ALTERNATIVE USES OF BIOMASS FOR ELECTRICITY PRODUCTION IN A LOCAL NIGERIAN COMMUNITY

***ALABI, S.A AND **DIJI, C.J**
**Fan Milk (Nig) Plc, Eleyele, Ibadan, Nigeria*
***Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria*

Abstract

Biomass is a renewable energy resource and refers to all of the earth's living matter, plants and animals, and the remains of this living matter. Biopower is the process of using the energy derived from biomass for electricity production. This paper reports the study of a proposal to use Biopower for meeting the energy needs of a rural community in Edo state, Nigeria. The community is currently not on the national grid but operates a feed mill that utilizes biomass and generates biomass residues that can be used for electricity production. Three scenarios were proposed for the study. Scenario 0, the reference scenario involved powering the community through diesel generation, while Scenario 1 involves using part of the biomass residue generated in the community for electricity production and Scenario 2 involves using all the biomass residue to power the community and selling the left over to the national grid. Based on economic, financial and technical consideration, the study recommended Scenario 2 as the most feasible and beneficial option for using Biopower in the selected community. The study however recommended this option and lists the technical limitations and challenges of the project in the community.

***Keywords**: Biomass, Biopower, Local Community, Nigeria*

Introduction

Biomass is a renewable energy which includes all of the earth's living matter, plants and animals, and the remains of this living matter. Plant biomass is a renewable energy source that is produced through photosynthesis when plants capture carbon dioxide from the air and combine it with water to form carbohydrates and oxygen under the influence of sunlight. There are many types of plants in the world, and many ways they can be used for energy production. In general there are two approaches: growing plants specifically for energy use, and using the residues from plants that are used for other things. The best approaches vary from region to region according to climate, soils, geography, population, and so on. Some common biomass materials include trees, grasses, other crops, oil plants and biomass residues. Biomass residues are the leftover wastes that can be used for energy. The forestry, agricultural, and manufacturing industries generate plant and animal wastes in large quantities. City waste, in the form of garbage and sewage, is also a source for biomass energy. Forestry wastes are the largest source of heat and electricity now, since lumber, pulp, and paper mills use them to power their factories. One large source of wood waste is tree tops and branches normally left behind in the forest after timber-harvesting operations. Other sources of wood waste are sawdust and bark from sawmills, shavings produced during the manufacture of furniture, and organic sludge (or "liquor") from pulp and paper mills.

People generate biomass wastes in many forms, including "urban wood waste" (such as shipping pallets and leftover construction wood), the biodegradable portion of garbage (paper, food, leather, yard waste, etc.) and the gas given off by landfills when waste decomposes. Even our sewage can be used as energy; some sewage treatment plants capture the methane given off by sewage and burn it for heat and power, reducing air pollution and emissions of global warming gasesThe energy content of biomass usually measured in MJ/kg is the amount of energy released when a given unit of biomass is combusted. The energy released from biomass has a variety of uses, including basic life functions, direct combustion, charcoal production, liquid fuels and gaseous fuel production. Biopower is the process of using the energy content of biomass materials for electricity production; it involves the use of various Biopower technologies to convert renewable biomass fuels into electricity. This study reports the proposal for the alternative uses of biomass residues for the production of electricity for a rural community in Edo state, Nigeria. It highlights the economic, financial, as well as biomass content consideration in selecting the appropriate technological combinations in the use of biomass residues for electricity production in that community. The study is divided into five parts. The first part is the introduction, while the second section discusses the various uses of Biopower technologies for electricity production and section three highlights the factors considered in the design considerations of the Biopower plant. The results of the study are discussed in section four, while section five concludes.

2.0 Use of Biomass for Electricity ProductionBiopower technologies convert renewable biomass fuels into electricity (and heat) using modern boilers, gasifiers, turbines, generators, and fuel cells. Biomass can be converted into electricity in one of several processes. The majority of biomass electricity is generated today using a steam cycle, as shown in figure 1. In this process, biomass is

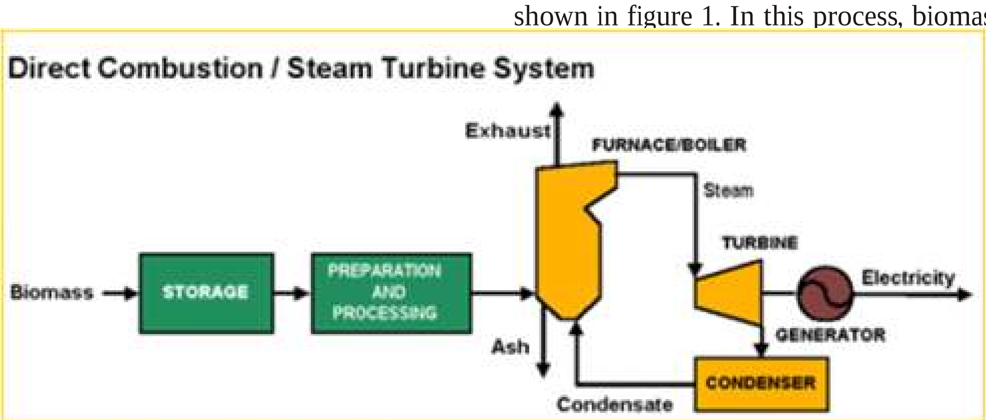


Figure 1: Direct Combustion method of producing Electricity from Biomass

In a direct combustion system, processed biomass is the boiler fuel that produces steam to operate a steam turbine and generator to make electricity.

Biomass can also be burned with coal in a boiler (in a conventional power plant) to produce steam and electricity. Co-firing biomass with coal is an affordable way for utilities to obtain some of the environmental benefits of using renewable energy. Solid biomass can be converted into a fuel gas in a Gasifier such as the one shown in Figure 2. In this method, sand (at about 1,500°F) surrounds the biomass and creates a very hot, oxygen-starved environment. These conditions break apart wood or other biomass and create an energy-rich, flammable gas. The biogas can be co-fired with wood (or other fuel) in a steam boiler or used to operate a standard gas turbine.

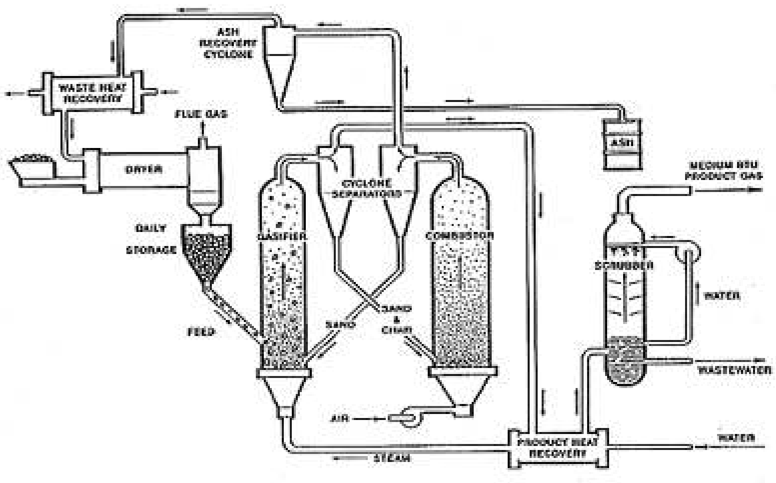


FIGURE 1. BATTELLE'S BIOMASS GASIFICATION SYSTEM

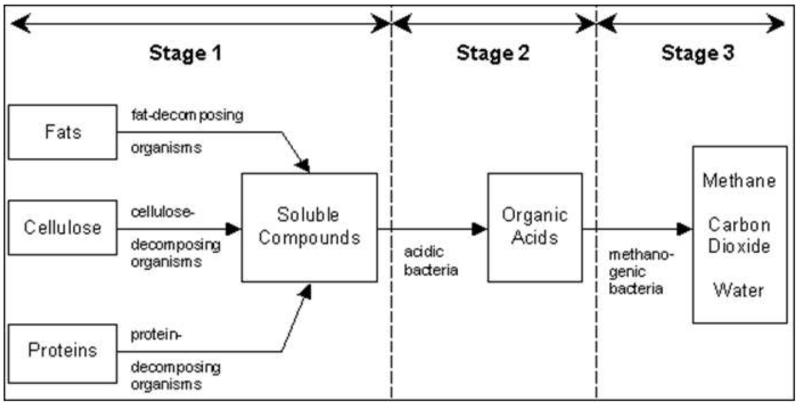


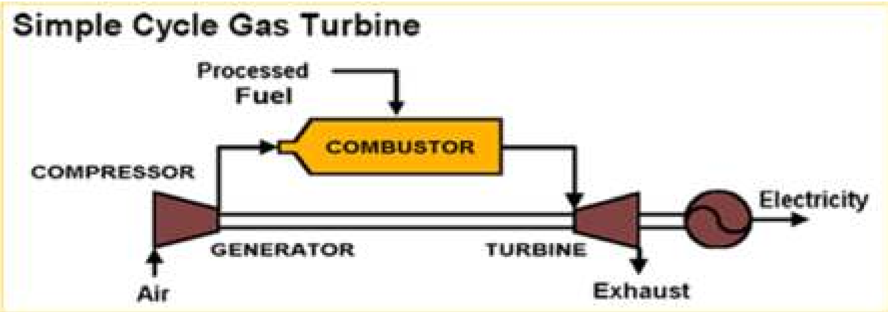
Figure 3: Anaerobic digestion for biogas production.

Landfills also produce a methane-rich biogas from the decay of wastes containing biomass. However, landfill gas must be cleaned to remove harmful and corrosive chemicals before it can be used to generate electricity. Fuel gases made from biomass can be used to generate electricity in a gas turbine, as shown in Figure 4, or in a combined-cycle generating unit. In a simple-cycle gas turbine, compressed gas is ignited, and the hot gases rotate a gas turbine, generating electricity. In a combined-cycle unit, the hot waste gases from the gas turbine are used to create steam to run a steam turbine and generator.

Figure 4: A simple-cycle gas turbine, Landfills also produce a methane-rich biogas from the decay of wastes containing biomass. However, landfill gas must be cleaned to remove harmful and corrosive chemicals before it can be used to generate electricity. Fuel gases made from biomass can be used to generate

electricity in a gas turbine, as shown in Figure 4, or in a combined-cycle generating unit. In a simple-cycle gas turbine, compressed gas is ignited, and the hot gases rotate a gas turbine, generating electricity. In a combined-cycle unit, the hot waste gases from the gas turbine are used to create steam to run a steam turbine and generator.

Figure 4: A simple-cycle gas turbine,



Research Methodology

Specific Area of Study

The area of study, designated as Community A is located in Edo state, a South – South state in Nigeria, which is about 22 km from Benin City, the capital of Edo state. The community has a population of about 2000 people, with around 200 households. The community has a health care centre, schools, a cassava and maize processing machine as well as a water pumping machine. It also has an industry that processes oil palm into various products. In the oil palm industry, various products like special palm wine, refined, bleached and deodorized palm oil, palm fatty acid; olefin and stearin, crude palm kernel oil and refined palm kernel oil are produced from oil palm fruits and kernel.

The Oil palm industry has an hourly capacity of 40 tonnes of Fresh Fruit Bunches (FFB/hr). It has an oil palm plantation with mature palm of 7,000, 3,000 and 2,780 hectares in various farm locations in Edo and Delta States. Human activity in the community which includes - bush burning, cultivation and planting; has been so intense in the village, that most of the forest has become degraded. The major arable crops grown are cassava, yam, cocoyam, plantain, maize, melon, sweet potato, pineapple and vegetables. Farm landholdings range from 0.3 ha to 3 ha. Major tree crops grown include oil palm, cocoa, rubber, timber, coconut, mango, orange, walnut and guava. Other farming activities include sheep and goat rearing, poultry and rabbit keeping and fish farming.

The Community was selected as an area of study due to its proximity or nearness to the grid and the presence of a mill delivering residues in that village. It was considered important to start by studying a case where realization could be possible within a reasonable time and with a reasonable demand of resources and cost.

3.2 Electricity Demand of the Village and the Mill

The demand for electricity in the community comes mainly from the use of electricity for lighting in households, for farming activities, agro-industries, and small commercial and manufacturing establishments, which use electricity for irrigation pumping, water supplies, crop processing, refrigeration, and motive power. The major focus of the community's electrification is to connect it to the national grid. The community is currently not connected to the national grid, which means that the main lighting sources are kerosene lamps and candle waxes.

The processing machines as well as the water pumping machines used in the community are operated on diesel. Wood fuel is used for cooking and space heating during the dry harmattan season. The only electric appliance in use in the households is the radio operated for a short period of the day. The electricity supplied to the mill comes from a diesel plant. Electricity requirement in the mill is for processing the oil palm, lighting, refrigeration, for operating the boiler and for meeting other electrical demands in the mill.

The estimated electricity demand of the mill is currently 20 kWh of electricity per tonnes of produced palm oil FFB. This gives an annual electricity demand of 1460 MWh. The mill process steam demand is 2 tonnes per hour steam. This gives a process steam flow rate of 0.6kg/s, resulting in a process steam demand of 7200MWh per year. The specific electricity demand of households was estimated as 2324 Wh per day, which comes to an annual demand of about 850 kWh. Hence the households will demand about 120 MWh of electricity per year. The total electricity demand in the village, from both the mill and the 200 households in the village is about 1630 MWh per year.

3.3 Statement of the Problem

For the purpose of evaluating the use of the biomass material for meeting the energy needs of the community, two different Scenarios have been studied and compared to a reference scenario (Scenario 0):

Scenario 0:

Presently the mill uses diesel (generator) to produce electricity. The people of the village use energy, in kerosene lamps, corresponding to 120 MWh. This is equivalent to 12000 litres diesel

Scenario 1:

Using some of the biomass fuel produced to fulfill the steam and total electricity demand of plant and village.

Scenario 2:

Using the total available fuel residues to generate as much electricity as possible to meet demand of both village and plant, and sell the excess electricity to the grid.

4.0 Results and Discussions

4.1 Biomass Sources from Village and Mill in Area of Study

About two to three farmlands are

cultivated by the farmers in the community for each crop grown. They cultivate about three hectares of land for timber and rubber trees, the latex of the latter from which polymer products are produced. The trees are also logged for wood production, this result in the generation of saw dust which can be use for power production. Cassava is one of the staples in the village, it is widely cultivated. During the processing a lot of peels and bagasse are generated. These are good sources from which power can be generated. Other biomass residues generated from the village are peels from yam, cocoyam, plantain and banana. Residues are also generated from maize, melon and walnut.

From the mill, a lot of residues are generated daily during the processing of the oil palm. This residues are generated in the form of empty fruit bunches, fibers and shells. Around 72-76% of the crop input into the milling process becomes residues. The mill generates around 28000 kg of fibers and 12000 kg of shells per day. The residues of fibers and shells have a heating value of 17800 kJ/kg and 18133 kJ/kg respectively. The total energy from the residues corresponds to 73000 MWh per year. The chemical properties of the biomass residues, the ash content and heating values (Table 1) show that the residues can be used for the generation of power to both the mill and the community.

As shown in the table below, the yam peelings have high moisture content more than 50%. Operational experiences suggest that there can be significant decrease in boiler efficiency when the moisture content exceeds 50%, if the feed stocks are allowed to air-dry to 30% moisture, there can be usable net heat gains. However, if the feed stocks are allowed to absorb moisture during storage, a point can be reached where combustion can no longer be sustained. In this instance boiler blackouts can occur and an auxiliary fuel will be needed to sustain combustion. Boilers specifically designed to handle high moisture content fuel do not have these problem.

Table 1: Typical Moisture Contents of the Residues

S/N	CROP	RESIDURE	Moisture Content (Percentage)
1	Coconut	Husks Shells	10.3 8.9
2	Oil Palm	Fibre Shells	40 10
3	Maize	Stalks Husks	7.5 11.1
4	Cassava	Stalks Peelings	N.A 50
5	Yam	Peelings	64.5
6	Melon	Shells	27.60

The EFB is also a residue generated from the mill. It has a heating value of 6028 kJ/kg at a moisture content of 65%. The ash content is about 6.5% by weight of the EFB with the presence of potassium in form of potassium oxide (K^O) having a concentration as high as 30-40%. This serves as a valuable substitute for chemical fertilizers. Operational experience shows that the use of the EFB in the boiler for energy production or burned in the incinerator is harmful to the environment. Hence, the EFB is applied directly to the plantation along with inorganic fertilizers to increase the rate of decomposition. The palm kernel cakes (PCK) are also used as fertilizers in the fields. Hence, the organic waste from the mill serves as useful product on the plantation as soil enrichments.

4.2 Design Scenario of the Biomass Plant

Reference Scenario 0

This is the reference case representing current practices in village and mill. The mill uses electricity produced from a diesel generator, and the village has no source of electricity. The residents of the village currently use kerosene lamps which produce energy corresponding to 120 MWh (equivalent to 12000 litres of diesel). Implicit in this Case is that both village and mill do not depend on electricity from the grid, as they are not yet connected to the grid.

Scenario 1

In this scenario, some of the fuel residues available in the mill are used to meet the power demand of both the village and the mill. In order to calculate the fuel required, the electricity and heat generated, some assumptions were made on the combined heat and power plant (CHP).

These assumptions are outlined below.

1. Steam pressure and temperature out from the boiler are 40 bars and 400°C
2. Steam pressure and temperature out from turbine are 3 bars and 150°C
3. Steam turbine and generator mechanical efficiency is 98%
4. That 90% of backpressure steam is used as a process steam in the factory and the remaining 10% is internal heat consumption in the power plant used for heating of the feed water.
5. That all process steam can be recovered from the factory as condensate at a temperature of 98 °C.

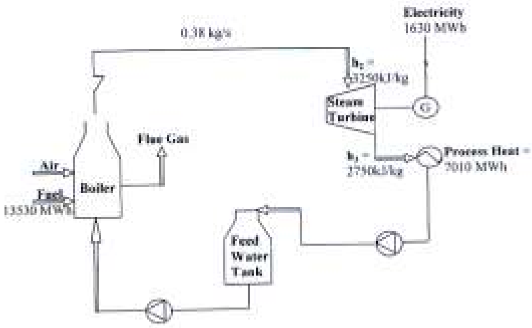


Figure 1: Scenario 1 - Production of electricity and heat from the biomass residues

In Scenario 1, using the assumptions outlined above, the calculated biomass energy to generate the required 1630MWh (186kW) of electricity is 1544kW. The calculated process steam flow rate is 0.38kg/s, while the process steam generated is 7627MWh (800kW). The power to heat ratio is 0.2.

Scenario 2

In this case, all the biomass residues corresponding to about 73 000 MWh (8330kW) are used as fuel. The process steam flow rate is calculated as 2.05kg/s, about 1004.5kW (8807MWh) of electricity is generated from the process. The excess electricity that can be sold to the national grid from this process is calculated as 818.43kW (7177MWh). The generated CHP heat is 4795kW (42020 MWh), while the power to heat ratio is 0.2. The flow diagram is presented in Figure 2 below.

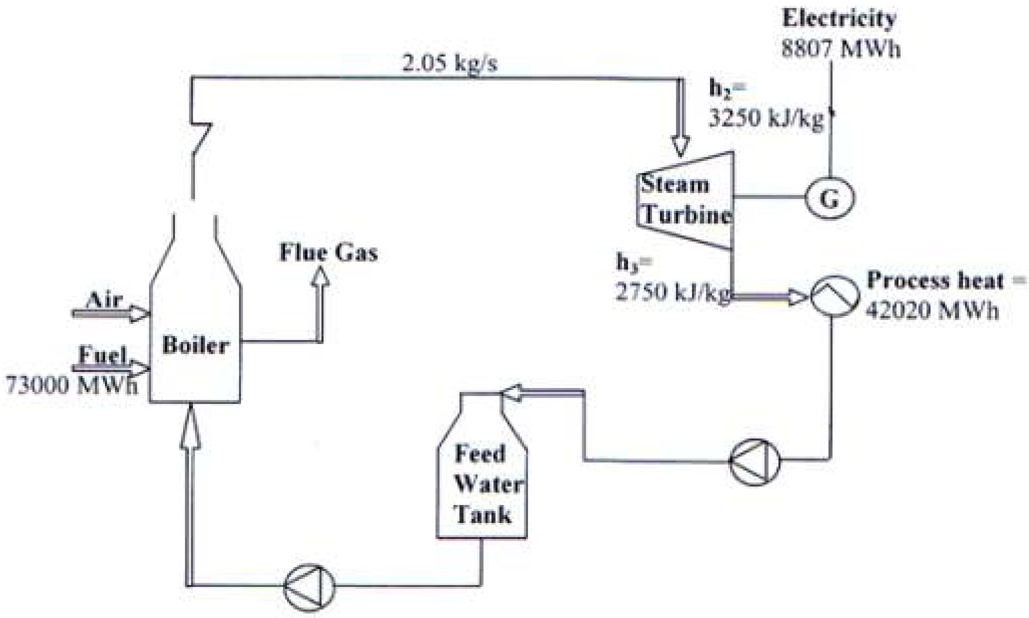


Figure 3: Scenario 2 - Production of Electricity and Heat from Biomass Residues

4.3 Financial and Economic Analysis of the Various Scenarios

The financial analysis of this work is calculated based on the two scenario studied. Assumption was made on the total investment on the CHP plant. The investment of a similar plant in Denmark is used as a guide. The analysis highlights the difference in electricity generation cost using diesel as source of fuel for the boiler (present situation), from that of substituting diesel with biomass. The quantity of diesel required to operate the boiler is calculated from the steam demand.

Scenario 0: Reference

Consumption of diesel oil in plant: From the annual steam demand in the mill, and with an energy content of 2.33 kg/MJ, in steam, calculating with an energy content of 38.68 MJ/1 of diesel. The annual diesel required is presented in Table 2.

Table 2: The Annual Diesel Required to Operating the Plant

Annual required process steam	(MWh)	7200
Annual process steam generated	(MWh)	7627
Required diesel for process steam	(litres)	720000
Unit price of diesel	($/litre)	0.76
Annual cost of required diesel	(S)	547200

Consumption in the village: As explained in section 6 above, in the reference case (Case 0), the village is not connected to the grid. Kerosene is used as a source of energy. The diesel equivalent of the approximately 120 MWh of energy from kerosene is estimated to be 120000 litres (as shown below).

Approximately 120 MWh = 120000 litres diesel = $91200

Therefore,

Total consumption cost = 547200 + 91200 = $638400

The electric capacity, full load operation time, the total annual electricity generated for scenario 1 and their specific investment according to are as presented in the Table 3 below

Table 3: Shows the calculated data for Scenario 1 and 2

Parameters (units)	Scenario 1	Scenario 2
Electric capacity (kWel)	272	1467
Full load operation time (hours)	6000	6000
Total annual electricity generated (MWh)	1630	8803
Specific investment ($)	4000	4000
Total investment ($)	1080000	5868000

From the current electricity sales price of 0.06 $/kWh, the annual revenue generated from sales of electricity to the community is calculated as presented in Table 4.

Table 4: Annual revenue from Electricity sales in Scenario 1 and 2

S/N	PARAMETERS	Units	Scenario 1	Scenario 2
1	Annual Electricity Generated	MWh	1630	8803
2	Annual Electricity Sales	MWh	120	7343
3	Annual Sales Price	S/kWh	0.06	0.06
4	Annual Sales Revenue	$	7200	440,580

The economic analysis of the two scenarios in comparison to the reference scenario is shown in Table 5.

Table 7: Economic Analysis of Scenario 1 and 2, and the reference Scenario.

Parameters	Unit	Reference Scenario	Scenario 1 Production for Plant + Village	Scenario 2 All available Residue is used, surplus to grid
Interest rate	%/year		5	5
Depreciation time	year		15	15
Capital cost	$/year		108000	586800
Fuel price	$/kWh		neg	Neg
Fuel price	$/litre	0.76	neg	Neg
Fuel cost(excl ash disposal)	$/year		neg	Neg

4.3 Discussions of Result from the Scenarios

The financial calculation is based on technical data available from literature. The calculation is especially sensitive to uncertainties in the relatively large contributions from investment cost, maintenance cost and electricity market price. A more exact calculation would need a more detailed engineering and design study and an updating of price level. This is important for a future project but outside the scope of this study.

From the above analysis, it is obvious that scenario 2 offers the greatest benefit for the use of biomass for electricity generation for the community and mill as it offers the greatest economic and financial advantages. However in order for the effective application of the technology in the identified community, the following technical challenges have to be overcome. These include:

1. There is Limited technical capacity to design, install, operate, manage and maintain co-generation technologies in Nigeria.
2. High capital cost of co-generation equipment and projects.
3. Capital investment of the industries located in the rural areas should also be directed to new innovation in terms of energy use and not only committed to their industrial related investment.
4. The involvement of government in encouraging private companies by provision of subsidies and tax reduction from power generation.

Conclusion

The use of biomass residues for power production in rural Nigeria has been with a typical village (containing a Mill) taken as scenario study. Two scenarios have been considered scenario1 and scenario 2. These scenarios were compared to a Reference scenario (Scenario 0). These case studies considered the possibility of using the biomass residues generated from the local palm oil processing mill located in the villages to generate power to meet the demand of both the mill and the village.

From the scenarios study, it is shown that scenario 2 is more profitable to the industry, with a shorter payback period due to the excess heat and electricity generated. Scenario 1, in comparison to the present cost of operating the boiler on diesel fuel is economical to the industry, but it has a longer pay back period of about 10 years, and also, the process steam flow rate is lower than that required in the mill. Hence scenario 2 is recommended since sufficient power is generated to serve the mill, village and the electricity grid, a shorter payback period is required, and the process steam generated more than meets the mill steam demands.

In conclusion, there should be an encouragement from the government, for the biomass residues in Nigerian rural areas to be used in generating electricity for the rural dwellers, by encouraging the local industries located in these areas to invest on electricity generation. Also other renewable energy sources like solar radiation should be utilized and invested on for electricity generation.

References

Alberto Julio Tsamba. (2005). Pyrolysis profiles and Global kinetics of Tropical Biomass

Azali A, Nasrin A.B, Choo Y.M, Adam N.M and Sapuan S.M. (2005). Development of Gasification system fuelled with oil palm fibers and shells. American Journal of Applied sciences (special issue) pages 72-75

Consultative Group on International Agricultural Research (CGIAR). (1996). Yam Cultivation <http://www.cgiar.org/impact/research/vam.html Accessed November 2005

Consultative Group on International Agricultural Research (CGIAR). (1996). Sorghum Cultivation<http://www.cgiar.org/impact/research/sorghum.html Accessed November 2005

Douglas F. Barnes, Robert Van der Plas and William Floor. (1996). Tackling the rural Energy problem in Developing countries. World Bank Book series. <http://www.worldbank.org/fandd/english/0697/articles/020697.htni>Accessed July 3 2006

Jacques Moulot. (2006). Advancing the implementation of the Energy Agenda in Africa. Paper presentation in UNECA Http://www.gfse.at/fileadmin/damgfse%206/PLENARYI/UNECAGFSE6 Present Accessed April 2007

Danish board of District heating. (2005). Gasification breaks through in biomass

<http://www.dbdh.dk/pdf/ren-energy-pdf/sidel4-17.pdf> Accessed April 10 2007

Fawehinmi A.s and O.V Oyerinde. (2002). Household Energy in Nigeria: The Challenge of Pricing and poverty in fuel switching. Journal of Energy and Development, pp 277

Hubert E. Stassen. (1995). Small-Scale Biomass Gasifier for Heat and Power. World Bank Technical Paper, Energy Series. http://www.wds.worldbank.org/external/default/wdscontentserver/WDSP/lB/1999/is > Accessed July 3 2006

Jared P. Ciferno and John. (2002). Benchmarking Biomass Gasification Technologies for fuel, chemical and hydrogen productions. Http://www.netl.doe.gov/technolOgies/coalpower/gasification/pubs/pdf/BMassGasfmal Accessed May 2007

Mohamed Garba (2000). Study of possibilities and some problem of using cane Residues as fuel in gas Turbine for power Generation in the Sugar Industry. PhD Thesis. Division of Energy Engineering, Department of Mechanical Engineering, Lulea university of Technology. Paper 3,page 2

Phyllis data base for Biomass and Ash composition of Biomass<http://www.ecn.nl/phyl i s > Accessed January 2006

Quaak Peter, Knoef Harrie and Hubert E. Stassen. (1999). Energy from Biomass:A review of combustion and gasification technologies, Page 6. World Bank technical Paper, Energy series

Ravi. N. Menon, Zulkifli Ab Rahman and Nasrin Abu Bakar. (2003).Empty fruit bunches Evaluation: Mulch in Plantation vs. Fuel for electricity generation generation Oil palm industry Economic journal vol 3 <http://palmoilis.mpob.gov.mv/publications/opieiv3n2-15.pdf> Accessed July 2007.