Energy Economics Letters
ISSN(e): 2308-2925
journal homepage: http://www.aessweb.com/journals/5049

ENERGY SELF-SUFFICIENCY OF SEMI-MECHANIZED OIL PALM PROCESSING: A CASE STUDY OF BAYELSA PALM MILL, ELEBELE, NIGERIA

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ABSTRACT

The study was designed to assess the energy requirement, biomass generation and the contribution of biomass in oil palm processing from1 tonne of fresh fruit bunch (FFB) by a semi-mechanized palm oil processing mill in Nigeria. The energy required for the extract oil from fresh fruit was measured at the Bayelsa Palm Mill, Elebele, Nigeria. The average weight of FFB was 13.5 kg. The mass balance of FFB during processing is 26.0 % empty fruit bunch (EFB), 1.5 % chaff, 18.5% nut, 30.0 % palm press fibre (PPF), 14.0% moisture and 10.0% crude palm oil (CPO).The biomass generated during the processing of CPO from 1 tonne of FFB is 259.0 kg (EFB), 301.9 kg (PPF) and 14.8 kg (chaff). Of these, only 234.9 kg of EFB was utilized as fuel for boiling, while 1.85 liters of diesel was used to power generator for stripping, digestion/pressing and fiber separation. Majority of the biomass generated were un-utilized. About 40% of the potential energy in the biomass was utilized by the mills, while the rest was disposed by open combustion. The total energy utilized for the processing of FFB is 4291.39 MJ/ tonne. Of these, biomass fuel accounted for 97.5%, while fossil fuel supplied the remaining 2.5%. We conclude that the excess biomass can be converted into liquid fuel via pyrolysis and/or gasification and used for digestion purposes to attain 100% energy self-sufficiency to prevent air quality impacts associated with the open air combustion of excess biomass. Other potential biofuel that could be generated from oil palm waste biomass include solid (briquette), liquid (bioethanol, bio-methanol, bio-oil) and gaseous fuel (biogas, bio-hydrogen).

Keywords: Bioenergy, Biofuels, Biomass, Oil palm, Power, Semi-mechanized processors.

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DOI: 10.18488/journal.82/2015.2.3/82.3.35.45
ISSN(e): 2308-2925

Contribution/ Originality

This study presents the energy requirement, biomass generation and the contribution of biomass in the processing from1 tonne of fresh fruit bunch of oil palm, by a semi-mechanized palm oil processing mill in Nigeria using various measurements approach and suggested potential means of utilizing the excess biomass from the mill for energy generation.

1. INTRODUCTION

In the past few decades, the use of biomass has been explored for the generation of energy. This becomes imperative due to the depletion of non-renewable energy resources such as petroleum which the World have depended on since 19th century. Also increase in fuel prices have contributed to the search for alternative energy, particularly in developing countries. The continued use of fossil fuel causes environmental, social, and health effects, which threatens sustainability (Ohimain, 2013a). Biomass fuel is carbon neutral, therefore it helps in balancing oxides of carbon in the atmosphere (Ohimain, 2011). Biomass helps in the removal of CO_2 through photosynthesis. The combustion of biomass produces CO_2 which is reabsorbed into biomass photosynthetic pathway. Unlike conventional fuel such as petroleum, biomass fuel renders environmental benefits such as renewability, sustainability, non-toxic, biodegradable (Ohimain, 2013b).

Biomass have proven to be a good substitute for various fuel supplied by conventional energy resources. Biomass can be utilized as a solid fuel (e.g., briquette, biochar), liquid (bioethanol, bio-methanol, bio-oil) and gaseous (bio-methane, biogas, bio-hydrogen). Biomass energy can be used for power generation (electricity), transportation and kitchen fuel using diverse conversion technologies. In Nigeria, most industrial activities such as wood milling, oil palm processing produces enormous wastes, which typically environmental nuisance. Specifically oil palm processing generates waste biomass such as empty fruit bunch (EFB), palm press fiber (PPF), palm kernel shell (PKS) and chaff.

Palm oil industry has continued to play an essential role in the Nigeria economy through employment and wealth creation. Oil palm is a means of livelihood to millions of families, especially rural dwellers (Akangbe *et al.*, 2011; Foundation for Partnership Initiatives in the Niger Delta (PIND), 2011; Ohimain *et al.*, 2012). Palm oil accounts for over 95% of Nigerian vegetable oil mix. Izah and Ohimain (2013a) reported that over 90% of crude palm oil (CPO) supplied is used for food purposes. Between 2000 and 2013, Nigeria oil palm industry has not grown and more recently stagnated (United State Department of Agriculture (USDA), 2013) in comparison to the major producing countries such as Indonesia, Malaysia and Thailand (Fig. 1). Despite this trend, Nigeria is the fifth highest oil palm producing nation in the world, as such the biomass produced during oil palm processing is enormous. In addition to biodiesel production (Pleanjai *et al.*, 2007; Izah and Ohimain, 2013b) palm oil is also used as food and in other industries. For example, oil palm is used as ingredient for pharmaceutical products, shampoo, soap, detergent, lip stick, cosmetics, and polish making (Aghalino, 2000; Basiron and Weng, 2004; Embrandiri *et al.*, 2012).

The processing of fresh fruit bunch (FFB) of oil palm generates between 10 and 30% of palm oil (Prasertsan and Prasertsan, 1996; Mahlia *et al.*, 2001; Chavalparit *et al.*, 2006; Hambali *et al.*, 2010; Ohimain *et al.*, 2013a) depending on the variety and bunch size. The quantity of solid waste generated form processing mills has been variously reported in literature. Ohimain *et al.* (2013a) reported the material-mass balance of smallholder oil palm processors in Nigeria. Other country mass balance report includes Thailand (Prasertsan and Prasertsan, 1996; Chavalparit *et al.*, 2006) Indonesia (Hambali *et al.*, 2010) and Indonesia/Malaysia (Mahlia *et al.*, 2001). The palm oil extraction method is either wet or dry milling techniques.

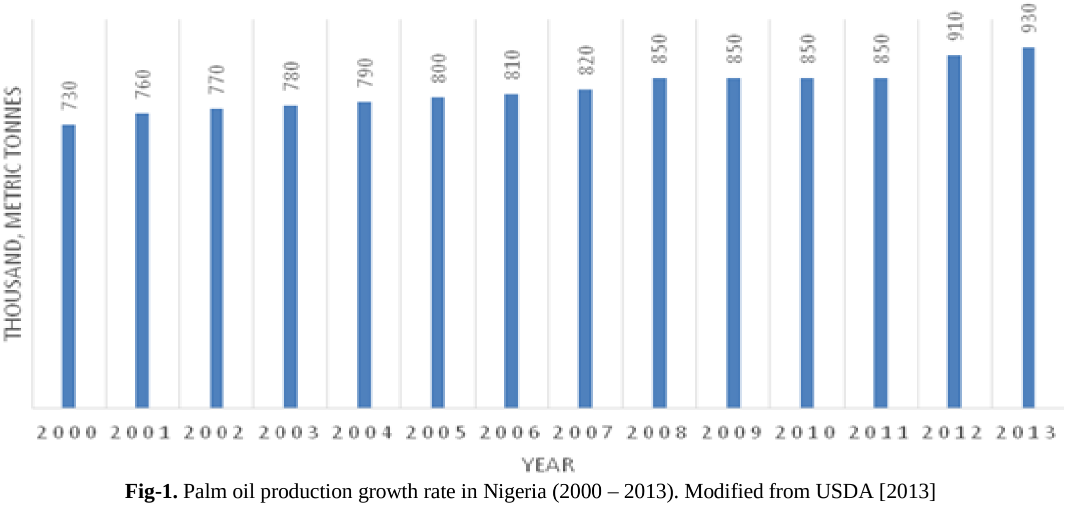

Fig-1. Palm oil production growth rate in Nigeria (2000 – 2013). Modified from USDA [2013]

In major palm oil producing nations, where large scale mills are available (i.e., processing 10 – 60 tonnes of FFB/hr) (Mahlia *et al.*, 2001) wet mill is frequently used. In lesser palm production nations such as Nigeria, the dry mill approach predominates. The oil palm industry in Nigeria is dominated by 80% smallholders who use rudimentary/manual equipment for processing (Ohimain and Izah, 2014). While semi-mechanized accounts for 16% of the sector sharing about 50% the characteristics of both smallholder and mechanized processors (Ohimain and Izah, 2013). Like traditional mills, semi-mechanized mill utilizes manual energy in some processing activities such as bunch loading for the stripper and sieving processes. The remaining process uses heat or electrical energy for processing. In countries such as Indonesia and Malaysia, 14.5 – 25 kWh of electricity is required to process 1 tonne of FFB (Mahlia *et al.*, 2001; Chavalparit *et al.*, 2006; Yusoff, 2006; Ohimain and Izah, 2014). Excess biomass from palm oil mills in Malaysia is converted into fuel/power via gasification, pyrolysis and direct combustion using small and modular systems. Sumathi *et al.* (2008) reported that the excess biomass from oil palm processing wastes could generate 10MW of electrical energy in Malaysia. Synthetic biofuels have been produced from oil palm biomass in addition to biodiesel, bio-methanol and bio-ethanol. The Malaysian government has also proposed a biomass plant with 11.5MW capacity that could supply electricity to the national grid (Sumathi *et al.*, 2008). The mill utilizes oil palm processing solid wastes such as EFB as boilers fuel while non-renewable energy is used to fuel generators. Energy

Wise (2011) estimated that palm oil mills with 30 tonne FFB/hr capacity can generate all the energy required by the mill and still contribute 1.2 to 2.5 MW electricity depending on the plant efficiency, while the excess waste biomass can produce 70 tonnes/day of marketable biomass fuel.

Electricity supply has been sporadic with frequent black and brown outs in the major industrial cities of Nigeria. Jekayinfa and Bamgboye (2008) noted that the industrial sector has the largest commercial energy consumption apart from the transportation industry. The supply of transportation fuel has been challenging despite Nigeria being the 12th highest producer of crude oil in the world (Ohimain, 2013a). Nigeria is a major importer of refined oil products. Therefore, the oil palm industry has promising potentials for the diversification of energy supply of the country. But unlike other producing nations with similar climatic and soil requirements, which favors the cultivation of oil palm, Nigeria still harvests from wild groves scattered over the southern region of the country. Like traditional processing mills, semi-mechanized mills utilize and burn off excess waste biomass. These excess wastes can be converted into various forms of energy, which could enhance the energy supply in Nigeria. Therefore this study is designed to [a] quantify the solid wastes generated during palm oil processing by semi-mechanized mill, [b] quantify the biomass wastes utilized during palm oil processing and [c] suggest conversion technologies for the excess wastes into biofuel.

2. MATERIALS AND METHODS

2.1. Field Visit

A field trip was undertaken on 3 - 7 June, 2013 to Bayelsa State Oil Palm Mill, Elebele, Nigeria for sample collection and measurements.

2.2. Description of Bayelsa Oil Palm Mill

The Bayelsa State Oil Palm Mill is the only semi-mechanized mill operating in Bayelsa State. The mill is located at Elebele in Ogbia local government area of the state (4º 52' 12.8"N; 6º 18' 51.2" E). The mill uses a batch process with over 50% of its operation manual. The manual activities include bunch reception, bunch loading on stripper, sieving, loading of boiler with solid wastes biomass and oil drying. Mechanical sieve is used to separate the chaff from the palm fruits. The mechanized activities are powered by diesel generator for threshing, oil extraction/pressing, fiber separation, and clarification. The various equipment power by diesel generator include stripper/thresher (used to separate the EFB from the palm fruit), digester (used to crush the boiled palm fruit), presser (used for oil extraction from the crushed fruit), separator (used to separate PPF from nut), clarifier (used to separate POME from the oil), and boiler firer (used to supply air to the boiler). The processing activities using electricity are carried out concurrently apart from clarification activity. The semi-mechanized mill processes 10 batches of 1 tonne FFB daily. The mill has staff strength of 12 persons distributed into the various processing activities. Of these, about 70% are males while the rest are females. The mill completes a full batch operation ranging from bunch reception to oil storage in 3 – 4 days. Of these, fermentation activities take 2 – 3 days so as to facilitate threshing/stripping. The mill process a mixture of *Tenera* (high oil yielding variety) and *Dura* (low yielding variety). The process of oil palm extraction at the mill is presented in Fig. 2.

2.3. Mass-Balance Computation and Wastes Utilization

To determine the mass balance of 1 tonne of the fresh fruit production of oil in the process, the weight of the FFB and the various solid wastes generated including EFB, PPF and chaff were measured using weighing scale. Also the quantity of the solid waste used as boilers fuel and the excess was measured.

2.4. Energy Use Computation

The volume of fossil diesel used for threshing, digestion/pressing, clarification and fiber separation was measured using a measuring cylinder. The total energy used by the mill was obtained by first converting both energy sources (biomass and diesel) to a common energy unit (MJ). This was done by multiplying the weight of biomass used to fire the boiler and the liters of fossil diesel used for digestion/pressing, stripping, clarification, fiber separation with their respective calorific values for EFB, PPF and chaff (mean 17.75, 18.75 and 17.78 MJ/kg, respectively) (Ohimain and Izah, 2014). The energy content of fossil diesel is 56.3MJ/l was also employed in the computation (Nanaki and Koroneos, 2012).

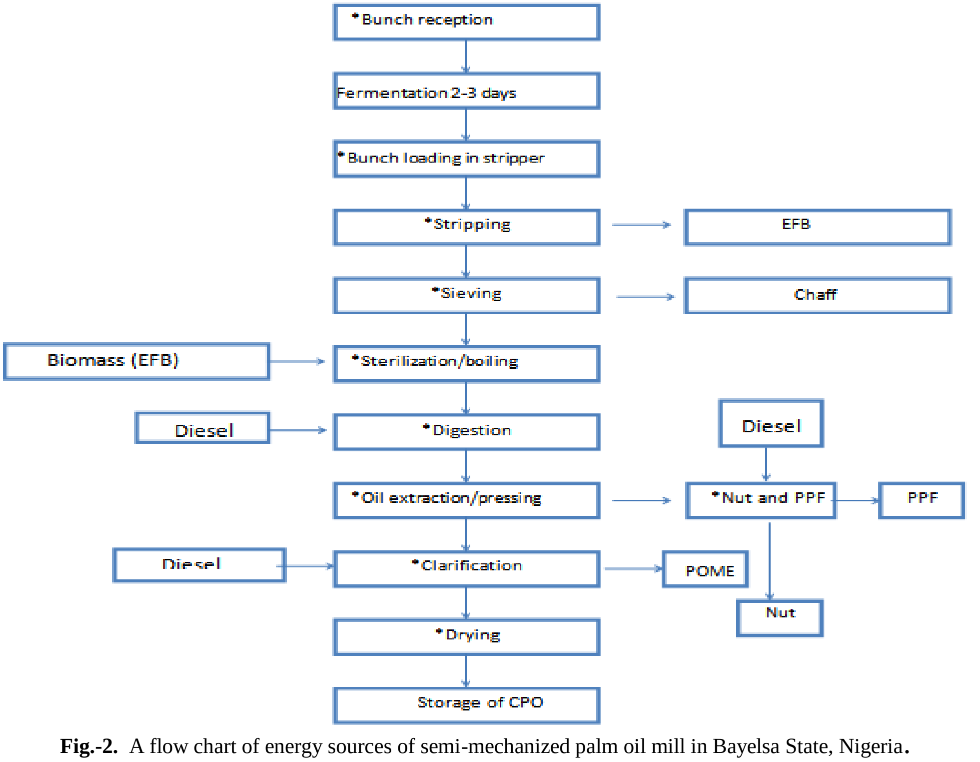

Fig.-2. A flow chart of energy sources of semi-mechanized palm oil mill in Bayelsa State, Nigeria.
(EFB = empty fruit bunch; PPF = palm press fibre; CPO = crude palm oil; * = phase in oil palm processing that requires human energy)

3. RESULTS AND DISCUSSION

Biomass can be used as energy source for food processing. The mass-balance of the production of 1 tonne (i.e. 1000 kg) of FFB in semi-mechanized palm oil mill is presented in Figure 3. The number of FFB in one tonne is 74, with an average weight of 13.5 kg. The mass balance of FFB during processing comprise of 72.5 % (threshed fruit), 26.0 % (EFB) and 1.5 % (chaff) at the first stage, 54.0% (mesocarp/pericarp) and 18.5% (nut) at the second stage, and 30.0 % (PPF), 14.0% (moisture) and 10.0% (CPO) at the final stage. The result of this study is comparable to previous reports. The processing of FFB generates 41 – 75% (threshed fruit), 11.8 – 27.5% (nut), and 10.62 – 28.1% (PPF), 9.4 – 28.2% (CPO) (Prasertsan and Prasertsan, 1996; Mahlia *et al.*, 2001; Hambali *et al.*, 2010; Ohimain *et al.*, 2013a). Also, EFB was reported in the range of 20.0 – 59.0% (Prasertsan and Prasertsan, 1996; Chavalparit *et al.*, 2006; Hambali *et al.*, 2010; Ohimain *et al.*, 2013a). Ohimain *et al.* (2013a) and Prasertsan and Prasertsan (1996) reported moisture content of the mesocarp in the range of 9.0 – 14%. Ohimain *et al.* (2013a) reported chaff in the range of 0.8 – 2.4%. The fractions of the byproducts generated during the processing of FFB into CPO are dependent on the oil palm variety, FFB quality and bunch size (Ohimain and Izah, 2014). At the Bayelsa Palm Mill, the processors combine *Tenera* and *Dura* varieties during processing. Unlike smallholder palm oil processors in Nigeria, the Bayelsa Palm Mill does not ferment and repress the PPF to obtain the second grade oil.

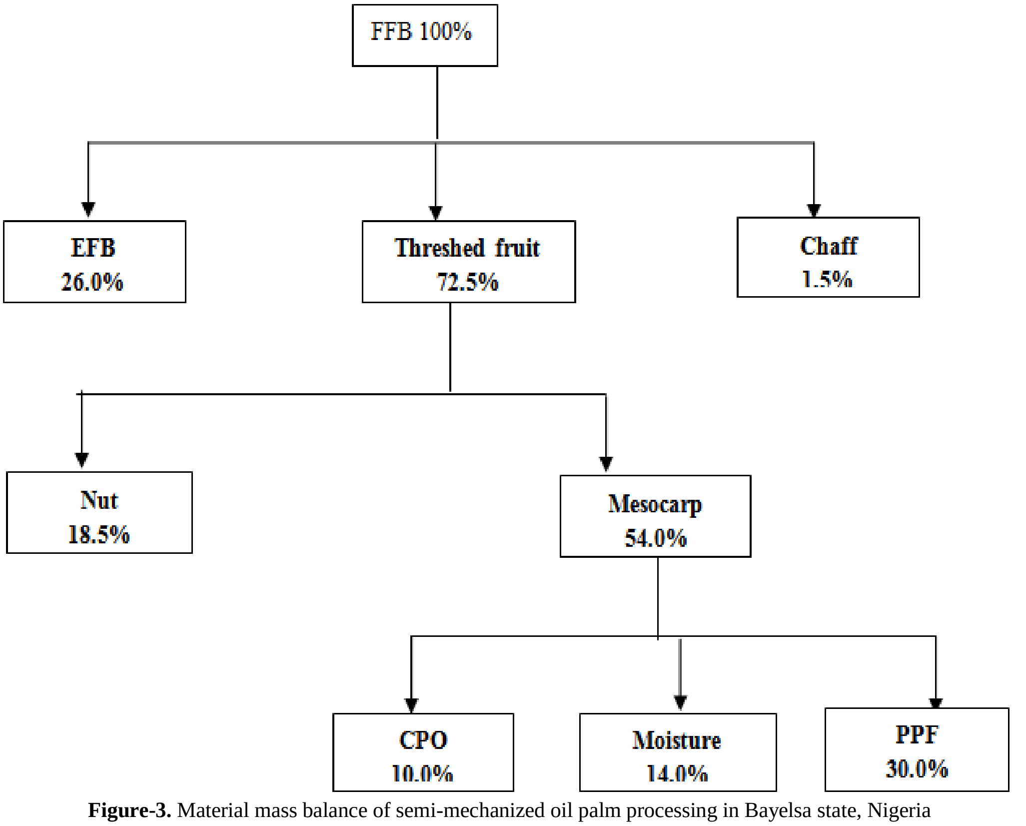

Figure-3. Material mass balance of semi-mechanized oil palm processing in Bayelsa state, Nigeria

Solid wastes generation, utilization and energy content from the processing of 1 tonne of FFB are presented in Table 1. The biomass generated during the processing of CPO from 1 tonne of FFB is 259.0 kg (EFB), 301.9 kg (PPF) and 14.8 kg (chaff). The fraction utilized for boiling are 235.9 kg (EFB), 0.0 kg (PPF) and 0.0 kg (chaff), while the rest are un-utilized. The energy content of the biomass generated is 4187.23 MJ (EFB), 5660.63 MJ (PPF) and 263.14 MJ (chaff). Of these only 4187.23 MJ from EFB was utilized by the mill for boiling. Ohimain and Izah (2014) have reported biomass generation from smallholder processing mills for the processing of 1 tonne of FFB as EFB (240.8 – 308.5 kg), PPF (238.4 – 281.8 kg) and chaff (14.2 – 24.3 kg). They also stated that 119.3 – 152.1 kg of oil palm biomass (EFB, PKS, PPF and chaff) was used for boiling/sterilization.

Table-1. Utilization of biomass fuel for boiling operations in the processing of 1 tonne of FFB

Solid wastes	Biomass wastes generated (kg)	Biomass wastes Utilized (kg)	Biomass wastes Un-utilized (kg)	Energy content of utilized biomass wastes (MJ)	Energy content of un-utilized biomass wastes (MJ)
EFB	259.0	235.9	23.1	4187.23	410.03
Chaff	14.8	0	14.8	0	263.14
PPF	301.9	0.0	301.9	0	5660.63
Total	575.7	235.9	197.4	4187.23	6333.80

The volume of fossil diesel used for every 1 tonne of FFB is 1.85 liters. The diesel energy utilized for stripping, digestion/pressing and fiber separation is 90.08 MJ and for clarification is 14.08 MJ (Table 2). The total energy for the processing of 1 tonne of FFB in the mill is 4291.39 MJ (Table 3). Out of these, 97.57 % was obtained from waste biomass while diesel accounted for the remaining 2.43%. The total energy of the biomass (EFB, PPF, chaff) generated during palm oil processing in the mill is 10521.03 MJ. Out of these, 39.80 % was utilized for boiling while the rest 60.20 % was un-utilized. Ohimain and Izah (2014) reported that in a smallholder processing mill, the processing of FFB requires a total energy of 2179.43 – 3014.31 MJ/ tonne. Of these, biomass accounted for 98.22 – 98.75 % (used for boiling/sterilization), while diesel supplied the remaining 1.28 – 1.78 % (used for digestion). Also (Chavalparit, 2009) reported that the energy required for oil palm processing utilizes 2 % from fossil fuel.

Table-2. Diesel fuel used by semi-mechanized palm oil mill for processing of 1 tonne of FFB

Activities	Quantity (liters)	Energy content (MJ)
Concurrently operation (stripping, digestion/pressing, fiber separation)	1.6	90.08
Clarification	0.25	14.08
Total	1.85	104.16

Table-3. Contribution of biomass fuel in the processing of 1 tonne of FFB by semi-mechanized palm oil mill

feature	Sources of energy	Energy value (MJ)	%
Energy utilization	Biomass	4187.23	97.57
	Diesel	104.16	2.43
	Biomass + diesel	4291.39	100
Biomass utilization	Utilized	4187.23	39.80
	Un-utilized	6333.80	60.20
	Total biomass	10521.03	100

The excess biomass generated during the processing of oil palm is typically disposed via open combustion releasing CO_2, other air emissions into the environment. In most oil palm processing mill in Nigeria, the excess biomass waste are burnt off (Fig. 4**)** releasing pollutant gases like carbon monoxides, sulphur dioxide, nitrogen dioxide, suspended particulate matters (Ohimain and Izah, 2013; Ohimain *et al*., 2013b).

Fig-4. Excess oil palm biomass being disposed via burning

The energy content of this biomass makes it a suitable raw material for energy conversion. Authors have severally reported the heating value of oil palm processing wastes (EFB, PPF and chaff). Ohimain and Izah (2014) reported average value of 17.75, 18.75 and 17.78 MJ/kg for EFB, PPF and chaff respectively. Sumathi *et al.* (2008) reported 18.84 MJ/kg and 19.07 MJ/kg for EFB and PPF respectively. Prasertsan and Prasertsan (1996) reported 9.6 MJ/kg and 4.4 MJ/kg for EFB and PPF respectively. Also the energy content of these wastes is comparable to that of bagasse from C_3 and C_4 plant used for power generation. Sugumaran and Seshadri (2009) and Tiwari (2011) reported 16.46 – 18.10MJ/kg as heating value of sugarcane bagasse. Forest wood have similar calorific value with oil palm processing waste in the range of 10.17 - 22.03 MJ/kg (Lucas and Fuwape, 1984; Nwachukwu and Lewis, 1986; Fuwape and Akindele, 1997; Ogunsanwo *et al.*, 2003; Erakhrumen, 2009). Therefore, oil palm wastes are suitable raw material for electricity generation via direct combustion.

Oil palm processing biomass especially the EFB contain lignocellulosic material consisting of carbohydrate polymers (i.e., cellulose and hemicellulose) and lignin, hence bioethanol can be synthesized from it via hydrolysis followed by simultaneous saccharification and fermentation. Bioethanol is extensively used as fuel to reduce vehicle's gaseous emissions such as oxide of carbon and other smog-causing particulates (Shuit *et al.*, 2009). Nigeria is in the process of producing bioethanol from twenty factories in different parts of the country (Ohimain, 2010). Several feedstocks have been selected for the industry, most of which are first generation feedstocks which are also food crops. Therefore, the excess oil palm biomass can be utilized to prevent the food versus fuel crises that could arise from the use of food crops for bioethanol production. Solid biofuel such as briquette can also be produced from oil palm biomass using screw extrusion technology (Shuit *et al.*, 2009).

4. CONCLUSION

This study evaluated the energy production and requirement from the processing of 1 tonne of FFB in semi-mechanized palm oil mill in Bayelsa State, Nigeria. The mass balance shows that 10.0% of FFB form the CPO while the remaining 90.0% form other products and wastes. The energy utilized in the processing mill is < 2.5 % diesel and >97.5 % oil palm waste biomass. About 39.8% biomass generated (i.e. EFB, PPF and chaff) was utilized for boiling purposes, while the rest 60.2% were un-utilized. The excess biomass is burned in the processing mill, which leads to environmental pollution. Therefore, we conclude by suggesting that the excess waste from the oil palm process should be integrated into the nation's energy sources mix. The excess biomass can be utilized for power generation and production of diverse biofuels such as bioethanol, bio-methanol, biogas, bio-hydrogen, and briquettes.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following undergraduates students of Niger Delta University that participated in the field sampling exercise; Jenakumo Nimi, Fawari Amanda, Fikiye Ilaye and Idoniboye-Obu Precious. The authors also wish to thank the management of Bayelsa Palm Limited, Nigeria for allowing us to conduct this research in their oil palm processing mill. Thanks to Dr. Beth Middleton of the USGS National Wetlands Research Center, 700 Cajundome Blvd, Lafayette, LA for proofreading the manuscript.

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