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Electricity Production from Biomass in Nigeria: Options, Prospects and Challenges

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Abstract. Biomass power, also called bio power, is electricity produced from biomass fuels. Biomass consists of plant materials and animal products. Biomass fuels include residues from food production and processing, trees and grasses grown specifically as energy crops, and gaseous fuels produced from solid biomass and wastes. This paper highlights the various biomass materials available in the country and the available technologies that are used for converting biomass to electricity. The paper also highlights the broad policy objectives of government with regards to the development of renewable energy in general and biomass development in particular. The paper concludes by exploring based on global experiences and best practices, the various options, and their resulting prospects and challenges in producing electricity from biomass. The paper highlighting the fact that though the prospects of using biomass for electricity generation is high; land availability, plant location, scale and choice of technology and distribution of economic benefits are factors that have to be considered in deploying biomass for electricity generation in Nigeria.

Introduction

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. In terms of their physical and chemical characteristics, biomass material differ from other conventional energy sources in a number of ways that include lower density; higher moisture content, often up to 50%; lower calorific value; broader size distribution, unless pre – conditioned by screening, crushing or pelletizing; the variability of the materials as fuels and the sulphur and nitrogen contents are often lower. Bioenergy, which is transformation of biomass and waste materials into a source of energy is closely related to biomass potential and availability and is generally accomplished through biological, thermal and chemical processes [1].

Biomass provides 14% of the world's energy resources or about 28 million barrels of oil equivalent per day (Mboe/day) and is the most important source of energy in developing countries [2]. Nigeria with total land area of 92.4 million hectares has a huge biomass resources consisting of wood, forage grasses and scrubs, animal wastes arising from forestry, agricultural, municipal and industrial activities, as well as acquatic biomass; which have been estimated to be 144million tonnes/year [3]. In recent times, there has been renewed interest in biomass energy development due to several factors, some of which include: Growing concerns about climate change; Technological advances in biomass conversion, combined with significant changes in the global energy market; Biofuels have the unique characteristics of being the only source of renewable energy that are available in gaseous, liquid and solid states; Increasing focus on security of energy supply and Increasing interest in renewable energy generally.

Bioenergy could in principle provide all the world's energy requirements, but its real technical and economic potential is much lower. The World Energy Council (WEC) survey of energy resources estimates that Bioenergy could theoretically provide 2900EJ/year of energy, but technical and economic factors limits its current practical potential to just 270EJ/year [4]. According to the report, the practical potential is limited by several factors which include poor matching between demand and resources, and high costs compared to other energy sources. Biomass energy brings numerous environmental benefits—reducing air and water pollution, increasing soil quality and reducing erosion, and improving wildlife habitat. Biomass reduces air pollution by reducing carbon dioxide emissions by 90 percent compared with fossil fuels and makes productive use of crop residues, wood-manufacturing wastes, and the clean portion of urban wastes. Biomass energy also reduces water pollution because fewer fertilizers and pesticides are used to grow energy crops, and erosion is reduced. In contrast to high-yield food crops that pull nutrients from the soil, energy crops actually improve soil quality; since they are replanted only every 10 years, there is minimal ploughing that causes soil to erode. Finally, biomass crops can create better wildlife habitat than food crops. Since they are native plants, they attract a greater variety of birds and small mammals and improve the habitat for fish by increasing water quality in nearby streams and ponds.

In addition to the many environmental benefits, biomass offers many economic and energy security benefits. By growing our fuels at home, we reduce dependence on fossil fuels and the problems associated with disruptions in their supply. Farmers and rural areas will gain a new and valuable outlet for their products and improve the rate of development in the rural areas.

This paper is an exploratory study of the options, prospects and challenges of generating electricity from biomass in Nigeria. The paper is divided into five parts. The first part includes the introduction to biomass and bioenergy, while the second part discusses various Biomass - to - electricity conversion options. The third part introduces the assessment indicators for evaluating energy conversion processes, while the fourth part evaluates the options, challenges and prospects of developing biomass based power plants in Nigeria. The fifth part concludes.

Biomass Power

Biopower or biomass power is electricity produced from biomass fuels. Biomass – fired plants have been explored, both in developed and developing countries. For example in India, biomass power – generated capacity of about 302Mw have been commissioned through 54 projects by India's ministry of New and Renewable energy Sources [5]. There are also several biomass – fired and co – fired plants across Europe and America [6]. The Energy Information Administration (EIA) in its annual energy outlook of 2002, projected that biomass will generate 15.3 billion kilowatts of electricity or 0.3% of the projected 5,476 billion kilowatts of total generation in 2020 [7].

Biomass-based power systems are unique among nonhydro renewable power sources because of their wide range of applicability to a diverse set of needs. Biomass systems can be used for village-power applications in the 10–250 kW scale, for larger scale municipal electricity and heating applications, for industrial application such as hog-fuel boilers and black-liquor recovery boilers, in agricultural applications such as electricity and steam generation in the sugar cane industry, and for utility-scale electricity generation in the 100 MW scale. Biomass-based systems are the only nonhydro renewable source of electricity that can be used for base-load electricity generation.

Converting Biomass to Electricity: Technical Options: There are basically two modes of utilizing biomass for electricity production. The first is by a dedicated use of biomass, while the second is by co – firing biomass with an existing fossil fuels plant. The technology for the primary direct use of biomass for electricity production is direct combustion, gasification, pyrolysis and biochemical degradation.

Direct Combustion: Direct combustion involves the oxidation of biomass with excess air, giving hot flue gases which are used to produce steam in the heat exchanger sections of the boiler; the steam then turns a turbine, which is connected to a generator that produces electricity. Biomass can also be co –fired with coal in a boiler (in a conventional power plant) to produce steam and electricity. The majority of biomass electricity is generated by the direct combustion process.

Gasification: Gasification for power production involves the devolatization and conversion of biomass in an atmosphere of steam and /or air to produce a medium or low calorific value gas known as producer gas, which is used for power generation. A large number of variables affect gasification – based process design. Three major variables can be identified, these are: gasification medium, gasifier operating pressure and reactor type. Gasification medium, refers to the source of heat to drive the process. In directly heated gasifiers, the heat to drive the process is generated within the gasifiers; while in indirectly heated gasifiers, biomass heating and gasification is accomplished through heat transfer from a hot solid or through a heat transfer surface. Gasifier operating pressure refers to the operating pressure necessary for optimum performance. A pressurized gasifier will produce gas at a pressure suitable for direct turbine application and provide the highest overall process efficiency. Alternatively, the gasifier can be operated at low pressure and the cleaned product gas compressed to the pressure required for gas turbine applications.

The third major variable is reactor type. For biomass gasification four primary types of reactor systems have been developed. These are: Fixed – bed reactors; bubbling fluid – bed reactors; circulating fluid – bed reactors and entrained flow reactors. Gasification reactors operate under the same principles as comparable combustors.

Pyrolysis: Pyrolysis, which is the burning of solid fuels in the absence of oxygen, involves the conversion of biomass to liquids, gases and char – liquid fuels, which are introduced into a gas turbine integrated with a combined cycle for power production [8]. Pyrolysis is the fundamental chemical reaction process that is the precursor of both the gasification and combustion of solid fuels.

Conventional pyrolysis occurs under a slow heating rate. This condition permits the production of solid, liquid and gaseous pyrolytic products in significant portions. However at present, the preferred pyrolysis technology is fast or flash pyrolysis at high temperature with very short residence times [9]. Fast pyrolysis (also defined as thermolysis) is a process in which a material such as biomass is rapidly heated to high temperature in the absence of oxygen, while flash pyrolysis is the thermochemical process that converts small dried biomass particles into a liquid fuel (bio – fuel or bio – crude) for almost 75%, and char and non – condensable gases by heating the biomass to 775K in the absence of oxygen. Biomass pyrolysis is an attractive option because solid biomass and wastes can be readily converted into liquid products. These liquids, as crude bio – oil or slurry of char or oil, have advantages in transport, storage, combustion, retrofitting and flexibility in production and marketing.

Biochemical Processes: Biochemical processes involves the production of biogas for electricity generation and other uses by digesting food or animal wastes in the absence of oxygen. This process, called anaerobic digestion, will occur in any air tight container containing a mixture of bacteria normally present in animal waste. Different types of bacteria work in sequence to break down complex chemicals, such as fat and protein, into progressively simpler molecules. The final product is a biogas containing methane and carbon dioxide. The biogas can be used for heating or for electricity generation in a modified internal Combustion engine. However, advanced gasification technologies are necessary for converting animal waste to a biogas with sufficient energy to fuel a gas turbine.

Assessment Indicators for Evaluating Biomass Energy Conversion Systems: In assessing the options, challenges and prospects of using biomass for electricity production, five major indicators were considered. These are the Political, Economic, Environmental, Technological and Social indicators. The Political indicator refers to the political will and determination of the Nigerian government to formulate and implement policies and programmes that will lead to project conception, implementation and development of biomass – based power production. The Economic indicator comprises the economic assessment of the energy conversion system considering the efficiency of the system, electricity cost and investment cost.

The environment indicator involves the evaluation of the CO_2 concentration in flue gases of the power plant [10]. The CO_2 cycle in utilization of biomass is the main advantages of the biomass based power plant systems, whereas the NOx and SO*x* concentration in the flue gas contributes adversely to the utilization of biomass. For this reason, the evaluation of concentration of these gases in the biomass energy system is of primary interest for the quality assessment of the energy system. The technological indicator comprises two sub-elements: Development Capital and Market elements. The Development capital sub-indicator is determined by the amount of research and development going on in the development of biomass – based power plants, while the market segment is based on the forecast of energy consumption in the period of the next 50 years. The social indicator considers the social aspects of evaluation of power plants, considering new job opportunities; area required and health effect on the surrounding population. The New Job sub-indicator comprises the number of jobs to be open per unit MW [11], while the area required assess the high requirements of land for the construction of a power plant and the health parameter is assessed by measuring the NO*x* concentration in the surrounding of the power plant.

Evaluation of Biopower in Nigeria

Prospects: There is now a consensus in Nigeria, that renewable energy can play a significant role in the overall energy development of the nation. These views were well articulated in the Nigerian National Energy Policy (NEP) and further amplified by the Renewable Energy Master Plan (REMP) of the country which was developed by the Energy Commission of Nigeria (ECN), in conjunction with the United Nations Development Programme (UNDP) in November 2005 [3].

The overall objective of the REMP is to articulate a national vision, targets and a road map for addressing key development challenges facing Nigeria through the accelerated development and exploitation of renewable energy and puts in place a comprehensive framework for developing renewable energy policies, legal instruments, technologies, manpower, infrastructure and market to ensure that the visions and targets are realized. The master plan sets clear and verifiable national targets in the short, medium and long term. Short term targets will be achieved by the year 2007, medium term targets will be achieved by the year 2015 coinciding with the target year for the MDGs; and long term targets are set for 2025, two decades after launching of the REMP.

By 2007, the REMP envisages an aggregate electricity demand of 7000MW with new renewable energy (excluding large scale hydro) playing a marginal role. In 2015, the country will likely achieve a doubling of electricity demand to about 14,000MW of which new renewables will constitute about 5% (710MW). In 2025, aggregate electricity demand will increase to 29,000MW with new renewable energy making up 10% of the total energy demand of the country. Small hydro plants will represent over 66% of the entire new renewable energy contributions; solar PV 17%, biomass 14%, wind 1.3% and solar thermal 0.7% [3]. The REMP projects that biomass will be expected to contribute a total of 50MW and 400MW respectively of electricity in the medium and long term.

Currently, a lot of research efforts are going on in the area of exploiting biomass energy for electricity production, while substantial research results have been achieved by relevant agencies in the public and private sector in biogas production, the development of improved wood stoves and biomass briquetting technologies [12]. The implications of these targets is a rapid scale up of most of the renewable energy technology applications, as the REMP envisions towards the coming decades a nation driven increasingly by renewable energy and this makes the prospects of biomass development for electricity generation in Nigeria very high.

Options: With respect to selecting the best options in technology for the development of Biopower, the country has to be guided by best global practices and the experience of other countries. Currently, with prices ranging from 7.5 to 16.4 c/kWh and an average price of 6.9 c/kWh, biomass power production is not cost effective, considering that fossil fuel technologies are available for an average of 4.2–4.8 c/kWh [13]. However, according to Sa´ez et al,[14] when externalities, such as human health, soil erosion, etc. are included, the total price of biomass is cheaper than coal.

Nonetheless, biomass has been considered the most profitable renewable energy source after hydropower, with respect to total energy and carbon reduction costs [15]. Compared to the median electricity costs of the remaining renewable electricity technologies shown by Evans et al, [13] biomass is cheaper than photovoltaic (24 c/kWh), approximately equal with geothermal (6.8 c/kWh) but more expensive than wind (6.6 c/kWh) and hydro (5.1 c/kWh). Investment costs for biomass to energy conversion exceed other thermal technologies by a factor of 3–4 due to higher processing volumes and increased handling requirements. The capital intensive nature of biomass technology can deter investment. Also, financing biomass plant construction can be complicated because many conversion technologies are still in pilot scale [16].

When selecting between different technologies, combustion based technologies are more profitable over their life cycle than gasification and pyrolysis, despite higher operating costs [17]. Capital costs for direct combustion are around $1.9–2.9/kW, while for pyrolysis, costs are much higher at $3.5–4.5/kW, making it one of the most capital intensive electricity generation technologies, comparable with nuclear [18]. Efficiencies of energy conversion from biomass also vary widely across different technologies. This is an area under intense research and development, with many new, highly efficient technologies emerging. Currently, the average efficiencies of biomass to electricity systems stands at about 27%, with combined cycle gasification processes showing the greatest efficiencies of up to 43% [13, 19].

According to most authors, electricity generation from biomass produces low net carbon emissions, mostly in the form of carbon dioxide [13]. Other greenhouse gases, such as methane and nitrous oxide are emitted in smaller amounts (2% or less of total emissions) [20]. Where emissions include methane and nitrous oxide, figures are reported as carbon dioxide equivalent, or CO_2eq. The average and highest carbon emission reported in literature are 62.5 gCO_2/kWh and 132 gCO_2eq/kWh respectively [21], which is less than one third of the lowest natural gas and one fifth of the lowest coal fired power station emissions proven at present. Wihersaari, [20] calculated the minimum greenhouse gas reduction when substituting biomass in the place of fossil fuels at 74%, up to a maximum of 98%.

Challenges: Even though the prospects of Biopower are very high, land availability; biomass plant location; choice and scale of technology; and distribution of economic benefits have been identified as challenges to be considered in using biomass for electricity production.

Growing biomass for electricity production on a significant scale consume both land and labour. Land use in particular is a key issue in the production of Bioenergy resources, because using land for energy crops means that less land is available to grow crops. Thus it is imperative to ensure that sufficient cropland is available to produce food for the rapidly growing Nigeria's population, taking into consideration that biomass energy can help enhance development and food production. Also, bioenergy production for electricity purposes can be a way to rehabilitate marginal and degraded land and bring it back into profitable use. This will only happen, however, if it is supported by policy. Without policy, there is danger that bioenergy production will seek good land, where yields are higher and so compete directly with food production.

Since biomass is a low energy density fuel, the biomass conversion facility should be located near the source of the bioenergy to avoid high transport cost. Also measures have to be put in place to protect small farmers near such a plant. However, this consideration must be balanced with the benefits of sighting such a plant, factors such as increased rural employment at all skilled levels, a secure market for agricultural production and the provision of cheap indigenous supplies of energy should also be considered.

The biomass conversion facility should be evaluated based on both the number of acres that can be treated and the demonstrated capacity to sustain this treatment over the duration necessary to amortize biomass facility investment. Also the biomass project should demonstrate a collaborative multi – stakeholder commitment for developing ecologically defensible strategies. The choice of technology for biomass conversion should be based on demonstrated minimum efficiency of at least 35% or higher. The facility should also be able to capture and reuse otherwise wasted losses and demonstrate the capability of being economically self – sustaining. The selection of technology for biomass conversion should also consider minimum investment risk and maximum financial returns; with consideration of part funding of the project by local investment. This is because biomass projects represent an important opportunity for building local capacity and local economic assets. This should not however lead to selection of antiquated biomass technology systems, which maybe reliable but are less efficient and often have high level of pollutant emissions.

Most biomass facilities require harvesting operations, sometimes using highly mechanized operations often conducted by non – local contractors. Thus the value of economic activity should be geared towards sharing the benefits of the economic activity with the objective of a high value/high return community based approach. Projects which can demonstrate the highest contribution to local economic development in disadvantaged areas should be encouraged. The creation of local economic value is substantially affected by the degree to which value – added enterprises are integrated with biomass utilization facilities. Proposals which develop or encourage co – location of value – added enterprises with biomass facilities will generate significant greater economic value while reducing the local demand on resources.

Conclusion

Biomass energy represents a veritable renewable energy source for electricity generation. The paper highlighted the various technological options in the conversion of biomass to electricity, the prospects of using these conversion processes considering their efficiencies, costs and environmental impacts. The paper also examined the prospects of developing biomass based power plants in Nigeria and concluded that it is very high considering policy objectives and pronouncements of government and current high level of research activities in the sector. The paper however identified the issues of land availability, plant location, scale and choice of technology, and distribution of economic benefits as major challenges to the accomplishment of this objective in Nigeria.

References

[1] Leskoviku A. Energjite e Rinovushme ne Shqiperi. National Agency of Energy; (2006)
[2] Afgan, N.H., Al Gobaisi, D., Carvalho, M.G. and Cumo, M., Sustainable energy Management. Renew. Sustain. Energy Rev. 2 (1998) 235–286.
[3] Energy Commission of Nigeria (ECN), Renewable Energy Master Plan, FGN, 2005
[4] World Energy Council (WEC), Survey of energy Resources 2007, London WEC, 2007
[5] MNRE annual report 2008 – 09, New Delhi, Ministry of New and renewable Energy, 2009 www.mnes.nic.in
[6] Wiltsee, G; Lessons learned from Existing Biomass Power Plants; National Renewal Energy Laboratory, Report No. NREL/SR- 570- 26946, 2000.
[7] Energy Information Agency, Annual Energy Outlook 2002 with projection to 2020. Report No: DOE/EIA – 0383 (2002)
[8] Katyal, S. Effect of Carbonization temperature on combustion reactivity of bagasse char. Energy resources Part A, 29 (2007) 1477 – 85
[9] Demirbas, A. Producing bio – oil from olive cake by fast pyrolysis. Energy resources Part A, 30 (2008) 38 – 44.

[10] Bain R. L, Overend R.P, Craig K.R. Biomass-fired power generation. Fuel Process Technology, 54 (1998) 1–16.
[11] United Nation Development Programme (UNDP). World Energy Assessment; Energy and The challenges of sustainability. ISBN: 92-1- 126126 - 0 (2000).
[12] Sambo, A.S; Renewable Energy for rural development: The Nigerian perspective. ISESCO Science and Technology vision 1 (2005) 12 -22.
[13] Evans A, Strezov V, Evans TJ. Assessment of sustainability indicators for renewable Energy Technologies. Renew Sustainable Energy Review, 13(2009)1082–8.
[14] Sa´ez RM, Linares P, Leal J. Assessment of the externalities of biomass energy, and a Comparison of its full costs with coal. Biomass Bioenergy, 14 (1998) 469 – 78.
[15] Hatje W, Ruhl M. Use of biomass for power- and heat-generation: possibilities and limits. Ecology Engineering, 16 (2000) 41–9.
[16] Clean Energy Council (CEC). Australian bioenergy roadmap: setting the direction for Biomass in stationary energy to 2020 and beyond; 2008.
[17] Caputo AC, Palumbo M, Pelagagge PM, Scacchia F. Economics of biomass energy Utilization in combustion and gasification plants: effects of logistic variables. Biomass Bioenergy 28 (2005) 35–51.
[18] Yoshida Y, Dowaki K, Matsumura Y, Matsuhashi R, Li D, Ishitani H, et al. Comprehensive Comparison of efficiency and CO2 emissions between biomass energy conversions Technologies — position of supercritical water gasification in biomass technologies. Biomass Bioenergy, 25(2003) 257–72.
[19] Gustavsson L, Madlener R. CO2 mitigation costs of large-scale Bioenergy technologies in Competitive Electricity Markets. Energy, 28(2003) 1405–25.
[20] Wihersaari M. Greenhouse gas emissions from final harvest fuel chip production in Finland. Biomass Bioenergy, 28(2005) 435–43.
[21] Styles D, Jones M.B. Energy crops in Ireland: quantifying the potential life-cycle Greenhouse gas reductions of energy-crop electricity. Biomass Bioenergy, 31(2007)759–72.