 95% of holocellulose conversion by wet

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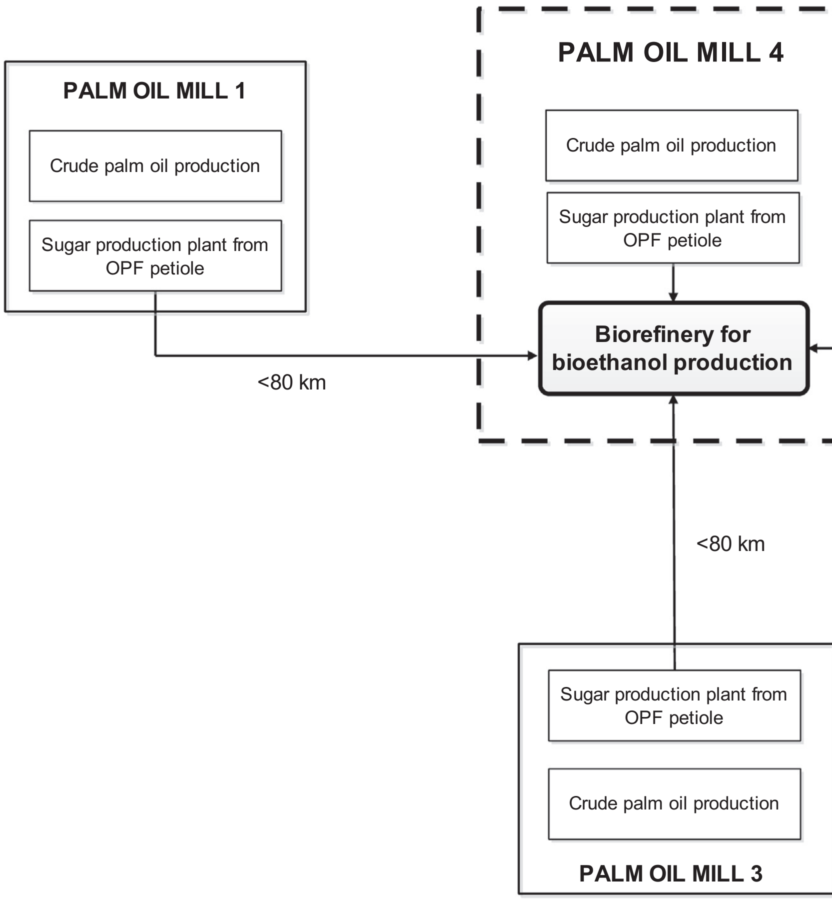


**Fig. 1.** Schematic diagram of a proposed integrated palm biomass biorefinery concept for bioethanol production from OPF petiole.

disc-milling and enzymatic hydrolysis, thus suggesting OPF pressed fibre as a new promising fermentation feedstock [7]. The sugars produced from OPF petiole at the mills will be concentrated and transported to an integrated biorefinery for conversion into bioethanol via fermentation. The bioethanol is finally recovered through distillation process. All the processing steps will utilize the excess steam and energy at the mills.

In this paper, a mechanism for fermentable sugars and bioethanol production from OPF petiole is proposed via an integrated technology approach to an existing palm oil mill in order to utilize the surplus energy available at the palm oil mill. Currently, most palm oil mills are self sufficient in terms of energy without relying on external energy for operation. The normal practice is by deploying a cogeneration approach to produce steam and electricity for the milling process [9]. Typical palm oil mills utilize readily available biomass after the oil extraction from the FFB as boiler fuel which comprise of mesocarp fibre and shell. The steam produced at the mill is normally more than sufficient for the required use and thus the excess steam is released to the atmosphere. As reported by Chiew et al. [10], 23.8 MJ of electricity and 24.2 MJ of steam remain unused in the process or released to the air after meeting the electricity and steam demands of the mill. Currently, palm oil mill managers do not put any attention on this issue as the water and biomass fuel can be obtained at no charge. Hence, this study was aimed to assess the feasibility of integrating a bioethanol production plant from OPF petiole to an existing palm oil mill to utilize excess steam and electricity. The energy balance at the existing mill and energy required for fermentable sugars and bioethanol production from OPF were estimated. The process and cost models of bioethanol production from OPF sugars were developed using SuperPro Designer software version 8.0 by Intelligen Inc., Scotch Plains, New Jersey, USA.

## 2. Methods

### *2.1. Basis of the proposed model*

In this study, it is assumed that OPF petiole sugars produced from at least 4 palm oil mills will be transported to a biorefinery for bioethanol production within an 80 km radius. In the business model proposed, the sugar production plant and the biorefinery for bioethanol production are considered as separate entities. The sugar production plant is done at the individual mills and hence generate profit from the sale of OPF sugars to the biorefinery. Additionally, it is assumed that the biorefinery will be located at one of the 4 mills to utilize the surplus energy from the palm oil mill. It is estimated that external energy will be required by the biorefinery if OPF petiole sugars are supplied from more than 4 palm oil mills. The average processing capacity of oil palm FFB is 240,000 t/y/mill [11] with average OPF petiole collected at 57,600 t/y/mill. The schematic diagram of the proposed concept is shown in Fig. 1. The main criteria to be considered in choosing the ideal palm oil mill to locate the biorefinery is the sufficient excess energy available at the palm oil processing lines to run the biorefinery. As an example, palm oil mill no. 4 was chosen to locate the biorefinery.

### *2.2. Process description*

#### *2.2.1. Fermentable sugars production from OPF petiole*

The fermentable sugars production is carried out by the oil palm processing mills and supplied to the biorefinery. The processing