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Design of a Biomass Power Plant for a Major Commercial Cluster in Ibadan, Nigeria
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Abstract

The Nigerian electricity supply industry is currently under reforms, due to inadequate power supply to meet basic needs. Current government policy favours the development of alternative and renewable energy options to meet the shortfalls in electricity supply. The paper presents a proposal for the establishment of a biomass power plant at the Sango plank market, a major commercial cluster in Ibadan. Field studies showed that the plank market generates a biomass feed of sawdust and wood chips of 25,000tonnes/year.The paper proposesthe establishment of a 10MW direct combustion conversion process, biomass power plant at a capital investment of $1.77 million. Based on standard accounting practices, the generating cost of the plant was estimated at $0.56/kWh.Based on the Annual cost and present worth method the study also found the biomass plant more economical viable than using equivalentdiesel generating plants. The study concludes by showing the economical and environmental benefits of setting up the biomass to the Sango community.

Key words: *Electricity, Biomass, Sawdust, Design*

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I. INTRODUCTION

The power sector in Nigeria is currently under reforms. These reforms are due to various constraints, challenges and difficulties being encountered in the generation, transmission and distribution of electricity in the country. Some of this constraints and challenges includes: inadequate electricity supply, incessant power outages, low generation capacity, and high technical and non – technical losses.The reforms in the Nigerian power sector are being guided by the Electric Power Sector Reform Act (EPSR) of July, 2005 and the Renewable Energy Master Plan (REMP) of November, 2005. . The objective of the EPSR and REMP is not only to promote private initiative in improving energy supply to the national grid, but also to promote the use of renewable energy sources for electricity generation in the country.

This study presents a proposal for the establishment of a renewable biomass power plant, at the Sango plank market, a major commercial cluster in Ibadan, Oyo state, Nigeria. The structure of the paper is organised as follows: The first section includes the introduction; section 2 discusses the concept of biopower and electricity production from biomass. Section 3 introduces the Sango plank market and its current energy and environmental challenge. Section 4 discusses the design considerations for the proposed biomass plant, while Section5discusses the relevant technical and environmental design features of the proposed biomass plant. Section 6 concludes.

II. BIOMASS POWER

Biomass is defined as organic material, available on renewable basis, which are produced directly or indirectly from living organisms without contamination from other substances or effluents. Biomass includes forest and mill residue, agricultural crops and wastes, wood and wood wastes, animal waste, livestock operation residues, aquatic plants, fast growing trees and plants, municipal and industrial waste. World – wide biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs (McGowan, 1991). In developing countries, biomass provides 35% of the energy used in rural areas, where it is the most accessible and affordable source of energy (Hall et al, 1992).Biomass power, also called biopower is electricity produced from biomass fuels.. Biomass is easily produced in almost any environment, regenerated quickly and has a long history of being used for direct heating applications. Biomass is the only fuel available for renewable, combustion based electricity production. For this reason it has gained significant attention as a substitute for fossil fuels.Biomass fuels include residues from food production and processing, trees and grasses specifically grown as energy crops, and gaseous fuels produced from solid biomass, animal wastes, and landfills. The biomass fuel which was considered for the proposed biomass power plant is sawdust and other wood shavings. The use of biomass to produce electricity has steadily increased by an average of 13TWh per year between 2000 and 2008. Biomass based electricity has maintained its market share of total global generation of over the last 20years, at approximately 2% (Euromonitor International, 2009). The use of biomass for electricity production is also widespread. Currently there are 62 countries were electricity is produced from biomass, as shown in Table 1. From the table it can be seen that USA is the dominant biopower producer at 26% of world production, followed by Germany (15%) , Brazil and Japan (both 7%) .

Table 1: Global Distribution of Biomass Energy use in 2008

S/N	COUNTRY	BIOPOWER PRODUCTION (%)		S/N	COUNTRY	BIOPOWER PRODUCTION (%)
1.	United State of America (USA)	26		9.	Italy	3
2.	Germany	15		10.	Spain	2
3.	Japan	7		11.	France	2
4.	Brazil	7		12.	Netherlands	2
5.	United Kingdom	5		13.	Austria	2
6.	Finland	4		14.	Thailand	2
7.	Canada	4		15.	Australia	1
8.	Sweden	3		16.	Rest of the World	15

Source: Euromonitor International, 2008.

2.1 Biomass Conversion

Biopower technologies convert renewable biomass fuels into electricity (and heat) in several ways, but can be classified into three major types. Each category has undergone significant development and therefore has many different methods available.

2.2 Direct Combustion

The majority of biomass electricity is generated by the direct combustion process. This process involves the direct burning of biomass in a boiler to make steam; the steam then turns a turbine, which is connected to a generator that produces electricity. Biomass can also be burned with coal in a boiler (in a conventional power plant) to produce steam and electricity. It typically operates on a Rankine cycle (Bain, et al, 1998)

2.3 Pyrolysis

Pyrolysis is the thermal destruction of biomass in an anaerobic environment, without the addition of steam or air to produce gases and condensate vapours (Bain et al, 1998). Combustion of these gases occurs in a gas turbine, typically combined cycles (Ganesh, et al, 2001).

2.4 Gasification

In gasification, biomass is partly oxidized by controlling oxygen by the addition of steam to produce combustible gases, which have a high calorific value (Bain et al, 1998). Product gases are then fed into a combined cycle gas turbine power plant (DTI, 1998). Direct combustion is the oldest and simplest, but most inefficient technology. Gasification and pyrolysis have higher efficiencies, but require significant more process control and investment.Biopower is a natural fit for the electric power industry and is good for the environment. This is because biomass fuels are renewable, they help reduce greenhouse gas emissions from fossil fuels and make productive use of crop residues, wood – manufacturing wastes, and the clean portion of urban wastes. It will also ensure global energy security (McKay, 1998)Nigeria has an enormous potential for biopower. She has an estimated biomass energy resource base of 144million tonnes per year, with an estimated agricultural landscape estimated at 71.9 million hectares. Also it is estimated that 285.1 million tonnes of livestock manure is produced annually in the country. Other available biomass resource base available and possible includes aquatic plants such as water hyacinth and municipal wastes both of which constitute major environmental problems (REMP, 2005).

2.6 Electricity from Wood

Sawdust is composed of fine particles of wood. This material is produced from cutting with a saw, hence its name. The most common way to convert this biomass fuel derived from wood to electricity is to combust them. They can also be gasified to produce combustible gasses, or converted to liquid fuels. The energy content of sawdust is about 12558kJ/kg, which is about half the amount of heat from fuel oil or three – quarters of that from mineral coal (Corder, 2004)

A significant environmental benefit of using sawdust and wood shavings for electricity generation is that their energy value is utilized while landfill disposal is avoided, also as long as clean – burning combustion technologies are employed, carbon emissions to the atmosphere can be minimized (Bogot, 2000)

III. THE SANGO PLANT MARKET

The Sango plank market is located within a few metres from the main Sango market, in the Ibadan North Local government area of Oyo state, Nigeria, and occupies a land area of over 100m^2. It is adjacent to the highly populated Sango residential area. The plank market supplies most of the timber needs of the Ibadan city and its neighbouring towns of Oyo and Shaki. It is a major market for the logging of timber and trade in wood products. The market has a total of 620 shops and is structures into six sections namely: the carpenters, turners, wood planners, plank sellers, metal workshop fabricators and plank cutters. The plank market operates for 10hrs (8am – 6pm) for 6days a week (Mondays – Saturdays); the mill is closed on Sundays.Table 2 shows the division of the plank market.

The market current source of electricity is through the public owned Power Holding Company of Nigeria (PHCN) which it shares with the nearby residential areas. This supply arrangement is ineffective and inefficient considering the rated capacity of the installed transformer in the entire Sango area. The result is that the PHCN devised a load sharing arrangement which guarantees electricity supply to half the market for four (4) hours, 2 days a week and the other half alternates the arrangement for the next two days. As a consequence of these many of the shop owners have resorted to the use of small portable generators to power their machines and equipments at great financial cost.

The plank market is also confronted with the problem of economic disposal of sawdust and wood shavings, a consequence of their operations. Due to the economic activities at a market a large quantity of sawdust and other wood residues are produced daily. This is disposed off at a dump site were over 90% of it is burnt off to the atmosphere, alongside other waste generated from the other economic activities at the main market. About 10% of the sawdust and wood shavings are collected for use as equine and livestock bedding or small house – pet bedding applications, cooking fuels; however this uses are limited due to the cost of transporting the sawdust away from the sawmill.

Table 2: Division of the plank market

Category of Workers	Number of Shops
Carpenters	240
Turners	40
Plank Shops	210
Wood Planers	40
Plank cutters	30
Metal work Fabricators	60
TOTAL	**620**

Survey, 2011

Thus installing a biomass plant in the market will not only solve the electricity supply problem of the market but will also adequately address the problem of environmental degradation in and within the market.

IV. DESIGN CONSIDERATION

The design of the power plant is based on a high – value/high – return community based approach. The centrepiece of this approach is the development of value – adding processing centres that is expected to create economic opportunities for the market operators and management. This approach also emphasises a collaborative community based approach that will involve the market operators, managers and the local government as stakeholders in the biomass development project.In line with the aforementioned, the following design criteria were considered:

4.1 Plant Capacity

The capacity of the proposed plant was determined by the current and future electricity needs of the market, projected for the next 10years. To this end a mini energy audit was conducted to estimate the total power requirement of the market. Table 3 shows the breakdown of the basic energy consumption in each shop division of the market. From tables 3 and 4, it can be seen that the 620 shops in the market require a total of 4.6MW of electricity to power their equipments and machines. However for design purposes additional 20% of the power requirement of the plant was estimated each for minor load, required load and for further expansion.

Also provision was made for reserve capacity for the power plant. Based on this consideration, a generating capacity of 10MW was used for design and selection of the biomass plant.
In estimating the available biomass energy from the plank market, a daily generation of saw dust and wood chips from the various categories of workers was taken for six working days. The summary of the daily waste produced in the market is shown in table 4.

Table 3: Breakdown of basic energy consumption in each shop division

Worker Category	Basic Power Tools	Rating (HP)	TotalRating (HP)	Rating (KW)	No. Of Shops	TOTAL LOAD (kW)
CARPENTERS	Circular Saw	4.5	16.5	12.304	240	2952.96
	Band Saw	2				
	Mortis M/C	3				
	Spindle Moulding M/C	5				
	Sanding M/C	1.5				
TURNERS	Circular Saw	4.5	13	9.6941	40	387.764
	Crosscut Saw	3.5				
	Belt Sandler	2				
	Mortis M/C	3				
WOOD PLANERS	Circular M/C	4.5	8	5.9656	40	238.654
	Planners	2				
	Sanding M/C	1.5				
PLANK SHOPS	Electric Bulbs			0.6	210	12.6
METAL WORKSHOP FABRICATORS	Welding Machine	4	8	60	60	357.936
	Lathe Machine	4				
PLANK CUTTERS	Large Circular saw M/C	25	25	18.6425	30	559.275
TOTAL						**4509.189**

Survey, 2011

Table 4: Daily sawdust produced by the market

Worker Category	Day	No. of Sacks	Mass/Sack (kg)	Mass/Day (kg)	No. of shops	Total Mass/Days (kg)	Average Mass/Day (kg)
CARPENTERS	1	4	15.6	62.4	240	14974	30242.33
	2	8	16	128		30720	
	3	10	17.5	175		42000	
	4	6	17	102		24480	
	5	8	16	128		30720	
	6	7	17	119		28560	
TURNERS	1	8	18	144	40	5760	5476.67
	2	10	17	170		6800	
	3	11	12.5	137.5		5500	
	4	8	14	112		4480	
	5	6	15	90		3600	
	6	12	14	168		6720	
WOOD PLANERS	1	50	12	600	40	24,000	29,980
	2	75	15	1125		45000	
	3	42	14	588		23,520	
	4	45	12	540		21,600	
	5	52	12	624		24,960	
	6	60	17	1020		40,800	
PLANK SHOPS	1	2	10	20	210	4200	3675
	2	1	8	8		1680	
	3	3	10	30		6300	
	4	3	9	27		5670	
	5	2	6	12		2520	
	6	1	8	8		1680	
PLANK CUTTERS	1	20	12	240	30	7200	9370
	2	18	14	252		7560	
	3	22	15	330		9900	
	4	25	16	400		12000	
	5	26	14	364		10920	
	6	24	12	288		8640	
TOTAL							**78,744**

From table 4, it can be seen that the average quantity of sawdust and wood chips produced on daily basis is about 8 tonnes (78,744kg). Using this value, with a moisture content of 0.35 for sawdust; the daily heat available from the sawdust and woodchips was estimated using equation 1 (Gupta, 2004) as 642.8GJ, which is equivalent to 17.9MW/day of energy for a 10 hour per working day.

$$HA = (1 - mc) * HHV * M_{sawdust} \qquad (1)$$

Where HA is the heating value of the sawdust, mc is the moisture content of sawdust(0.35), HHV is the higher heating value or energy content of sawdust (12558kJ/kg) and $M_{sawdust}$ is Weight of sawdust and woodchip(78,744kg) (Ellis, 1992)

This available energy is adequate to power the proposed 10MW biomass power plant. It is also expected that in the event of shortfall in the supply of sawdust and wood chips for the plant, the municipal and agricultural waste in the market can be used as supplement.

4.2 Technology

The most significant factor considered in the choice and scale of technology for the proposed biomass power plant is that which will minimize investment risk while maximizing financial returns. The proposed plant is expected to use the conventional steam cycle generating electrical self – operating plant, using the direct combustion/steam turbine conversion Rankine cycle process as shown in figure 1 below:

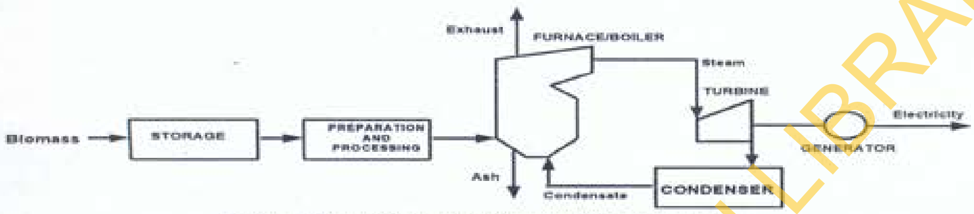

Figure 1: Direct Combustion/Steam Turbine System.

4.3 Cost Estimation

Capital Cost of Plant

The estimated capital cost of the plant included the preliminary cost, cost of design and planning, cost of land and other real estate, cost of transportation, erection and installation of equipment and overheads.

4.4 Annual Plant Cost

The annual plant cost of the plant was estimated using equation 2 (a – c) (Newman, et al, 2000).

$$APC = AFC + AOC \qquad (2a)$$

$$AFC = FCR * UC * C \qquad (2b)$$

$$AOC = FC + OM \qquad (2c)$$

Where APC is Annual Plant cost, AFC ($ per year) is Annual Fixed Cost and AOC ($ per year) is the Annual Operating Cost. The AFC consists of the interests, taxes, insurance, depreciation, managerial and general maintenance costs and rate of return of the plant and is evaluated with equation 2b. FCR (%) is the fixed Charge Rate, UC ($ /MW) is the Unit Capital Cost and C (MW) is the Plant Capacity. The AOC consists of the annual operating cost of the plant. The items which constitute the operating cost are: fuel, operating labour, maintenance cost and supplies. This cost is evaluated by using equation 2c; FC ($ per year) is the Fuel Cost and OM ($ per year) is annual cost of operating labour, maintenance, and supplies.

4.4 Generation cost

The Generation Cost consists of the cost of one unit of electricity generated from the plant and this was estimated using equation 3a and b (Newman et al, 2000).

$$GC = \frac{100 * APC}{E} \qquad (3a)$$

$$E = 8760 * CF * C \times 10^3 \qquad (3b)$$

Where GC ($ /kWh) is the Generation Cost, APC ($ per year) is the Annual Plant cost and E is the expected output of the generating unit for one year and is given by equation 3b. CF is the Capacity Factor for the plant and C (MW) is the capacity of the plant.

Table 5 presents the cost analysis for the project. From the table it is seen that the estimated Generation cost for the power plant is $0.56/kWh.

Table 5: Cost Analysis of the Proposed Biomass plant

ITEMS	DESCRIPTION
Plant Capacity	10MW
Capital Cost	$1.77 million
Unit Capital Cost	$0.177 million
Fixed Charge Rate	10%
Annual Fixed Charge	$0.177 million per annum

Fuel Cost	NIL
Labour Cost	\$0.052 million per annum
Maintenance Cost	\$0.052 million per annum
Supplies	\$0.0129 million per annum
Operating labour, maintenance etc	\$0.116 million per annum
Annual Plant Cost	\$0.294 million per annum
Capacity Factor	0.6
Energy Output	5256 X 10^4 kWh
Generating Cost	\$0.56/kWh

4.5 Economic Evaluation of Alternative

In order to meet the short fall in the supply of electricity, the operators of the plant market utilize small generating sets and there had been suggestions to buy three big diesel generators of 2MWcapacity each. The proposed biomass plant was thus compared with the diesel generators options using the Annual Cost method and the Present worth method.The annual cost method converts all costs into equivalent annual figures. The annual costs of the different alternatives were estimated by using the same fixed charge rate and the same period of analysis. The alternative giving the least annual cost is the best. Equation 4 (Newman, et al, 2000) was used to estimate the annual cost for the two alternatives.The Present Worth method consist of calculating the present worth of the different alternatives. The present worth is the sum which invested at the beginning of the project would yield an amount equal to the annual cost every year. The rules for calculating the present worth are:

[1] The present worth of different plans is estimated using the same period of analysis and the same time base irrespective of whether they have a common life or not or whether they are initiated in the same year or not.
[2] The same interest rate is used for calculating the present worth of different plans.
[3] The plan with the lowest present worth represents the minimum over all expenditure and is the optimum plan.

Equation 5 (Newman , et al) is used to estimate the present worth of the different plans.

$$TotalAnnualCosts = \left(r + \frac{r}{(1+r)^{r}-1} + t + i\right)P + AOC \qquad (4)$$

$$PresentWorth = \frac{\left(r + \frac{r}{(1+r)^{n}-1} + t + i\right)P + AOC}{r/[1-(1+r)^{-n}]} = P + \frac{(t+i)P + AOC}{r/[1-(1+r)^{-n}]} \qquad (5)$$

Where P is the Capital Investment, r is the interest rate, n no of years, i is the insurance rate, t is the tax rate on capital investment and AOC is the Annual Operating Cost.

Table 5 shows the result of the economic comparison between the biomass plant and the alternative of using Diesel generators. From the table it can be seen that for a period of 10years, it is more economical to use the proposed biomass plant over the diesel generator.

Table 5: Economic Comparison of Biomass Plant and Diesel Generating Plant

ITEM	PROPOSED BIOMASS PLANT	DIESEL GENERATING PLANT
Capital Investment (P)	\$1.77 million	\$0.548 million
Interest rate (i)	10%	10%
Number of Years (n)	10	10
Tax rate on Capital (t)	5%	5%
Annual Operating Cost	\$0.116 million	\$0.399 million
Total Annual Cost	\$0.4 million	\$0.947 million
Present Worth	\$1.996 million	\$3.179 million

V. THE PROPOSED BIOMASS POWER PLANT – THE SANGO PLANK MARKET

Based on the design considerations statedthe proposed biomass plant will have the following details.

5.1 Technical Details

The Biomass plant will building will be located in a cleared area of land adjacent to the Sango plank market, part of which is currently used as a dumpsite. The plant will comprise the following main facilities:

- Fluidized bed boiler using sawdust, wood chip and municipal and agricultural waste as fuel.
- Condensing steam turbo generator.
- Air cooled condensing plant.
- Water treatment and boiler feed water system.
- Ash disposal and waste water systems
- Fuel storage, handling and supply system.
- The Electrical power output will be supplied to the market through existing PHCN distribution system

- Biomass Feed will be approximately 25,000 tonnes/year
- Generating Plant Design 10MW (nominal) Conventional steam cycle.

5.2 Economic Impacts

The proposal involves a capital investment of $1.77 million to build the power station , and creation of approximately 50 short – term and 20 long – term jobs, both directly and indirectly within the local government with an additional $0.052 million per year in household income.

5.3 Transport

The location of the proposed plant within the vicinity of the Sango plank market and the Sango main market offers effectiveness in fuel transportation, by using the sawdust and wood chips that is currently burned in the open, and the municipal and agricultural waste that is currently evacuated from the market.

5.4 Water

The key objective of the proposal is to provide a "zero discharge" recycled water system with minimal impact on existing water resources in the area, disposal of waste water on site, and treatment of drainage run – off using water sensitive urban design.

5.5 Noise

Noise attenuation will be implemented on all contributing components of the plant in order to meet the local Environmental protection regulations.

5.6 Air Quality

Sophisticated technologies are available and are expected to be installed for removing any unburned particles from the air emissions and pollution control will be incorporated into the plant design to meet environmental and health standards. The proposed biomass plant will also incorporate detailed environmental management and monitoring plants to achieve compliance with relevant local, state and national environmental criteria.

VI. CONCLUSION

The study showed the design potential for the establishment of a biomass power plant, which will use sawdust and wood chips as its biomass fuel, at Sango plank market, a major commercial cluster in Ibadan. Based on a 25,000 tonnes/year availability of sawdust and wood chips, the study proposed a 10MW direct combustion conversion plant for the market at a capital cost of $1.77million per year. The study concluded by showing the economical and environmental benefits of the project to the immediate community.

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