A REVIEW OF ENERGY PRODUCTION FROM ENERGY CROPS

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ABSTRACT

This paper reviewed energy production from energy crops. In doing this many works involving biogas production, calorific values, production of bioethanol and biodiesel from such energy crops as typha grass, water hyacinth, duckweed, jatropha curcas and palm kernel and neem seed oils, bagasse, switch grass, cereal straw and potato and maize husks were reviewed. Results of researches showed that maximum Gross Calorific Value (GCV) and Net Calorific Value (NCV) of *Typha domingensis* were determined to be up to 1.272×10^4 kJ/kg and 1.199×10^4 kJ/kg respectively. Biogas from water hyacinth can contain up to 49-53% methane (CH_4), and which can further be improved using solid adsorbents and wet scrubbers to up to 70-76%. Researchers also show that about 27 litres or more of jatropha biodiesel can be obtained from 30 litres or more of jatropha oil. In general, it was found that the energy content of biomass (on a dry, ash-free basis) is similar for all plant species, laying in the range 17–21 MJ/kg. The paper concluded that there is the need to assess the annual tonnage yield of energy plants in Nigeria so the full amount of energy realizable from these alternative sources and more which are to be found in the country can be quantified, and that in order to fully utilize the full benefits of energy production from energy plants researches must move away from experiments/demonstration to large scale plants that will partially replace the energy sources as exist presently. Because literature revealed that, the energy production from both energy crop and agricultural residues is better in briquette form, design, construct and test briquetting machines for the various energy plants, was recommended.

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Energy is one of the important factors to global prosperity. The dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation, and human health problems. It has been predicted that in the year 2040, the world will have 9-10 billion people and these must be provided with energy and materials (Okkerse and Bekkum, 1999). It is estimated that in terms of primary source used, by 2030, the structure of energy production will be based on 75-85% of conventional fuel combustion, 10-20% of nuclear fission, 3-5% of waterpower, approximately 3% of solar and wind energy (Popscu, and Mastorakis, 2010). The most common forms of renewable energy are considered the solar, geothermal energy, water, wind and finally the biomass related energy. Some of the most important benefits of using renewable energy are based on the organic composition, lack of fossil driven CO_2 emission, does use mainly locally available-resources and are solution for all needs (Popscu and Mastorakis, 2010), covering the community. Combustion is the most developed and most frequently applied process used for solid biomass fuels because of its low cost and high reliability. During combustion; the biomass first loses its moisture at temperatures of up to 100°C, using heat from other particles that release their heat value. As the dried particle heats up, volatile gases containing hydrocarbons, CO, CH4 and other gaseous components are released. In a combustion process, these gases contribute about 70% of the heating value of the biomass. Finally, charred, oxidized matter and ash remains (IEA Bioenergy, 2002).

According to MBEP (2002), the concept of energy crops predates the discovery of oil in 1859 and that, infact, agricultural and forestry crops and their residues were a major source of energy prior to the discovery of oil.

Energy crops are a type of biomass. Biomass is any organic matter which is available on a renewable basis through natural processes or as a by-product of human activity such as agricultural crops and crop residues, wood and wood waste, and portions of the municipal solid waste stream. Biomass issued to generate electricity, and to produce fuels and other consumer products.

Shortly after the discovery of oil, biomass began to be replaced by fossil fuels which were less expensive and had higher energy content. Since then fossil fuels have dominated as the major source of energy generation and transportation fuels. However, because they are non-renewable, oil and natural gas cannot be relied on indefinitely. Also, unlike oil and natural gas, the cost of renewable energy (especially biomass) is expected to continue to decline as technology improves. A majority of the cost of biomass energy production is in the conversion process. As technological improvements reduce processing costs for biomass energy, it will be better able to compete with petroleum based energy (MBEP, 2002).

1.2 STATEMENT OF THE PROBLEM

Fossil-based fuel is the most widely used source of energy not only in Nigeria, but also the world over, with its attendant lack of renewability and adverse effects on the environment in the course of exploitation and utilization. There is, therefore, the need to explore other alternative sources that can substitute or partially replace the fossil-based fuel source. This is particularly more so for Nigeria that has been grappling not only with increasing cost of fossil fuels, but whose energy demand is ever increasing and with a power supply that is, at best, erratic and, at worst, almost non-existent. Further, many alternative energy sources from energy crops such as agricultural wastes, for example, potato peels, maize and rice husks, etc; and perennial grasses like typha, water hyacinth, giant reeds, etc., are usually allowed to go to waste in Nigeria, and, in fact, often constitutes an environmental problem. Thus, shortage in energy and environmental problems can be addressed by a study of alternative energy sources. Therefore, a review of the available energy crops and their potential as a source of energy, as well as the researches in the technologies for utilizing them for production of energy is needed.

1.3 SIGNIFICANCE OF THE STUDY

A review of energy production from energy crops will provide comprehensive information on the use of energy crops; provide basic energy crop information; and explore the opportunities and constraints for the development and use of energy crops. These will in turn highlight the possibility of partially replacing non-renewable sources for energy supply both at national and domestic levels. Significantly too, wastes from agricultural produce that can otherwise constitute environmental problems, plants that could otherwise pose problems to farmers, and plants that could otherwise endanger navigation on waterways and aquatic life, can be put to good use for the society. Further, a review on energy production from energy crops becomes significant when it is juxtaposed with the increasing cost of fossil-fuel based energy and the impending decrease in supplies of non-renewable sources of energy (MBEP, 2002), as this will pin-point the best energy production method for available energy crops to maximize the amount of energy derivable from these plants.

1.4 AIM AND OBJECTIVES

The aim of the study is to review the available literature on energy production from energy crops with a view to highlighting their potential use to compliment energy requirements. The objectives are to:

(i) use this review to identify energy crops in Kano and Nigeria that have high potential for large scale utilization;

(ii) identify which energy crops are more suited for electric generation, for ethanol production, for medium and small scale industrial heating application such as raising steam for rice processing and for domestic energy requirement such as cooking; and

(iii) To highlight research gaps in the utilization of energy crops for energy production.

1.5 SCOPE OF THE STUDY

This work covers the review of energy production from such energy crops as agricultural wastes and perennial grasses; it does not cover energy production and technologies for production from other alternative and renewable sources of energy like solar, wind, geothermal and hydro.

2 THEORITICAL FUNDAMENTALS

2.1 Energy Crops

Energy crops are specifically grown to produce some form of energy. Energy may be generated through direct combustion or gasification of the crops to create electricity and heat, or by converting them to liquid fuels such as ethanol for use in vehicles. Energy crops are generally divided into two types: herbaceous and woody.

2.2 Herbaceous Crops

Herbaceous energy crops are mostly types of grasses, which may grow in the wild or are harvested like hay. Perennial grasses, such as switchgrass, miscanthus, elephant grass, wheatgrass, typha plant, water hyacinth could all potentially be grown as energy crops. These grasses regrow from their roots and therefore do not require replanting for long periods of time (15 years or more).

2.3 Woody Crops

The other type of energy crops are Short Rotation Woody Crops (SRWC). This includes many types of trees such as cottonwood, silver maple, black locust, and poplar. SRWCs can be grown for a primary purpose such as paper production and the by-products can be utilized for energy. Many energy crops are currently being investigated, but many outside this may be better suited for a particular area but are not as suitable for widespread use.

2.4 Use of Energy Crops

Renewable energy currently accounts for a very small percentage of the total energy produced the world over. Biomass energy facilities generate a majority of the renewable energy in the US. In 1999, over 100 million tons of biomass was used to generate about 7,500 MW of power in the U.S. (MBEP, 2002). Energy crops can be used to generate electricity, and for the production of transportation fuels such as ethanol and for other biofuels like methane and biodiesel. Other uses include combustion for raising steam for electricity generation and for steam boiler/co-firing.

2.5 Uses of Energy Crops

There are many potential benefits from the use of energy crops. The three most dominant are: increased rural economic development, energy security, and environmental benefits.

2.5.1 Rural Economic Development

One compelling reason for generating energy from crops is to develop a new and profitable crop market.

2.5.2 Land Availability

Decreasing crop prices and profitability could result in an increase in the amount of land taken out of production.

2.5.3 Economic Activity and Employment

By utilizing available cropland there would be an increase in economic activity and employment in rural areas. A 500 MW biomass energy facility for example, could bring about 2,500 jobs (5 new full-time jobs for each megawatt the facility generated) into the community, and a 100 million gallon ethanol plant could create over 2,000 local jobs and much of the plant profits would be retained in the local community, (MBEP, 2002).

2.5.4 Energy Security

Energy generated through the use of energy crops would have the additional benefit of being a source of domestically produced, renewable energy. The use of energy crops to produce transportation fuels could increase our energy security by decreasing dependency on oil.

2.5.5 Environmental Benefits

Environmental benefits from the use of energy crops include water quality improvements, emission decreases at generation facilities, and wildlife habitat improvements (over traditional crops).

2.5.6 Water and Soil Improvements

Energy crops act as filter systems, removing pesticides and excess fertilizer from surface water before it pollutes groundwater or streams/rivers. Because of these filtering capabilities, energy crops are being considered as a supplemental crop to be planted with traditional crops for pollution control in the US, (MBEP, 2002). A typical example of such crop in Kano, Nigeria is the typha grass (Sabo, Ringim, and Karaye, 2016).

2.5.7 Emission Reduction

Another environmental benefit from the use of energy crops versus fossil fuels for energy production is a decrease in emissions. Unlike fossil fuels, plants grown for energy crops absorb the amount of carbon dioxide (CO2) released during their combustion/use. Therefore, by using biomass for energy generation there is no net CO2 generated because the amount emitted in its use has been previously absorbed when the plant was growing.

The amount of carbon emitted during energy production is considerably less for switchgrass and some woody crops, such as poplar in comparison to natural gas, petroleum and coal, (MBEP, 2002).

2.5.8 Wildlife/Natural Habitat Benefits

An additional environmental benefit from the use of energy crops is the habitat it provides for wildlife. A scientist from the National Audubon Society stated that energy crops such as switchgrass and poplars are a definite improvement for wildlife compared to traditional row crops.

3 RESEARCHES IN ENERGY PRODUCTION FROM ENERGY CROPS

3.1 WOOD FUEL AS A MAJOR SOURCE OF ENERGY

Wood is considered humankind's very first source of energy. Today it is still the most important single source of renewable energy providing about 6% of the global total energy supply. More than two billion people depend on wood energy for cooking and/heating, particularly in developing countries like Nigeria. It represents the only domestically available and affordable source of energy. Private households' cooking and heating with wood fuels represents one third of the global renewable energy consumption, making wood the most decentralized energy in the world. Wood fuels arise from multiple source including forests, other wooded land and trees outside forests, co-products from wood processing, post-consumer recovered and processed wood-based fuels. Wood energy is also an important emergency backup fuel. Societies at any socio-economic level will switch easily back to wood energy when encountering economic difficulties, natural disasters, and conflict situations or fossil energy supply shortages.

Use of wood for fuel however, is one of the greatest causes of desertification.

3.2 ENERGY FROM ENERGY PLANTS

3.2.1 Typha Grass

Also known as Southern cattail (*Typha domingensis*), Typha grass is a plant locally referred to as "*Kachala*" by the people living in the Hadejia River and "*Gerontsuntsu*" in Kano. It is a deep, rooted, perennial plant that has a cosmopolitan distribution in tropical and subtropical regions, (Sabo, Ringim, and Karaye, 2016). It is found in all wetland habitats including lakes, swamps, marshes, irrigation channels, roadsides, and manmade reservoirs. Cattails and other shoreline plants, in addition to performing important functions that help keep wetlands healthy, could also be used as a source of Energy, at domestic and industrial scale.

In an experiment conducted by Cervantes-Alcalá*et al* (2012) the typha plant was used to generate electricity directly using Sediment Plant Microbial Fuel Cells (SPMFC). In the study, they applied the SPMFC concept adapted to *Typha domingensis* and electrical current production was 47.9 ± 10.98 mA/m^2 with 6.12 ± 2.53 mW/m^2 power (data normalized to plant growth area). Trials were performed using an electrical motor which moved a cardboard propeller for 15minutes intervals during 6 days.

According to Hoevers, (2011), reeds and typha have attracted the interest of rural development initiatives as a potential resource for biofuels. The stems are a feedstock for charcoal for cooking, direct combustion of the woody stems, for cooking and electricity generation and biogas, for cooking and electricity generation. He asserted that *Typha* and reeds produce up to 20 t/ha annually which can be converted into charcoal briquettes and biogas. Thus the dependency of forest based firewood and charcoal is reduced, as well as the dependency on fossil fuels for electricity generation.

In a study to determine the Calorific Values (CV) of some agricultural residues Gravalos *et al* (2010), determined the Gross and Net CV's of typha in residue form to be 17.23 and 18.12 kJ/kg, respectively. However, in pellet form, the net CV was determined to be 16.584 kJ/kg with an ash content of 6.78 %. They concluded the pellets from forest residues show higher calorific values and lower ash content in comparison with pellets from agricultural crop and forage residues; that the residual biomass can be adapted to a wide variety of solid fuels; and that the results of calorific energy analysis in Cotton, Cardoon, *Typha Angustifolia*, and *Phragmites Australis* could be helpful to turn crop and forage residues into standardised pellets.

The effects of increasing concentration of cattail weeds (typha) using American cockroach gut microorganisms as an inoculum, expressed as percentage of total solids (TS) from 5, 15, to 30 and 60% on methane yield was investigated at ambient temperature of 29±1°C by Mshandete (2009). The results showed that highest methane yields were obtained at 5% TS for both individual and mixed cattail botanical fractions. A maximum methane yield of 447 CH_4 ml/g volatile solids (VS) and 288 ml/g VS added were obtained from leaves and whole cattail weeds (comprised of spikes, leaves, stems rhizomes and roots each 20% wet weight), respectively. An average methane content in the range of 72 and 79% was obtained in the biogas produced at 5 to 60% TS for both separate and mixed cattail botanical fractions. He further reported that lower TS % led to faster onset of biogas production and higher methane productivity. Blending of cattail botanical fraction at 5 to 60%TS in general did not improve the methane yield compared to that obtained from separate botanical fractions. Methane yield obtained from whole cattail weed was less by a factor of 1.6 compared to that of leaves at 5%TS. He then concluded that anaerobic digestion of cattail weed is feasible and could serve the dual roles for producing biogas, a clean renewable energy and reducing the weed as part of its management and that the methane yield reported in his study provided an extensive database on the extent of methane production from cattail weeds botanical fractions alone and in combination.

In Kano, Nigeria, Muhammad and Mukhtar (2016) assessed the energy values of *typha* grass found on the sewer sides of two industrial complex locations in Kano. The energy values were determined using Cussons bomb calorimeter model (P6310) From the results they obtained, the Gross calorific value (GCV), and Net calorific value (NCV) of *Typha domingensis* from Sharada industrial complex were found to be 1.158×10^4kJ/kg and 7.414×10^3kJ/kg respectively, while that of Challawa industrial complex were 1.272×10^4 kJ/kg and 1.199×10^4kJ/kg respectively. They asserted that from the values obtained *Typha domingensis* gave higher energy value than do most agricultural residues whose energy value falls between 14 – 19MJ/kg. They also did statistical analysis on the results using T-test and concluded that there were no significant differences in the energy values of *Typha* from the two sampling sites.

3.2.2 Water Hyacinth as Source of Biogas Production

Water hyacinth (*Eichhornia Crassipes*): is a floating plant, an invasive nuisance plant, a *non-grata* in much of the world where it often jams rivers and lakes with tons of floating plant matter (IEA, 2005). A healthy acre of water hyacinth can weigh up to 200 tons (IEA, 2005). It grows on fresh water. *Eichhornia Crassipes* form mats that clog waterways making fishing impossible and reduces water flow. Mats may double their size in as little as 6-18 days (Ludwig, 1988). It degrades the water quality by blocking the air-water interface and greatly reducing oxygen levels in the water, eliminating underwater animals such as fish and greatly reduces bio-diversity; mats also eliminate submersed plants by blocking sunlight, altering immersed plant communities by pushing them away and crushing them, and also alter animal communities by blocking access to the water and/or eliminating plants, the animals depend on for shelter and nesting (Schmitz *et al;* 1993). Millions of dollars a year used to be spent on water hyacinth control (Langeland and Cherry, 2008, Simpson and Sanderson, 2002, Van and Steward 1982). Several methods have been developed to help in its management: mechanical harvesters and chopping, biological controls (insects and fishes) and use of water hyacinth registered aquatic herbicides (Van and Steward, 1982).

From a study carried out at the Institute of Energy and Environmental Technology, Jomo Kenyatta, University of Agriculture and Technology, Kenya. Biogas was generated by collecting samples from Lake Victoria, pulped and blended with cow dung at a ratio of 3:1 as inoculums. The resultant mixture was mixed with water at ratio of 1:1 and fed into a $6m^3$ tubular digester. The digester was recharged with 20kg after every three days. The temperature, P^H variations, gas compositions, upgrading and gas yields were studied. The temperature ranged between 22.8°C-36.6°C and PH7.4-8.5. Biogas was found to contain 49-53% methane (CH_4), 30-33% carbon dioxide (Co_2), 5-6% nitrogen (N_2) and traces of hydrogen sulphide (H_2S). The biogas was upgraded using solid adsorbents and wet scrubbers increasing the methane content by up to 70-76%. The upgraded gas was used to power internal combustion engines coupled with an electricity generator and direct heat applications. The study concluded that *Eichhornia Crassipes*is a potential feedstock for biogas production especially in area where it is abundant.

Hoevers (2011) reported that biogas production from floating plants is 180 to 290 litres per kg dry weight, with a possible harvest of 40 to 50 t per ha per year, asserting that the annual biogas yield per ha can therefore be 10 million litres. He also reported that the methane content from floating plant biogas is 55 to 80%, and that even with a residence time of only 8 days biogas production from water hyacinth of 143 to 190 litres per kg dry weight has been reported. He further showed that with a biomass yield of 40 – 80 tones/hectare/year of water hyacinth, a biogas yield of 190 – 290 *l*/kg DM, with a methane content of 60 – 70 %.

3.2.3 Giant Reed as source of Biogas Production

Perennial grasses, and particularly giant reed, have already been recognized as high-yielding crops that can minimize environmental impacts, because of the reduced input requirement (Angelini *et al.,* 2009; Nassi o di Naso *et al.,* 2011). Giant reed is perennial rhizomatous species that has been traditionally cultivated in southern Europe, North Africa, Asia and the Middle East and has been recently introduced in the USA, where it is usually considered an invasive species; it has already been studied for bioethanol production, direct combustion, and other thermal transformations. Giant reed is considered a drought-tolerant species Angelin *et al., (*2009) and it can be grown in marginal or sub-marginal lands Nasso o di Nasso *et al.,* (2013), thus competition with food crops for soil use. Harvest time significantly influences biomass yield of giant reed and its characteristics (Nassi o di Nasso *et al.,* 2011, and it is usually seen as a major factor influencing digestibility and methane yields of energy crops (Kreuger *et al.,* et al.,2011; Kandel *et al.,* 2012). The Proportion of the stems respect to change, as well as chemical traits like concentration, C/N ratio, NSC (Non-Structural Carbohydrates), and cell wall components, thus influencing its biodegradability and methane output (Nasso o di Nasso *et al.,*2013). Previous studies assessed the capability of giant reed to regrow after an early cut but regrowth of perennial grasses is expected to vary according to the length of the growing season and the environmental conditions. Thus, biogas production could rely on multiple harvests per year, but several considerations are relevant to the question of whether single harvest or multiple harvest of a perennial crop for biogas is preferable, and many of these questions are not directly related to biodegradability (e.g. Crop duration, machinery requirements, nutrient uptake, environmental and economic sustainability). Despite the fact that biogas production from giant reed has already been hypothesized by some authors (Schievano *et al.,* 2012; Di Girolamo *et al.,* 2013), it is still a novel crop for this purpose. Therefore, further questions about biomethane potential and digestibility of giant reed under different management conditions should be addressed.

3.2.4 *Jatropha Curcas***,** *Neem* and Palm Kernel Seed Oils

Arguably one of the most popular energy plants in modern times, the oil from Jatropha Curcas seed has been used to produce biodiesel at various places with very promising results in terms of energy value and emission characteristics, especially when blended with the conventional diesel and other fuels and oils. It has the added advantage of not being edible plant. Its major drawback is the biodiesel's instability, frequently becoming very corrosive after a very short time. However, extensive researches are on-going to improve the stability. Neem oil is also a very popular choice for production of biodiesel.

In Bayero University, Kano, Nigeria, Onimowo and Abdullahi (2010) not only developed a pilot plant for the conversion of Jatropha curcas oil into biodiesel, they also used the plant to produce biodiesel from jatropha Curcas oil which was designed and fabricated. The plant was designed to process 30 litres of jatropha oil per batch into biodiesel with an output of 27 litres of jatropha biodiesel. This is equivalent to yield efficiency of 90%. The sample of the biodiesel produced was taken to KRPC Laboratory for analysis. The parameters tested and the results obtained are as follows: cetane index: 34.34, flash point: 162^oC, cloud point: 12.7^oC, pour point: 1.6^oC, kinematic viscosity: 5.64 cSt, specific gravity: 0.8862, sulfur content: 0.02 % (wt.), water and sediment: 0.4 %(vol.), and end boiling point: 340^{o}C. The test results were found to be within the limits of American Society for Testing and Materials (ASTM) specifications for biodiesel and diesel fuel. The cost of producing the biodiesel from the plant is was N137.80 / litre while the cost of fabricating the pilot plant is N226,100.00 – both being 2009 figures.

In a research work by Alamu, Akintola, Enweremadu, and Adeleke (2008), Palm kernel oil (PKO) biodiesel was produced using the transesterification process. They characterize the biodiesel using ASTM standard for fuel tests. They were able to produce 95.8% PKO biodiesel for three replications at 60 ºC reaction temperature and 90 min reaction time. Their results were also in good agreement with published data for other vegetable oil biodiesel as well as various international standards for biodiesel fuel.

On the other hand, Joshua *et al* (2011) carried out a comparative study of biodiesel produced from palm kernel and jatropha oils and found that when both biodiesels were compared with ASTM and EN standard values, jatropha biodiesel was of higher quality.

3.2.5 Energy from other Plants and Agricultural Residues

Maize Husk as a Source of Biogas Production

According to the food and agriculture organization of the United Nations, over 30 of all foods processed, manufactured for human consumption ultimately ends up as waste to give about 1.3x103 billion kg (Nathan and Pragasen, 2012). This large amount of food waste is evenly distributed between the developed and the developing countries. A huge amount of maize is produced annually in Nigeria and many other African counties, resulting in the generation of large quantities of maize husk (MH) as wastes. Though at the moment there is no easily accessible documented information on the actual amount of maize husk generated in Nigeria, it has been estimated that 4.11 million tons of maize residues are generated annually in Nigeria alone. These maize residues comprises mainly straw, husk, skin, trimmings and cobs Maize husks are usually burnt in open places or used as fire starters for cooking purposes in rural African communities. These disposal methods are wasteful and impact negatively on climate.

In a study undertaken by Eze and Ojike (2012), on the anaerobic digestion of maize wastes that are being indiscriminately dumped on Nigerian urban streets, Maize chaffs, stalks and cobs were shredded and mixed in water to waste ratios ranging from 3:1 to 4:1 (water to wastes) and anaerobically digested in three separate 0.1 m^3 digesters for 30 days. Results obtained show volume of biogas generated by the maize wastes as: chaffs, 89.5; cobs, 35; and stalks 44 litres. Their results also show that biogas from maize chaffs produced 67.25% CH_4; while that from stalks generated 66.30% CH_4; and from the cobs, 66.20% CH_4.

Biogas from Potato Peels

Potato is the third largest food crop in the world (Zhu *et al;* 2008). The several studies on the feasibility of anaerobic digestion of by-products from potato processing, Parawira *et al;*

*(*2004) have shown the greater interest of the industry and agricultural sector for biogas recovery through the treatment of those wastes by anaerobic digestion. Although, potato organic matter possesses a high content of carbohydrates, usually regarded as more suitable feedstock for the production of bioethanol rather than of biogas (Parawira *et al;* 2004a), it is less efficient to convert it into ethanol, thus not advisable. According to Gunaseelan (2004), the methane obtained from fruit and vegetable wastes is in the range of 180-732$cm^3.g^{-1}$ vs. and 190- 400$cm^3.g^{-1}$vs respectively, indicating fruit wastes as having a higher potential for biogas production. However, Parawira *et al.* (2004b) have shown that the co-digestion of solid potato waste with sugar beet leaves improved the accumulation of methane production and the methane yields by 31% to 62%, respectively, when compared with the anaerobic digestion of potato waste alone.

For his dissertation, Lucas (2014) studied the production of biogas from potato peels using anaerobic digestion (AD). He had a maximum production of CH4 of above 78.3% (v/v).

Energy from Bagasse, Duckweed, Switchgrass, Cereal straw

McKendry (2001), in an overview, gave the lower heating values of bagasse, switchgrass and cereal straw as 19.4, 17.4, and 17.3 MJ/kg (on dry basis). Hoevers (2011), on the other hand, reported that 20-45 t/ha/yr of Duckweed can yield a biomass of approximately 180 l/kg DM with a methane content of 55 – 65 %. In his conclusion, McKendry (2001) asserted, *inter alia* that the use of biomass, as a traditional energy source for the third world, can play a pivotal role in helping the developed world reduce the environmental impact of burning fossil fuels to produce energy but only if significant areas of replanting are actioned immediately; biomass can be a means of helping to reduce global warming, by displacing the use of fossil fuels; all biomass can be burned in thermo-chemical conversion plant i.e. combustion, to produce steam for use in a turbo-generator to produce electricity, while noting that some biomass species are better suited for biochemical conversion processes to produce gaseous or liquid fuels; the energy content of biomass (on a dry, ash-free basis) is similar for all plant species, lying in the range 17–21 MJ/kg; and that the principal selection criteria for biomass species are growth rate, ease of management, harvesting and intrinsic material properties, such as moisture/ash/alkali content, the latter properties influencing the operational characteristics of thermal conversion plant.

4. FINDINGS AND DISCUSSION

4.1 FINDINGS

From this review, it is found that:

(i) Energy plants can provide sources of alternative energy for electricity generation at the domestic and industrial level;

(ii) Energy from energy plants can be assessed by anaerobic conversion to obtain methane-rich biogas that could be used for domestic cooking and other heating requirements, as well as for raising steam for various processes such as in rice mills;

(iii) Other biofuels obtainable from energy plants include bioethanol and biodiesel which can be used, not only for electricity generation, but also for transportation;

(iv) The utilization of energy plants for energy can help reduce the environmental impact of burning fossil fuels to produce energy; as well as help remove the threats they pose both to aquatic life and navigation on waterways; engender rural economic development, energy security, economic activity and employment, land availability, emission reduction, and improve wildlife/natural habitat benefits;

(v) Plants that could significantly yield energy include *Typha* grass, water hyacinth, bagasse, *Jatropha Curcas*, duckweed, giant reed, and switchgrass, while agricultural residues include cereal straw, maize and rice husks potato peels, and *neem* and palm kernel seeds; the first five in the former category can be found in large quantities in Kano, mostly growing in the wild; while only palm kernel in the latter category cannot be found in Kano;

(vi) The energy content of biomass (on a dry, ash-free basis) is similar for all plant species, lying in the range 17–21 MJ/kg;

(vii) None of the energy plants are cultivated in Kano;

(viii) There is the need to assess the annual tonnage yield of energy plants in Kano; this way, the full amount of energy realizable from these alternative sources can be quantified;

(ix) In order to fully utilize the full benefits of energy production from energy plants researches must move away from experiments/demonstration to large scale plants that will partially replace the energy sources as exist presently.

(x) There is a need to design, construct and test briquetting machines for the various energy plants.

4.2 DISCUSSION OF FINDINGS

Energy plants are capable of yielding methane above 78.3% (v/v) and have energy value between 17 and 21 MJ/kg.

Plants that could significantly yield energy include *Typha* grass, water hyacinth, bagasse, *Jatropha Curcas*, duckweed, giant reed, and switchgrass, while agricultural residues include cereal straw, maize and rice husks potato peels, and *neem* and palm kernel seeds; the first five in the former category can be found in large quantities in Kano, mostly growing in the wild; while only palm kernel in the latter category cannot be found in Kano.

Energy from energy plants can be assessed by anaerobic conversion to obtain methane-rich biogas that could be used for domestic cooking and other heating requirements, as well as for raising steam for various processes such as in rice mills;

Other biofuels obtainable from energy plants include bioethanol and biodiesel which can be used, not only for electricity generation, but also for transportation;

While energy plants like typha grass, water hyacinth, bagasse, *Jatropha Curcas* and agricultural residues like cereal straw, maize and rice husks potato peels, and *neem* seed are capable of yielding significant amounts of energy for use in domestic cooking and heating, transportation, electricity generation, not much has been done to assess their potential use in Nigeria, and where such assessments are done, they are mostly at experimental or demonstration level.

A combination of these plants cultivated at large scale can boost the power supply and transportation, as well as meet domestic energy requirements in Nigeria at large and in Kano, in particular with its very large population.

5. CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSION

From literature, it was determined, that the maximum Gross calorific value (GCV), and Net calorific value (NCV) of *Typha domingensis* were determined to be up to 1.272×10^4 kJ/kg and 1.199×10^4 kJ/kg respectively; these are higher energy values compared to that of most agricultural residues whose energy value falls between 14 – 19 MJ/kg.

It was also revealed that biogas from water hyacinth can contain up to 49-53% methane (CH_4), 30-33% carbon dioxide (Co_2), 5-6% nitrogen (N_2) and traces of hydrogen sulphide (H_2S) and that this can be upgraded using solid adsorbents and wet scrubbers to increase the methane content by up to 70-76%.

Research has also shown that about 27 litres or more of jatropha biodiesel can be obtained from 30 litres or more of jatropha oil per batch into biodiesel with an output.

An assessment of the annual tonnage yield of energy plants in Kano in particular and in Nigeria in general is necessary if the full benefit of energy realizable from these alternative sources is to be realized and in order to do this researches must move away from experiments/demonstration to large scale plants that will partially replace the energy sources as exist presently

5.2 RECOMMENDATIONS

From this study the following recommendations are drawn:

(i) There is the need to assess the annual tonnage yield of energy plants in Kano; this way, the full amount of energy realizable from these alternative sources can be quantified;

(ii) There is the need to develop a briquetting machine for producing energy plant briquettes, as the briquettes to yield higher energy values;

(iii) In order to fully utilize the full benefits of energy production from energy plants researches must move away from experiments/demonstration to large scale plants that will partially replace the energy sources as exist presently.

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APPENDIX A: Some Energy Crops

Duckweed

Typha

Switchgrass

Water hyacinth

Giant reeds