

# Original Research Article

## Exploitation of Empty Palm Fruit Bunch for the Generation of Electricity

### ABSTRACT

This aim of this study is to evaluate the utilization of empty palm fruit bunch for the generation of electricity. The empty palm bunch was used in firing a steam turbine plant (boiler) for the generation of electricity. The power plant that was used in this research is owned by PRESCO Nigeria Limited located in Ikpoba-Okha local government area of Edo state. 1.7 MW of electricity was generated by burning empty fruit bunch (EFB) at a rate of 896 kg per hr. This value was compared with the traditional power plant fired by methane gas which produces 4.5MW. The cost of producing power using methane gas is very expensive estimated to about 2500 dollars compared to the cost of using EFB since it is a waste from oil palm plantation companies and abundant in nature. The use of EFB is very economical as an alternatives fuel in firing a boiler plant and elimination of wastes from the plant.

Keywords: *Palm fruit bunch, Waste conversion, Power generation, Renewable energy*

### 1. INTRODUCTION

Energy is a social and economic need of any country. The energy use in any country is expected to continue to increase as its population increases [1]. Nigeria's population has increased from 159 million in 2010 to about 187 million in 2019 which will demand about 25000 MW for homes and industries in other to have stable electricity. Electricity is essential for the economic growth and improvement of the standard of living of the increasing population. Therefore without adequate basic energy supply, people will not be able to meet up to their domestic needs such as cooking, light their homes, chilled up their perishable goods and other needs that require electricity [2].

The demand for energy is increasing globally especially in Nigeria, which the chief source of power generation is steam and gas turbine. A lot of research activity has been done in Nigeria and some are still going on how to find a solution to this power problem in the country in other to find substitutes to fossil energy [3]. These alternative sources intended to address concerns about the exhaustion of fossil fuel because they cannot be used forever.

Oil palm (*Elaeis guineensis*) is one of the most important economic oil crops in Nigeria. According to the Rainforest Movement (WRM), oil is indigenous to the Nigerian coastal areas [4]. An oil palm plantation produces enormous volumes of wastes such as empty fruit bunches (EFB), palm kernel shell (PKS) and palm oil mill effluent (POME). Empty palm bunch contains neither chemical nor mineral additives; it is free from foreign materials depending on handling operations at the mill. Pre-processing of EFB is essential before it can be measured as a high-grade fuel. The moisture content is approximately 70%. This material is very cheap for the generation of electricity due to its availability compared to the conventional system (hydro and gas turbine) which is very expensive. It is very economical compared to the general flaring of gas which is the major source of global warming.

Nigeria generates a considerable quantity of agro-waste. This will present great prospects for exploiting biomass in an eco-friendly and commercially viable manner. EFB can be transformed into renewable energy resources through

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Comment [N19]: Apart from depletion, other significant concerns include the adverse effect on the environment, the unstable politics/market and particularly in Nigeria, the proliferation of 'resource control' struggles with the attendant sabotage activities as well as epileptic/interrupted power supply. You need to articulate some of these reasons also.

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39 meet the needs of industries and the national grid. To achieve this, pre-treatment steps such as shredding and dewatering  
40 are required in order to improve the fuel property of the empty palm bunch. In fact, palm oil mill (POM) using a  
41 cogeneration system for producing steam and electricity demands using one source of fuel in the milling process. The  
42 cogeneration system consists of a boiler, turbine, and generator. Fiber and shell are burnt directly in the boiler to form  
43 superheated steam (fiber 65:35). Half of the steam is used for milling processes. Residual steam is converted to electricity  
44 using a turbine. Fiber, shell and empty palm bunch are useful for the heating purpose because of its calorific value.

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45 Palm oil is currently the world largest source of edible oil. Palm oil mill in Nigeria produces about 0.94 million tones and  
46 1.54% of world total oil produced in 2015. It is predicted that the demand of world palm will remain of high increase as  
47 followed by the population growth, food, and industrialization. The more crude palm oil (CPO) produced the more biomass  
48 wastes. A palm oil mill (PMO) wastes is around 13-17 % fiber, 6-10 % shell and 25-27% empty fruit bunch (EFB) based  
49 on its capacity. However, this biomass waste is needed to be utilized effectively to overcome the problem. These waste  
50 can be converted into energy using incineration or other chemical processes. Palm biomass has been long identified and  
51 utilized as renewable energy but there is rare energy power plant applied. Due to its heating value, it can be used as fuel  
52 for electricity production. According to the global market, the price of petroleum is increasing steadily. As a result industrial  
53 sectors are searching for alternative means for generating their electricity to replace the petroleum fuel in order to reduce  
54 cost. Indonesia and Malaysia, which is the world's largest palm oil producing countries generate 53.6% and 36.8% of total  
55 world oil production with about 33.4 and 19.9 million tons per annum of crude palm oil, respectively. These have assisted  
56 in changing the economy of these countries drastically. They generate electricity from the waste biomass of empty palm  
57 bunch in addition to other products. One of the unique aspects of Malaysian renewable energy sources is that the palm oil  
58 mill is self-sufficient in energy using palm press fiber (PPE), empty fruits bunch (EFB), and shell as fuels to generate  
59 steam in waste fuel boilers for processing and power generation with steam turbines [5]. This delivery electricity concept  
60 can be applied to support electricity demand in Nigeria using the national grid line as the distributing system. Also, some  
61 companies in Nigeria such as NIFOR (Nigeria Institute for oil palm oil research) located in Ovia South East and PRESCO  
62 Palm Oil Industry located in Ikpoba-Okha Local Government, Edo State, Nigeria depend on empty palm fruit bunch for  
63 electricity generation, which has saved them from the problem of power interruption and cost. This empty palm fruits  
64 bunch is in abundance.

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Comment [N28]: Nigeria Institute for oil palm oil research (NIFOR)

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65 Oil palm biomass wastes emerge as a potentially major contribution to renewable energy as the government has now  
66 shifted from conventional sources such as coal, oil, and gas to promoting renewable energy sources in order to increase  
67 energy security. Indeed the combustion of fossil fuels' as sources of energy for heat, transportation, and electricity is  
68 known to be the major factor contributing to global warming. The world is moving from the conventional non-renewable  
69 energy sources to renewable energy sources due to their renewability and eco-friendly nature, which is critical for the  
70 future generation of power. The Malaysian government has made several efforts to encourage the use of renewable  
71 energy to scale down dependency on fossil fuels and to meet the growing demand for energy. As a result, the Fifth Fuel  
72 Policy was introduced in 2001 to encourage new renewable energy sources such as oil palm, rice husk, and wood waste  
73 to compliment the conventional energy supply [6]. The adoption of this fifth-fuel policy was supported by the  
74 implementation of the small renewable energy power (SREP) [7]. Sarawak, one of the largest towns in Malaysia has the  
75 potential to generate a total of 425 MW of electricity from biomass sources, where 375 MW of this amount was contributed  
76 by palm biomass. In Nigeria, most of the electricity generated is from gas fire thermal power plant which uses several  
77 methods in its conversion. One of the methods is burning the gas in a boiler to produce steam, which is then used by a  
78 steam turbine to generate electricity. Thus, this has led to the over-dependence on the conventional oil; this has led to gas  
79 flaring, which can be converted to more meaningful products instead of wasting the resources. Over-dependence on  
80 hydropower and steam turbine in Nigeria has made this biomass to be underutilized. Considerable research and  
81 development are currently ongoing to develop smaller gas fires that would produce electricity on a small scale. Currently,  
82 biomass is used for off-grid electricity generation but almost exclusively on a large industrial scale [8].

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83 Lignocelluloses biomass wastes produced from oil palm industries include palm kernels cakes (PKC), palm kernel shells  
84 (PKS), empty fruit bunch (EFB), oil palm tusk (OPT), oil palm fronds (OPF), palm press fibers (PPF) and palm oil mill  
85 effluent (POME). Oil palm waste is a reliable resource because of its availability, continuity, and capacity for renewable  
86 energy solution. Furthermore, the presence of oil palm waste has created a major disposal problem, thus has a negative  
87 effect on the environment. Therefore to avoid this negative effect on the environment this work will address this issue by  
88 EXPLOITING THIS PALM BIOMASS IN GENERATING ELECTRICITY. Apart from power generation, the fresh palm fruits  
89 (FPF) will also yield other products which will boost the economy and gross domestic product (GDP) of the country and  
90 create jobs. The increase in the population brings about an increase in the demand for electricity. Since the demand is  
91 high, the conventional source of generating electricity has not been able to meet the demands of the increasing  
92 population. The shortage of electricity has severely hampered the development of Nigeria, therefore to lessen the problem  
93 of power failure and the huge cost of using petroleum for generating power in industries, an alternative has been  
94 investigated.

The aim of this work is to evaluate the exploitation of empty palm fruit bunch as renewable energy for electricity generation. The empty palm bunch was used for firing the steam turbine (boiler) for the generation of electricity. The calorific value and the heat intensity was also determined.

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## 2. MATERIAL AND METHODS

### 2.1 Materials Collection

120 tons of fresh fruit bunch was obtained from the oil palm plantation of PRESCO Nigeria Limited located at Obaretin Estate, Ikpoba-Okha local government area, Edo state, which generates 60 tons of fresh fruit bunches/hour. The fresh fruit bunch was further processed in other to get the desired raw material, which was used to fire the boiler. The Fig. 1 shows the fresh and empty fruit bunch. The empty fruit bunches are fibrous materials and the moisture content is low compared to the other biomass residues. It contains residue of palm oil which gives it a high heating value than any other average lignocelluloses biomass.

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The palm press fiber and palm kernel shells that were generated in the palm oil mill (POM) were used as a solid fuel for steam boilers. The heat in the steam boilers was used in addition to empty fruits bunch (EFB) to run the steam turbine for generating the electricity. A careful breakdown was carried out in the course of this research in a well-established palm oil mill like PRESCO Nigeria. It is expected that every 100 tons of palm fresh fruit processed yields 20-24 tons of crude palm oil, 19-21 tons of empty fruits bunch, 15 tons of oil-rich fiber, 5 tons of shells, 3 tons of palm kernels, 16% moisture content and 20% effluent. The potential of biomass wastes of oil palm plantation is shown in Fig. 2.

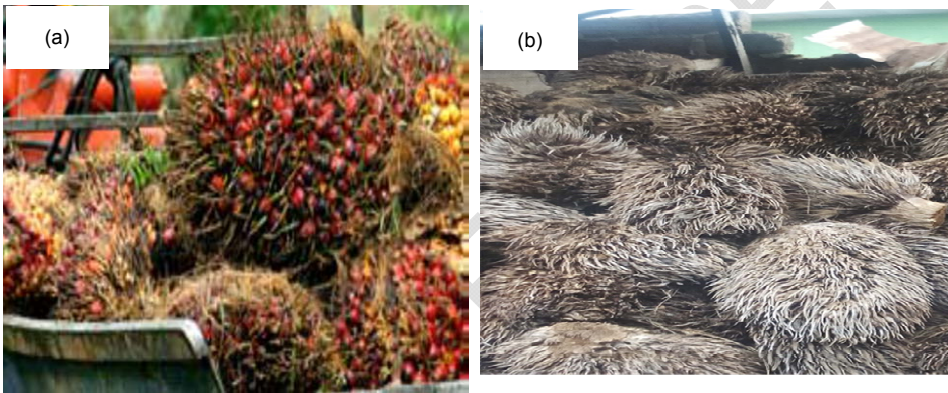


Fig 1. Fresh fruit bunch and empty fruit bunch.

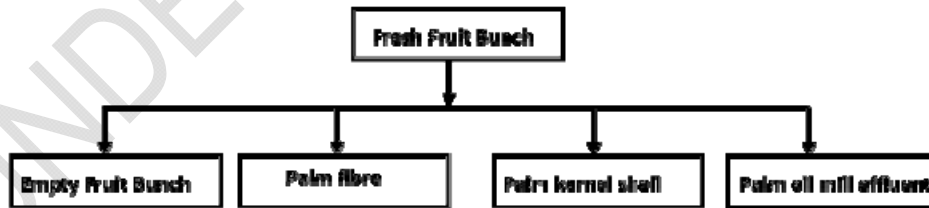


Fig. 2. Diagrammatic presentation of biomass/waste potential from oil palm plantation.

### 2.2 Pretreatment of Empty Palm Fruit Bunch

Pretreatment of empty palm fruit bunch is very important in order to increase its digestibility and its degree of conversion. The method of pretreatment that was used in this study is the chemical pretreatment, which involves diluting acid hydrolysis and alkaline pretreatment. Ammonia ( $\text{NH}_4$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) solutions were used to increase the digestibility of the EFB. Fast pyrolysis with alkaline solutions ( $\text{NaOH}$  and  $\text{Ca}(\text{OH})_2$ ) was done followed by the addition of  $\text{H}_2\text{O}_2$ . Alkaline pretreatment has been proved by researchers to be the best [9, 10, 11, 12]. The effectiveness of alkali pretreatment might be attributed to its capability in lignin degradation.

### 2.3 Conversion Process

The conversion process used for this research work was the thermo-chemical conversion. Thermo-chemical conversion of biomass (EFB) involves heating the biomass in the absence of  $\text{O}_2$  to yield a mixture of gas, liquid and solid [12]. The products were used as fuels after further conversion. Generally, lower reaction time (a few seconds or minutes) is required for thermochemical processes. These generally include biomass pyrolysis, gasification, and torrefaction [12].

#### 2.3.1 EFB pyrolysis

Pyrolysis is the thermal degradation of biomass materials in the absence of oxygen [13]. It can be performed at a moderate temperature ( $400 - 600^\circ\text{C}$ ) at a short period of time. Products of pyrolysis may comprise gases (methane, hydrogen, carbon monoxide, and carbon dioxide), liquids (water, and oil/tars) and solids (charcoal). The efficiency of pyrolysis and the fractions of gas, liquid, and solid produced basically depend on the process factors such as pretreatment condition, temperature, time of retention and reactor type [12]. Misson et al. [11] observed that  $\text{NaOH}$  and  $\text{Ca}(\text{OH})_2$  couldn't modify the composition of the lignin significantly. In addition, the pretreated EFB was catalytically pyrolyzed more efficiently than the untreated EFB samples under the same conditions. Sulaiman and Abdullah [14] also observed that gas production was more favorable at higher temperatures, and the moisture content was nearly constant in the range of temperatures examined using bench top fluidized bed reactor with a nominal capacity of 150 g/L.

#### 2.3.2 EFB Gasification

The gasification process is an extension of the pyrolysis process except that it is piloted at an elevated temperature ( $800 - 1300^\circ\text{C}$ ), which implies that it is more favorable for gas production [12]. The gas stream is largely composed of hydrogen, methane, carbon dioxide and carbon monoxide. Biomass gasification presents numerous advantages including decreased  $\text{CO}_2$  emissions, accurate combustion control, compact equipment requirements with a relatively small footprint, and high thermal efficiency [14]. The key challenge in gasification is allowing the pyrolysis and gas reforming reactions to occur using a minimum amount of energy; therefore, gasifier design is important. An entrained-flow gasifier for the gasification of EFB at  $900^\circ\text{C}$  was used by Ogi et al. [15]. The rate of gasification was enhanced ( $>99\%$ ) when  $\text{O}_2$  was added to  $\text{H}_2\text{O}_2$  than using  $\text{H}_2\text{O}_2$  alone. Gasification was suggested as the most appropriate thermo-chemical route for EFB conversion to biofuels [12]. Process flow diagram of EFB gasification unit is shown in Fig 3 [12].

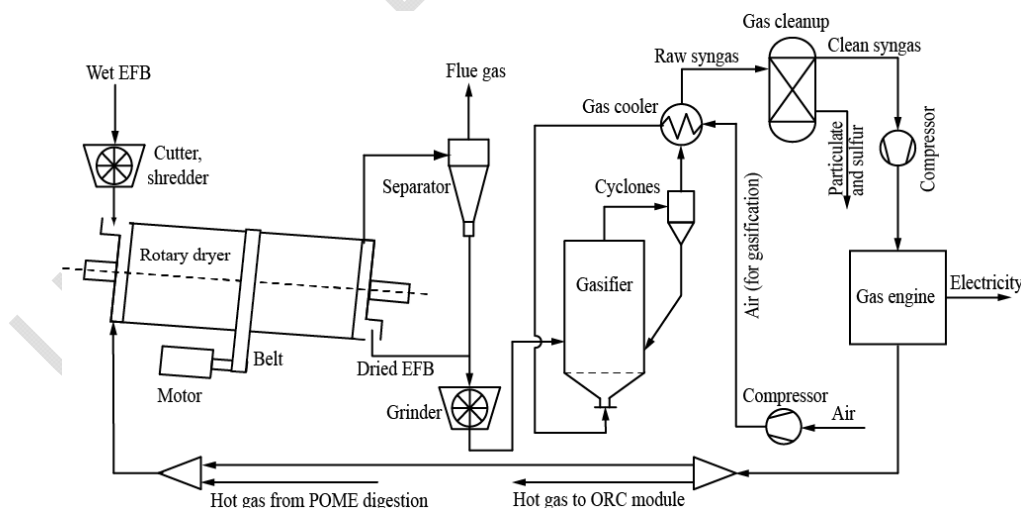


Fig 3. Process flow diagram of EFB gasification unit.

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### 2.3.3 EFB Torrefaction

Torrefaction is a thermal conversion of biomass at the low-temperature (200-300 °C) [16]. Biomass is pretreated to produce a high-quality solid biofuel that can be employed for gasification and combustion. It is centered on the removal of O<sub>2</sub> from biomass to yield a fuel with improved energy density. Several reaction conditions (inert gas, temperature, and reaction time) and biomass resources lead to differences in gaseous, liquid, and solid products. Uemura et al. [17] examined the influence of torrefaction on the basic properties of EFB, mesocarp fiber and kernel shells as a possible source of solid fuel. The mesocarp fiber and kernel shell exhibited excellent energy yield with values higher than 95% while EFB exhibited a poor yield of 56%. Torrefaction can also be achieved in the presence of oxygen [18]. Fig. 4 presents the pretreatment and the conversion process for palm empty fruit bunch [12].

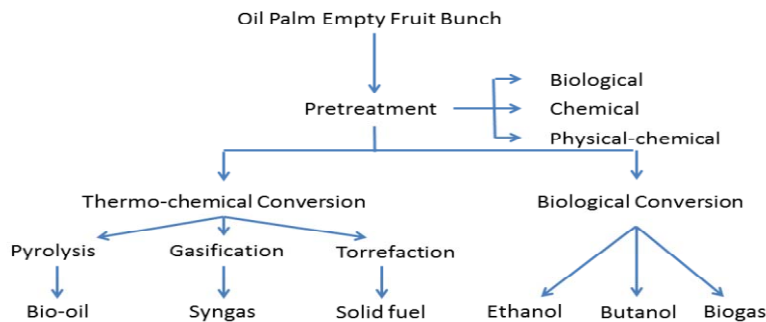


Fig. 4. The pretreatment and the conversion process for Palm Empty Fruit Bunch.

### 2.4 Equipment

The boiler used in this work is the PRESCO Nigeria steam boiler. It has a capacity of 25 bar and was used in burning 896 kg of EFB per hour, which generated 1.7 MW of electricity when compared with the combustion of methane gas, which will produce 4.58 MW of electricity. The boiler produced the required heat energy for generating the electricity. The heat generated with the boiler using 896 kg of EFB has a calorific value of 19500 kJ/kg. The chimney was used in order to allow smooth flow of heat generated by the boiler to effectively power the turbine without loss to the surrounding. It is 200m tall with a diameter of 3.3 m.

The steam turbine used in this work was PRESCO Nigeria limited plant located in Ikpo-Okha Local Government Area of Edo State. It has the capacity of generating up to 1.99 MW of electricity. But for the case of this work, 1.7MW was generated when a fuel (EFB) of 896 kg was combusted per hour.

### 2.5 Generation Process

The technology used for this project is the steam turbine. It involves some stages of conversion; it extracts thermal energy (heat) from the fuel (EFB) in the combustion chamber via the steam boiler to raise the steam, converting the heat energy generated into kinetic energy in the steam turbine and finally using a rotary generator to convert the turbine mechanical energy into electrical energy. Fig. 5 shows the electricity generation plant using EFB. The three stages of energy conversion are illustrated below

Heat energy (steam boiler) → Mechanical energy (steam turbine) → Electrical energy (Generator)

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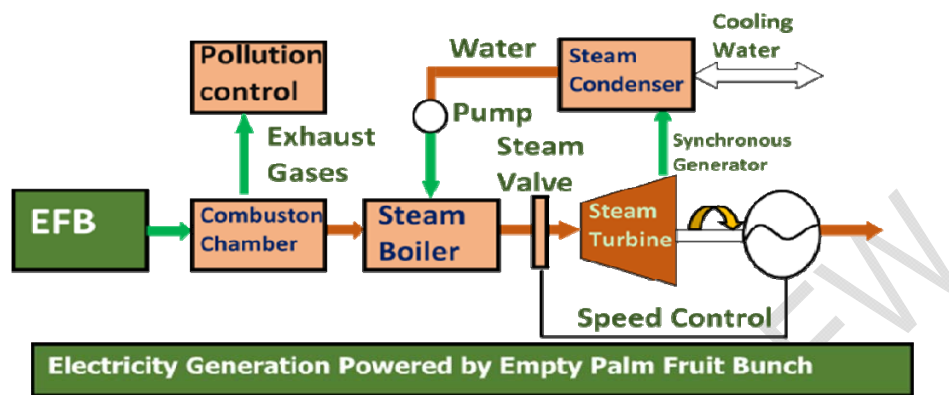


Fig. 5. Electricity generation plant using EFB.

To achieve this successfully, the moisture content of the fuel was totally reduced in order to increase the quality of heat needed to power the steam turbine.

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### 3. RESULTS AND DISCUSSION

#### 3.1 Physicochemical Properties of Empty Fruits Bunch (EFB)

Empty fruit bunch possesses its own properties like the other sources of fuel. The proximate and ultimate analysis was done on the EFB to ascertain its properties. The properties of EFB are presented in Table 1.

Table 1. Properties of EFB

Components	Value	Unit
Cellulose	58.3	%(w/t)
Hemicelluloses	23.4	%(w/t)
Lignin	19.2	%(w/t)
<b>Proximity Analysis</b>		
Moisture	9.36	%(w/t)
Volatile	78.59	%(w/t)
Ash	5.31	%(w/t)
Fixed carbon	15.42	%(w/t)
<b>Ultimate Analysis</b>		
Carbon	46.2	%(w/t)
Hydrogen	6.4	%(w/t)
Oxygen	44.39	%(w/t)
Nitrogen	0.66	%(w/t)
Sulphur	0.08	%(w/t)
<b>Other Properties</b>		
Low heating value	13200	kJ/kg
High heating value	19500	kJ/kg
Bulk Density	113.92	kg/m <sup>3</sup>

#### 3.2 Chemical Formula of Empty Fruit Bunch (EFB)

The chemical formula for EFB was derived in this study. The formula of EFB Fuel sample is given as:



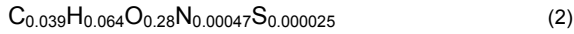
If Eq. 1 is on the basis of 95 kg sample of EFB, the composition by mass is given as (according to Table 1):

C:  $12a = 0.462$ ,  $a = 0.462/12 = 0.039$ ; H:  $1y = 0.064$ ,  $y = 0.064$ ; O:  $16r = 0.4439$ ,  $r = 0.028$ ; N:  $14v = 0.0066$ ,  $v = 0.00047$ ;

S:  $32m = 0.0008$ ,  $m = 0.000025$ .

Substituting these values of a, y, r, v and m yields Eq. 2, which is the formula of the fuel sample.

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The amount of heat liberated by the rate of feeding into the combustion chamber through the furnace was also evaluated. The empty palm fruits undergo a shredding process by cutting the EFB into smaller pieces to lose its structure, this help to improve the volume weight ratio and enhance the fuel characteristic. Fig. 6 illustrates the schematic diagram of the steam turbine [18].

The combustion ratio (CR) and heat released, Q were calculated below using Eqs. 3 and 4 [18], respectively. Eq. 3 was used to calculate the combustion rate by burning 896 kg of EFB per hour which gives the rate of feeding per hour.

$$CR = \frac{\text{Total mass of burnt fuel}}{\text{Burning Time}} \quad (3)$$

$$= \frac{896}{1 \text{ hr}} = 896 \text{ kg/hr}$$

$$Q = \text{calorific value} \times \text{combustion rate} \quad (4)$$

$$= 19500 \times 896 = 17472000 \text{ kJ} = 17.47 \text{ GJ}$$

The average feeding per hour of operation and heat released were obtained as 896 kg and 17.47 GJ, respectively.

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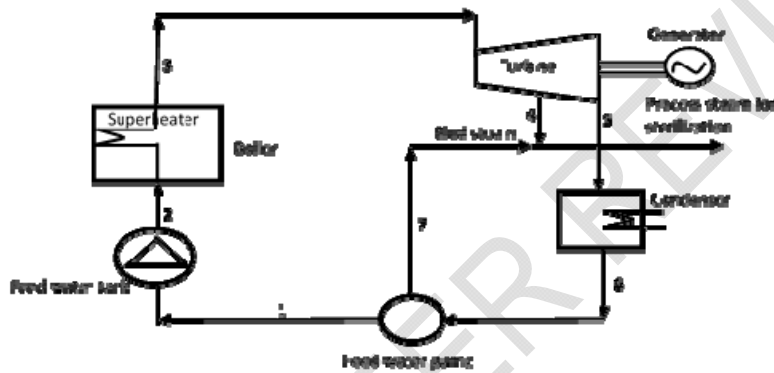


Fig. 6. Schematic diagram of the steam boiler.

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### 3.3 Combustion of Empty Palm Fruit Bunch

The combustion of EFB in the boiler taking the calorific value, its ash content, fuel size, and moisture content into account. Complete combustion of EFB will produce water vapor ( $H_2O$ ), carbon dioxide ( $CO_2$ ) and other products. The combustion of EFB is explained by Eq. 5:



$$C: 0.039=p, p=0.039; H: 0.064=2q, q=0.064/2=0.032; S: 0.000028=t, t=0.000025$$

$$0.028+2y = 2p + q + 2t$$

$$2y = 2p + q + 2t - 0.028$$

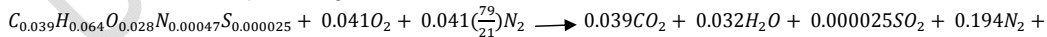
$$y = 2y = 2(0.039) + 0.032 + 2(0.000025) - 0.028$$

$$y = (0.011005 - 0.028)/2 = 0.041$$

$$N: 0.00047 + 2y(79/21) = 2u$$

$$u = \frac{0.00047 + 0.387}{2} = 0.194$$

Therefore, the balanced equation is given as



$$\text{Energy} \quad (6)$$

Eq. 6 shows the complete combustion of EFB. Water vapor, carbon dioxide and other products were obtained. If the EFB is completely dry, the moisture content is reduced.

### 3.4 Power Generated by the Empty Fruit Bunch

The power produced by burning 896 kg of empty fruit bunch is given below by putting the following parameters into consideration:

273 Calorific value (CV) = 19500 kJ/kg  
 274 Combustion efficiency ( $\eta_{\text{combustion}}$ ) = 95%  
 275 Mass of fuel (EFB) = 896 kg  
 276 Cycle efficiency ( $\eta_{\text{circle}}$ ) = 45%  
 277 Turbine efficiency ( $\eta_{\text{turbine}}$ ) = 90%  
 278 Boiler heat transfer efficiency ( $\eta_{\text{heat transfer}}$ ) = 90%

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280 The power generated was calculated using Eq. 7 [19]:

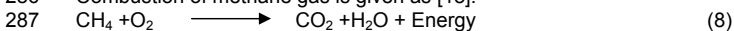
$$\text{Power} = \frac{m \times Cv \times \eta_{\text{turbine}} \times \eta_{\text{combustion}} \times \eta_{\text{circle}} \times \eta_{\text{heat transfer}}}{3600} \quad (7)$$

$$\text{Power} = \frac{896 \times 19500 \times 0.9 \times 0.95 \times 0.45 \times 0.9}{3600} = 1680.588 \text{ kW} = 1.7 \text{ MW}$$

Comment [N57]: On what basis?

### 284 3.5. Comparison between Empty Fruit Bunch Power Generated and the Conventional Gas Fired Boiler using Methane Gas of Same Mass of Fuel

285 Combustion of methane gas is given as [18]:



288 Heat released by methane gas is given as:

$$289 \text{Heat released, } Q = \text{calorific value} \times \text{combustion rate} \quad (9)$$

290 Where Calorific value of methane gas = 53178.2 kJ/kg, Mass of methane gas = 896kg

$$291 Q = 53178.2 \times 896 = 47447667.2 \text{ kJ} = 49.43 \text{ GJ}$$

292 Power produced from burning 896kg of methane gas is calculated using Eq. 6 when the same parameters for EFB were considered.

296 Where Calorific value (Cv) = 53178.2kJ/kg, Combustion efficiency ( $\eta_{\text{combustion}}$ ) = 95%, Mass of fuel (methane) = 896kg, Cycle efficiency ( $\eta_{\text{circle}}$ ) = 45%, Turbine efficiency ( $\eta_{\text{turbine}}$ ) = 90%, Boiler heat transfer efficiency ( $\eta_{\text{heat transfer}}$ ) = 90%

$$298 \text{Power} = \frac{m \times Cv \times \eta_{\text{turbine}} \times \eta_{\text{combustion}} \times \eta_{\text{cycle}} \times \eta_{\text{heat transfer}}}{3600} \quad (10)$$

$$300 \text{Power} = \frac{896 \times 53178.2 \times 0.9 \times 0.95 \times 0.45 \times 0.9}{3600} = 4583.109 \text{ kW} = 4.58 \text{ MW}$$

### 301 3.6. Calorific Value of Fuel from EFB

302 The various calorific values of various fuels, which was used in firing steam boiler from the palm oil mill is shown in Table 2 and Fig. 7. All the fuels can generate good heat for firing steam boiler but EFB has the highest calorific value, therefore, it is more favorable for this work. The calorific value of 19500 kJ/kg was produced when 896 kg of EFB was used in firing the steam boiler to get 1.7 MW of electricity. This value obtained is slightly higher than the results obtained by Olisa and Kontingo [18]. The authors obtained 1.5 MW by using 840 kg of EFB in firing a steam boiler.

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309 The moisture content of the fuel types was considered (Table 3 and Fig. 8). The moisture content was calculated using Eq. 11:

$$311 Y_w = \frac{M_1 - M_2}{M_1} \times 100 \quad (11)$$

312 Where  $Y_w$  is the moisture content,  $M_1$  is the initial mass of fuel and  $M_2$  is the final mass of fuel after drying.

313 It was observed that the empty palm fruit bunch has the highest percentage moisture. To ensure proper heating value, it was first dried up and a superheater was incorporated in the boiler in order to increase the heating rate.

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316 Power generated by the different mass of EFB fuel is presented in Table 4 and Fig. 9. The power generated by the different mass of methane is also presented in Table 5 and Fig. 10.

318 The types of fuels were also compared as seen in Table 6 and Fig. 11. The results revealed that EFB can produce about 36.6% of what the methane gas can produce giving the same amount of fuel. For the power plant using methane gas, it will cost more compared to the plant using EFB that may cost very little due to its availability especially to a country like Nigeria.

Comment [N60]: This also. The last 3 comments can warrant a change of your topic. Your topic indicated the exploitation of EFB only but now you are bringing in other types of fuels. You need to clarify this.

322 Table 2. The calorific value of various fuels.

Fuel	Calorific value(kJ/kg)
Empty fruit bunch	19500



Palm kernel shell	16200
Palm fiber	11500

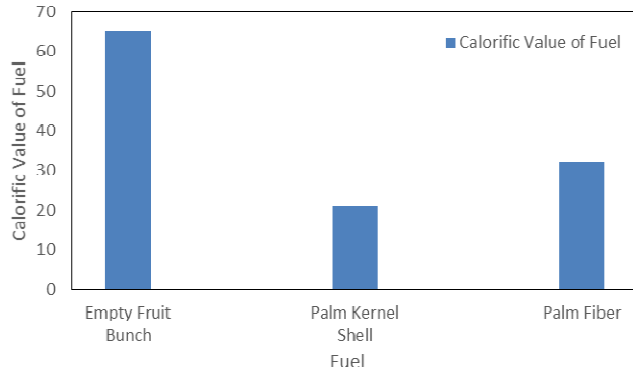


Fig. 7. Graph of the calorific value of the fuel types.

Table 3. The moisture content of the types of fuel.

Fuel	Moisture content (%)
Empty fruit bunch	65
Palm fiber	32
Palm kernel shell	21

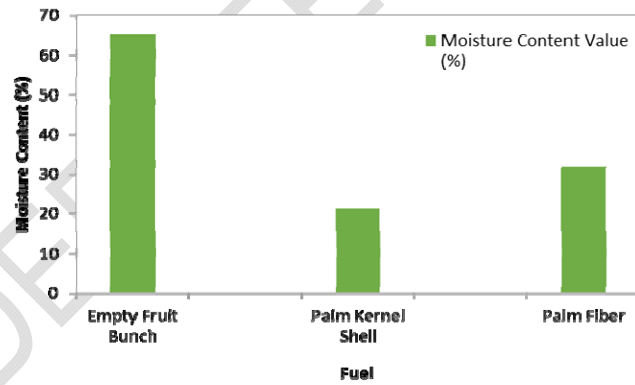


Fig. 8. Moisture content of the types of fuel.

Table 4. Power generated by the different mass of fuel (EFB).

Mass of fuel (EFB) in kg	Power generated (kW)
100	187.565
200	375.13
300	562.7
400	750.26
500	937.83
600	1125.4
700	1312.9
800	1500.52
900	1688.1

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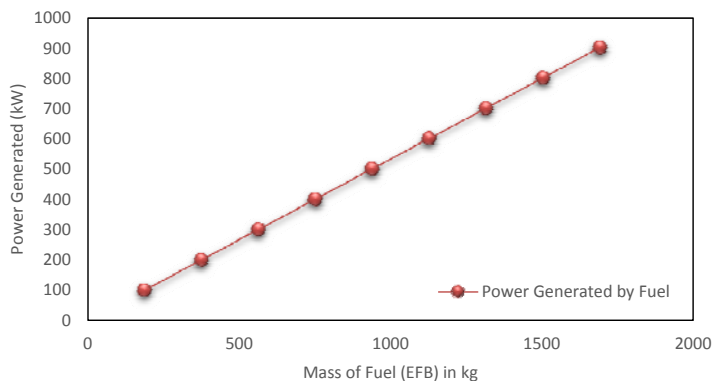


Fig. 9. Power generated by the different mass of EFB.

Table 5. Power generated by methane

Mass of methane (kg)	Power generated (kW)
100	511.507
200	1023.015
300	1534.523
400	2046.03
500	2557.54
600	3069.046
700	3580.6
800	4092.06
900	4603.6

Comment [N61]: Tables 4 and 5 are not necessary since the same information is contained in Table 6. Remove them.

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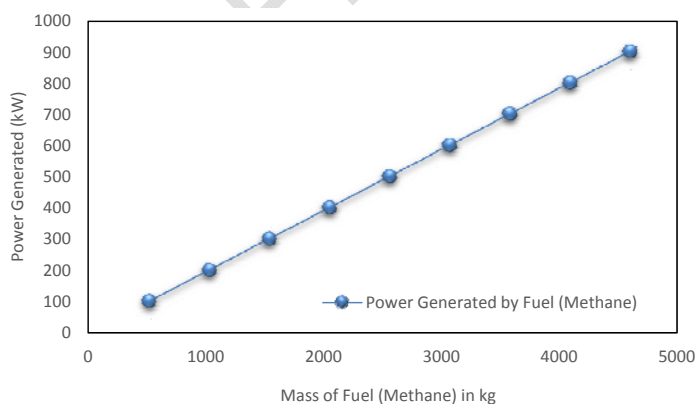


Fig. 10. Power generated by the different mass of methane.

Table 6. Comparison between the fuel types.

Mass of methane (kg)	Power generated (kW)	Mass of EFB (kg)	Power (kW)
100	511.507	100	187.565
200	1023.015	200	375.13
300	1534.523	300	562.7
400	2046.03	400	750.26
500	2557.54	500	937.83
600	3069.046	600	1125.4

Comment [N62]: Figures 9 and 10 are not necessary and should be removed. Figure 11 conveys the required information better

Comment [N63]: The 3rd column should be removed since the information is the same as that in column 1. Then change the title of column 1 to 'Mass of Fuel (kg)'

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700	3580.6	700	1312.9
800	4092.06	800	1500.52
900	4603.6	900	1688.1

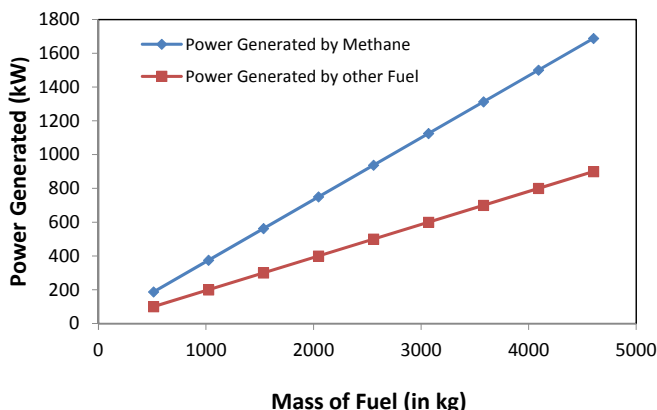


Fig. 11. Graphical comparison between the fuel types.

#### 4. CONCLUSION

Electricity is a social, economic necessity of a country. It is a major factor for the rapid development of any society and the transformation of any economy. The feasibility of using empty palm fruit bunch (EPFB), an abundant renewable energy resource for the generation of electricity was investigated. The power plant used for this research is owned by PRESCO Nigeria Limited. From the study, 896kg of EPFB produced 1.7MW of electricity when the steam boiler was used. This shows that EPFB is a very good alternative for power generation. Based on the findings from the study, other agro-based biomass can also be studied for the generation of electricity using cogeneration plant.

#### REFERENCES

- Bajaj S, Singla D, Sakhujia N. Stability testing of pharmaceutical products, J Appl Pharm Sci. 2012;02(03):129-138.
- Osaghae OJ. Potential biomass based electricity generation in a rural community in Nigeria. Master thesis, Department of Applied Physics and Mechanical Engineering. Division of Energy Engineering, Lulea University of Technology. 2009:1-25.
- Dimple E. Small-Scale Electricity Generation from Biomass, International J Sci Technol. 2011;5:43-46.
- Kate R, Deshmukh G, Tandale MS. Energy from biomass – a perspective under Indian conditions. Proc. of the International Symposium. Advances in Alternatives and Renewable Energy. Organised by University Technology Malaysia, Johor, Malaysia. 1997:63-69.
- WRM. World Rainforest Movement; Nigeria: Palm Oil deficit in a traditional Palm Oil Producing Country. 2001;
- Abdullah N, Sulaiman F. The oil palm waste in Malaysia, International J Sci Technol. 2013;2(5):839-846.
- Maulud AL, Saidi H. The Malaysian Fifth Fuel Policy: Re-strategising the Malaysian Renewable Energy Initiatives, Energy Policy. 2012;48:88-92.
- Aghamohammadi N, Reginald SS, A Shamiri, Zinatizadeh AAL, Wong LP, Sulaiman NMBN. An investigation of sustainable power generation from oil palm biomass, Chemical Engineering J. 2016;8:416.

**Comment [N64]:** There appears to be a problem here. Is it the data in the Table that was plotted or some other data? Pls clarify. The highest mass we have in the Table is 900 kg but we have more than 4000 kg plotted in your graph. Is the graph based on forecasted data? Recall too that you said in your materials and methods that you used 896 kg of EPFB. Kindly resolve all these so that the reader is not confused.

**Comment [N65]:** Why have the abbreviation changed from EPFB in your conclusion?

**Comment [N66]:** Separate

**Comment [N67]:** Separate

- 385 8. Hussain A, Ani FN, Darus AN. Thermo chemical behavior of empty fruit bunches and oil palm shells waste in circulating  
386 fluidized Bed combustor (CFBC), Journal of Oil Palm Research 2006;18:210-218.
- 387 9. Umikalsom MS, Ariff AB, Karim MIA. Saccharification of pretreated oil palm empty fruit bunch fiber using cellulase of  
388 *Chaetomium globosum*, J Agric Food Chem. 1998;46(8):3359–3364.
- 389 10. Han MH, Kim Y, Kim SW, Choi G-W. High efficiency bioethanol production from OPEFB using pilot pretreatment  
390 reactor. Journal of Chemical Technology and Biotechnology 2011;86:1527-1534.
- 391 11. Misson M, Haron R, Kamaroddin MFA, Amin NAS. Pretreatment of empty palm fruit bunch for production of chemicals  
392 via catalytic pyrolysis. Bioresource Technology 2009;100:2867–2873.
- 393 12. Geng A. (March 20th, 2013). Conversion of Oil Palm Empty Fruit Bunch to Biofuels, Liquid, Gaseous and Solid  
394 Biofuels, Zhen Fang, IntechOpen, DOI: 10.5772/53043. Available from: <https://www.intechopen.com/books/liquid-gaseous-and-solid-biofuels-conversion-techniques/conversion-of-oil-palm-empty-fruit-bunch-to-biofuels>  
395
- 396 13. Roddy DJ, Manson-Whitton C, in Comprehensive Renewable Energy, 2012.
- 397 14. Pandey A, Biofuels: Alternative Feedstocks and Conversion Processes, Biomass, Biofuels, Biochemicals, 1st Ed.,  
398 2011
- 399 15. Ogi T, Nakanishi M, Fukuda Y, Matsumoto K. Gasification of oil palm residues (empty fruit bunch) in an entrained-flow  
400 gasifier, Fuel. 2010.
- 401 16. van der Stelt MJC, Gerhauser H, Kiel JHA., Kiel JHA, Ptasinski K. Biomass upgrading by torrefaction for the  
402 production of biofuels: a review, Biomass and Bioenergy 2011;35(9):3748-3762.
- 403 17. Uemura Y, Omar WN, Tsutsui T, Bt Yusup S. Torrefaction of oil palm wastes, Fuel. 2011;90:2585-2591.
- 404 18. Olisa P, Kotingo KW. Utilization of palm empty fruit bunch (PEFB) as solid fuel for steam boiler, European J Eng  
405 Technol 2014; 2(2).
- 406 19. Rajput RK. Basic steam power cycle: Thermal engineering. New Delhi: Laxmi. 2009.

Comment [N68]: This reference was not cited