BAMBOO AS A SOURCE OF BIOENERGY FEEDSTOCK IN GHANA



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A THESIS SUBMITTED TO THE DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE WOOD TECHNOLOGY AND INDUSTRIAL MANAGEMENT

FACULTY OF NATURAL RESOURCES THE COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

NOVEMBER 2008

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DECLARATION

I do hereby declare that this submission is my own work towards the MSc degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.



ABSTRACT

Bamboos are used for several purposes for both domestic and industrial uses. They are used for making handicrafts and furniture, building, decorating, paper making and as firewood in many parts of the developing world. However, its potential as an energy crop has not received much attention. Its ability to grow on nutrient poor soils, little requirement of silvicultural management, easy harvesting characteristics, vegetative propagation, fast growth and a host of other desirable characteristics make it a good candidate as an energy crop. Energy crops are cultivated solely for use as sources of energy either through their conversion into gases, alcohols or direct burning (combustion). Among several other criteria, the basic ones for choosing a good energy crop includes ash content, calorific value and moisture content of the crop at harvest This study set out to determine the potential of some bamboo species found in Ghana to be used in the combustion process for the production of energy. The three bamboo species were collected from Subri Plantations in the Western Region of Ghana; Bambusa v. vulgaris and Bambusa v. vittata which are native bamboo species in Ghana and Bambusa heterostachya, an exotic species that has been introduced into Ghana, and tested for their fuel properties. Tests carried out were combustion in a furnace at 500°C for ash content, bomb calorimeter for determination of gross calorific value and oven method was used for moisture content. Analysis of the ash was done as well to test for the proportion of Carbon, Nitrogen, Sulphur, Chlorine and some metallic elements as well. Other tests done included determining proportion of cellulose, lignin, hemicellulose and extractives present in the bamboo. All three species proved to have good fuel characteristics that are suitable for combustion processes in bioenergy production especially when compared with energy crops such as *Miscanthus x giganteus* and *Panicum virgatum* (switchgrass). They all have gross calorific values (17.24-17.84 GJ/kg) that fall within the range for woody biomass which is of 15-20 GJ/kg. Their very low ash contents (0.9-2.90%) and average moisture content (16.30 - 11.41%) in addition to characteristic lignin, cellulose, hemicellulose and extractives content gives them desirable fuel properties that make them potentially suitable plant species for the reliable production of energy through the combustion process. Out of the three however, *Bambusa heterostachya* proved to be the most viable with a higher gross calorific value, very low ash content and the lowest moisture content.



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ACKNOWLEDGEMENT

I give thanks to Almighty God for his sustenance, care and love and for seeing me through to the end of this research.

I also give thanks to my husband, Mr. James Osei Kwarteng and my children; Maame Serwaah Kwarteng, Nana Afriyie Kwarteng and Barima Osei Kwarteng for putting up with me. To the Sarfo and Osei families I say a big thank you and dedicate this work to the memory of my late father, Mr. Stephen Kwaku Sarfo who died a few days to its completion. I also wish to express my gratitude to the staff of Wood Science and Technology Department of The College of Agriculture and Natural Resources, K.N.U.S.T. especially my supervisor Dr. N.A. Darkwa. Also to Dr. Charles Antwi-Boasiako, Mr.Osei Kofi and Johnson (workshop) for giving me the opportunity to complete this work and their guidance.

To Mr. Nathaniel Boadi of Department of Chemistry, College of Science, K.N.U.S.T, I ask for God's blessings for you and wish to express my unending gratitude for your assistance, guidance and facilities.

My thanks also go to Mr. Lyndar Sanchebe of Subri plantations, Western region,

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Tony of Soil Research Institute, Mr. Bansah and Mr. Boateng of Mechanical Engineering, Mr. Bernard Sarfo Amankwaah and all who lent me their assistance during this project. Finally to Mr. Glen Asomaning 1 say thank you very much for your unrelenting encouragement that pushed me on. May God bless all of us, may God bless Ghana.



CHAPTER ONE 1.0 INTRODUCTION 1.1 Renewable energy

Research into renewable energy sources are being pursued vigorously at both national and international levels. There are many factors leading to this turn of events. One compelling factor is the ability of fossil fuels, coal and natural gas to run out. As a nonrenewable and finite resource, fossil fuels as sources of energy are limited in supply because they are time-bound (Olah, *et al*, 2006). They are therefore bound to run out some time in the future. There are indications that fossil fuel will begin to dwindle out in the 21st century. Since they take millions of years to be produced, replacement of fossil fuels is a gradual process that cannot be relied on to continue serving future energy needs forever.

Another factor contributing to the pursuance of more renewable energy sources is the desire of nations to wean themselves off their dependency on the Middle East for an important commodity such as energy considering the political instability of the region. There is concern over the security of fuel supplies from the region and their rising cost (European Commission, 1997, Harvey, 2004.).

Another important issue driving the use of renewable energy is the growing concern about the environment specifically in the area of climate change. This seems to be one of the most important factors (Haq, 2007). Burning of fossil fuels to produce energy leads to the release of gases, including carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides, methane, and other gases termed as greenhouse gases (Olah, *et al*, 2006). These chemical compounds were incorporated into organic materials millions of years ago which have now become fossil fuels. Their release into the current atmosphere however causes an imbalance in the composition of these gases especially carbon dioxide and carbon monoxide leading to trapping of heat from the earth surface and a consequent increase in the atmospheric temperature of the earth. Termed as global warming, this has been said to be the cause of recent changes in the

weather for example heat waves, flooding, severe droughts and many other intensified natural disasters. Fossil fuels also release poisonous substances like lead into the atmosphere. Biofuels on the other hand incorporate the carbon dioxide released through their conversion process when replanting is done after harvesting.

Renewable energy seems to be the answer to future energy needs. All sources of energy that when properly managed can be an unlimited source in terms of time are referred to as renewable energy (Picchi *et al.*, 2007). So far, solar energy, wave energy, tidal energy, geothermal energy, hydropower and biomass energy are some of the renewable energy sources currently in use. These energy sources are all inexhaustible and environmentally friendly. Renewable energy currently contributes 14% of the world's energy consumption with biomass contributing the larger part (about 10%) (Filho and Badr, 2004). Whiles an EU Biomass Action Plan has set a target of 8% biofuel (energy content) consumption for member countries by the year 2010, the U.S has set a minimum target of producing and using 250 million gallons of renewable fuel from cellulosic biomass by 2013 (Hart, 2007).

U.S President George Bush (2006) in his state of the nation address said he wants 75% of oil imports from the Middle East replaced by biofuels by 2025. In his view, reducing their dependency on oil is required for the security, prosperity and environment of the United States. Several countries in Asia and South America have also introduced the use of biofuel blends with diesel as transportation fuel. Brazil is the leading country in the use of ethanol blended biodiesel (REN21-GSR, 2010). The use of biofuel has been hailed by all as a more reliable source of future energy. Its utilization for the production of electricity is therefore the next best option for developing countries like Ghana with its erratic electricity supply solely from hydropower.

1.2 Energy resources of Ghana

Ghana falls within latitude 4, 44° S and 11,11° N and longitude 3,11° W and 1,11° E. The annual rainfall is generally high ranging between a high of 2,200 mm in the rain forest areas to less than 900 mm in the northeastern open savannah woodlands. A low of 700-800 mm per annum were however recorded in the savannah coastal plains east of Accra (Energy Commission of Ghana, 2010). The rainfall pattern falls within two main regimes of rainfall distribution; the first occurring in the southern parts from May to August and from September to October. The second regime is in the northern part of the country where there is only one rainfall season from November to May. The land area is approximately 238,539 km² and the climate is tropical, hot and humid. 23.9 Mha of the land is covered by vegetation with 20.831 Mha as farmlands, 8.5 Mha as savannah, 1.6 Mha as high forest, 0.4 Mha as mangrove and 0.075 Mha as plantations The current population is estimated at 20 million (Energy Commission of Ghana, 2010). The location of Ghana and its natural endowments give it a lot of renewable resources that can be utilized for the generation of energy. Of the total energy supply of the nation the shares in total energy consumption in 2004 was woodfuel 63%, 30% petroleum and 7% electricity. Water covers about 8,520 km² of land area. Hydropower is currently the main source of energy with two dams currently supplying 1027 Mw of electricity to the nation at Akosombo and Kpong water dams (Akuffo, 2003). The construction of a third hydropower dam, Bui dam, has taken off and was commissioned in August 2007. Though renewable, the tendency of the rivers to run dry or reduce in volume has led to long periods of shortages in electricity supply over the years. Its dependency on rainfall patterns, which can be low and unpredictable, is therefore a shortcoming of hydropower supply in the country.

A thermal generation plant was added to the national electricity grid in 1990 and in 2004 was supplying 550 MW, about 20% of electricity consumption in the country. A diesel plant is sited

at Tema with a capacity of 30 MW. But the use of petroleum products to power these sources make it an expensive venture for a country like Ghana that imports almost all its fossil fuel supplies, importing for example 1,813,464 tonnes of crude oil in 2004 (Energy Commission of Ghana, 2010). However there have been two discoveries of oil in substantial and commercial quantities this year, 2007, and its drilling may reduce the cost of petroleum products in the country. Currently, transportation fuel is 100% petroleum. Only a handful of individuals have started producing ethanol and mixing it with diesel to try in their vehicles.

Research has been done into Solar and wind energy under the Solar and Wind Energy Resource Assessment (SWERA) by the Energy Commission as part of an international energy program with the view of pursuing these resources as possible energy supplies for the country. Winds of 5 to 6 m/s at 12 a.g.l with corresponding power densities of 119 to 419 W/m² were measured along the coastlines of the country which is deemed favourable for wind energy harvesting. Direct solar energy has been used for drying purposes in the agricultural sector, domestic users, industrial sectors and many aspects of Ghanaian life for a long time. The amount of sunlight radiation received in Ghana per day is around 5.567-5.765 kWh/m², sufficient for the installation of solar energy systems. The problem with adopting widespread and large scale use of solar energy however lies in the quite expensive cost of installation although the gadgets and equipments are duty free (Energy Commission of Ghana, 2010).

Wood fuel is the main source of energy for the rural populace who make up about 67% of the population. Tree residues, fallen branches, stumps, diseased plants and many other sources serve as the feedstock for this sector. It is mainly used as firewood in traditional earthen tripod stoves where a large percentage of the heat produced is lost to the atmosphere. Some industries

9,0

with wood and agricultural waste have been utilizing biomass in their boilers to produce heat and steam for use in their various processes. Table 1.1 gives a list of some woodfuel consumers and estimated consumption in Ghana. Charcoal is the second form of woodfuel for domestic and sometimes industrial uses.

		Charcoal usage	
Consumers			
Demand Sectors	Firewood usage (t/a)	Charcoal Usage (t/a) fuelwood usage Equivalent (t/a)	Overall Woodfuel Consumption (t/a)
NYN HSP	AN ALL A	SANE NO	BADHER

Table 1.1 Woodfuel consumption in Ghana

Source: Akuffo, (2003)

Biomass resources in Ghana have been listed as agricultural residues, wood processing residues and woodfuels like diseased coconut and palm trees, as the viable crop biomass resources in the

country

						-
Residential Urban	6458000	652000	651600	5213000	5865000	(Akuffo,
Rural	11400000	5546000	241400	<mark>193</mark> 1000	7477000	2003). The
Industrial						combustion
Fish smoking	71000	767000			767000	process can
Gari making	70000	420000	/6		420000	be employed
Pa <mark>lm oil</mark>	59000	71000	¥ /		71000	
Bakeries	34000	195000		7-2-	195000	to produce
Potters	16800	18000			18000	heat and
Others	53690	<u>268000</u>	24	1	268000	electricity to
Commercial			2	1110		industries
Chop bars	12916		93800	750000	750000	and
Street sellers	64580		106600	853000	853000	
Grills	6458		21300	170000	170000	residential
Public		700000		< >	700000	consumers by
Total	i	8637000	1114700	8917000	17554000	the
	40				NO.	installation of

appropriate boilers. Whiles there are small boilers that can produce energy for industrial users, there are some that can produce enough for whole communities and regions with extra heat for drying and other purposes. Biomass energy is a serious option under consideration by the Energy Commission of Ghana.

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1.3 Sources of Biomass

Biomass comes from various sources; agricultural and forestry residues, municipal solid waste and manufacturing waste, vegetable oils and dedicated energy crops or virgin wood and wood residues (Filho and Badr, 2004). Biomass is defined as biological material, either living or dead. The energy obtained from biomass comes in different forms. The various fuels derived from biomass are all grouped together as biofuels. Combustion of biomass produces heat for processing and steam for the production of electricity. This energy source is termed as biopower. Forest residues, industrial waste, municipal waste, chaff and crop residues from farming activities can be used as feedstock for this process. However energy crops must be cultivated to ensure continuous supply of feedstock when considering the biopower industry.

A lot of plants are being investigated for their properties as possible fuel plants to be used as feedstock all over the world. *Miscanthus x giganteum* (Miscanthus), *Panicum virgatum* (switchgrass), corn, soybean (U.S), rapeseed, poplar and sunflower (Europe) and many other grasses are currently under investigations as energy crops (Biomass Energy Centre (BEC), 2006; Lewandoski *et al*, 2003). Whiles countries like Brazil are seriously working on sugar cane to produce ethanol and bagasse for combustion, some Asian countries like Indonesia and Malaysia are focusing on the palm tree (Hart, 2007). They are usually fast growing crops, require minimal attention for growth and produce a large proportion of biomass in a relatively short period amongst other factors.

Bamboo is a member of the grass family. It is said to be the fastest growing plant on earth. It can reach its full height in 90 days and produce a lot of leaf and root biomass in addition to its

hollow stem. It can be grown to reclaim depleted land and therefore need not compete for agricultural land. It also does not need frequent tending and is perennial with vegetative propagation. This makes it a viable candidate as an energy crop in horticultural terms.

In Ghana, the most common and abundant bamboo in the wild is *Bambusa v. vulgaris* followed by the *Bambusa v. vittata*. There are two known bamboo plantations in the country located in the Western and Eastern regions. These plantations have introduced about twenty new species mainly from Asia (Personnal Communication, Lyndar Sanchebe, Subri Plantations, November 2007). *Bambusa heterostachya* is one of such species introduced into the country. These three species are the ones under investigations in this study. Currently bamboo is mainly used for furniture making, fencing, crafts, baskets, roofing, scaffolding, building materials, cutlery and firewood in Ghana.

1.4 Analysis of biomass

Apart from the growth characteristics, there are chemical characteristics that also determine the potential of a plant as an energy crop and its suitability to a chosen conversion process. In this study, the fuel properties of the three bamboo species will be determined with the main focus on its use as a biofuel in boilers.

Proximate and ultimate analyses will be done to determine the various chemical properties of the three species and their suitability. Whiles ultimate analysis will be done to give the elemental components of the biomass; the proximate analysis gives the ash content, moisture content and the total energy content (Mclaughlin *et al*, 1996; National Renewable Energy

Laboratory (NREL), 2007). Fixed carbon content will also be determined. The determination of moisture content is necessary due to the fact that some amount of energy is spent in the drying of the biomass during combustion. The moisture acts as some sort of heat sink since some energy of vaporization is used (Yrjola, 2006). This also implies that the same biomass will give different total energy outputs at different harvesting moisture contents. The moisture level also affects handling and transportation and their cost due to weight and volume considerations. The gross calorific value gives an indication of the amount of heat and the potential value of electricity that can be produced by the biomass.

Elemental analysis of the ash will also be carried out. Ash content and its chemistry affect the efficiency of the boiler whiles increasing its maintenance cost. Ash is deposited on the boiler surfaces during combustion and give boilers a major setback; ash causes slagging and fouling of boilers the extent of which is determined by the elements present in the ash and their levels. There is also a small amount of toxic emissions. These inorganic elements are Silicon (Si), Potassium(K), sodium (Na), phosphorus (P), iron (Fe), chlorine (Cl), magnesium (Mg), sulphur (S), Calcium (Ca) and these are all found in the ash.

Because research into biofuels has only recently been intensified, new technologies are still coming up and there are minor variations in definitions and standards from country to country. The European Union set up a committee named it CEN/TC 335, with the task of setting standards for biomass fuel characteristics. The committee produced a set of standards named CEN/TS for a range of characteristics and are still working on some others. The U.S has set up a National Renewable Energy Laboratory to set standards for the testing of characteristics of biomass materials for fuel. They have already come up with a set of standards based on ASTM and TAPPI standards called the Laboratory Analysis Procedures (LAPS). The FAO has also

set up a definition list to unify the various terminologies in the field of biomass. The process of unifying all these standards and terminologies are still on-going and therefore there is no one standard set up for biomass research currently (FAO, 2004). Various laboratory methods available in Ghana for the determination of the various parameters will therefore be employed in this research.

1.5 Objectives

The main objective of this study is to determine the fuel properties of *Bambusa v. vulgaris*, *Bambusa v. vittata and Bambusa heterostachya* primarily by:

- 1. Determination of ash content, moisture content and calorific value of the three species
- 2. Determination of some metallic elements in the three species
- 3. Determination of some non-metallic elements of the three species.



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CHAPTER TWO 2.0 LITERATURE REVIEW

2.1 BIOENERGY

2.1.1 History of bioenergy

Energy is an essential part of human life and man's dependency on energy has increased with time. Sources of energy have evolved over the years. The use of biomass to produce energy has been there for centuries by the burning of woodfuels. The history of biodiesel is however of recent origins. In 1900, Dr. Rudolph Diesel, who designed the diesel engine, made it to run on peanut oil, the original biodiesel and demonstrated this at the world exhibition in Paris. He predicted the recurring importance of biodiesel for future use. Henry Ford's first automobile invention, a quadricycle, was made to run on ethanol in 1896. His famous model 'T' was made to run on ethanol, gasoline or a combination of both. He was extracting his oil from hemp seeds and he managed to get some fuel stations to sell his biodiesel (Grosser, 1978; Pahl, 2007). Low prices of petroleum due to government subvention however forced out biodiesels until world war two when disruptions in petroleum oil supplies compelled both sides to resort biodiesels. However, the popularity was short lived after the war until OPEC actions and oil crises in the 1970's forced the world's attention back to biodiesels. Some scientist, including a well known biodiesel researcher, Tom Reed, started the use of vegetable oils as feedstock for the production of biodiesel (Pahl, 2007). Used vegetable oil was also introduced whiles various plants were

brought into the fold for the extraction of their fatty acids and alkyls. In recent times, attempts to wean nations of their dependence on middle East oil and concerns over global warming have pushed the attention back to biodiesels. As the visionary Rudolf Diesel said in 1912 "The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and the coal tar products of the present time."

2.1.2 Biomass sources

A biomass is basically defined as a biological material derived from a living or recently living organism. In the energy context, it usually refers to plant material but also refers to animal and vegetable materials (BEC, 2006). It is also defined as an organic material from an animal or a plant (NREL, 2007). Some definitions include the conversion of metabolic waste of living organisms into biomass. In the energy industry, biomass refers to plant matter grown for use as biofuel but also include plant or animal matter used for fibres, chemicals or heat. Biomass is the most common form of renewable energy. Though widely used in the third world, it is in recent times that it has become popular in the western world (McKendry, 2002). For many people, biomass as a fuel was associated with smoke, dirt and carrying of heavy logs but improved stoves and equipments have made the direct use of biomass attractive. Though in industrialised countries biomass contributes 3% of primary-energy consumption, in developing countries they constitute about 35% of primary-energy consumption (Filho and Badr, 2004). Biomass provides a cost-effective and carbon-neutral source of energy that could provide 15% (from the current 1%) of the electricity demand from industrialized countries by 2020 (Bahr, 2004).

Sources of biomass have been classified into various forms: 1.Municipal solid waste / food residues This includes all the solid organic waste from domestic sources like homes, institutions, schools and municipal areas (Butler, 2007). They may include food scraps, paper, glass, metals, plastics, leather, rubber, textiles, vegetation and several other sources of waste (Franklin report, 2003). Slurry and sewage are also harnessed for energy production with biogas from landfills mainly consisting of gases released through anaerobic digestion of the organic components.

2 Wood residues

These are mainly the off-cuts and leftovers from forestry and wood industry activities. They involve the bark, leaves, branches, sawdust, wood chips, core wood and any other untreated wood pieces. Some of these are also processed into charcoal briquettes and wood pellets. There is always a danger of contamination by soil and other substances involved in the process.

3 Process waste, industrial waste and by-products

Black liquor from the pulp industry, paper, pulp, and organic waste and by-products from the food industries are also used as feedstock in some conversion processes. Used vegetable oil can also be converted into biodiesel for use as a transportation fuel.

4 Agricultural residues

Farm residues and some agro-process residues are utilised as biomass. Rice and corn straw, rice husks, corn cobs, palm pulp and others.

5. Dedicated energy crops/virgin wood

These are plants that are specifically grown for the biomass value. These include grasses, hemp crops like corn, soy bean, sugar cane, palm fruit and grasses like hemp, switch grass, *Miccanthus, Jatropha*, e.t.c. For crops like corn, whiles the crop is being used to produce liquid fuel, the straw could be burnt for heat or used to produce steam for the production of electricity (NREL, 2006). These crops are usually short rotation crops; growing fast and storing a lot of biomass in the process. There have been concerns expressed however on the possibility of farmlands being used to cultivate energy crops rather than food crops. There is also the fear of monoculture as more people turn to planting these crops. Virgin woods are untreated wood and may include sawdust and bark of woods.

6.Vegetable oils

Peanut oil, soybean oil, palmnut oil and almost all known cooking oils are used in the production of biodiesels. Animal fats can also be used. Used vegetable oil is also a source of biomass for the production of biodiesel. Although vegetable could be burnt directly in diesel engines, it does not flow well, forms gummy deposits on fuel injectors and produce acrolein and some aldehydes which are undesirable. Its conversion to its ethyl and methyl esters however eliminates these problems (Harvey, 2004). Base catalyzed transesterification is primarily the chemical reaction used in the conversion using alcohol usually methanol and ethanol (NREL, 2006). The products are alkyl esters and the biodiesel produced is non-toxic and biodegradable. It is used as transportation fuel and can be combined with conventional diesel in various proportions or alone. A test carried out at the New England Fuel Institute (NEFI) Training facility in Massachusetts by a group of scientists showed that a blend of 20% soy-based biodiesel fuel combined with 80% low sulphur (0.05%) highway biodiesel showed a reduction in gas emissions sulphur dioxide down by 83%, carbon dioxide 20%, nitrogen oxide 20% and

particulate matter was also down compared with conventional home heating oil (Batey, 2003). A lot of research has been done on this topic and oil blends have been shown to be more efficient and environmentally acceptable than conventional fossil fuel products.

2.1.3 Biofuels

The various fuels derived from biomass are all grouped together as biofuels. The biofuels that are currently being derived from biomass are in gaseous, liquid and solid forms. They include pyrolysis gas, methane gas, Hydrogen gas, pyrolysis liquid, biodiesel, ethanol, methanol, fuelwood, charcoal and briquettes. They are used as a source of heat, steam, electricity and transportation fuel. The initial state of the biomass and the conversion process employed determine the type of biofuel that is eventually produced.

2.1.4 Future of bioenergy

The energy derived from biological material sources is termed bioenergy. Africa and Asia already utilizes bioenergy amounting to about 50% of their total energy consumption (Picchi *et al*, 2007). Governments in most countries of the developed world have all embarked on programs to find more sources of feedstock to produce bioenergy. The Kyoto protocol requires that countries that have ratified it reduce their carbon dioxide emissions by a certain quota (REN21, 2010; Kyoto Protocol, 1997). The Department of Energy of United States of America has launched a Biomass Program where they are investing millions of dollars to do research, build plants and encourage the general use of biodiesels for transportation and biofuels for domestic and industrial use (Biomass Program, 2006). The European Union has endorsed a white paper that proposes 12 % Renewable Energy Sources by 2010 of total energy consumption (European Commission, 1997). They are using and doing research on rapeseed oil

and promoting its uses (Gaya and Patel, 2003). Some ongoing research is on the use of algae and other biological material sources as feedstocks for their use as biofuels.

2.2 CONVERSION PROCESSES

According to FAO terminology definitions, energy conversion in physical terms is a process which transforms energy from one form into another, for example, the conversion of wood into heat by combustion (FAO, 2004). In energy terms, it refers to production processes that transform one fuel into a fuel that can be transported or transmitted, for example electricity generation from coal, or charcoal production from wood. Energy from biomass is basically solar energy incorporated through photosynthesis into carbohydrates. The energy in biomass is stored in chemical bonds in its various component carbohydrates (GCEP, 2002). There are many processes that can be employed to convert biomass into energy. They range from simple and inexpensive to complex, technical and expensive. The term biorefinery has been coined to encompass any facility that integrates biomass conversion processes and equipments into the production of fuels, power and chemicals from biomass (NREL, 2007). The main forms of conversion processes are thermal, biochemical and esterification.

2.2.1 Thermal conversion

Thermal processes involve the use of heat at some point in the conversion process. It varies according to the degree of burning and the method of burning. It is usually used to produce heat for use in industries or used to produce steam to turn steam turbines and in turn produce electric energy. It also leads to the production of liquids and gases that are used for energy production and other chemical by-products that can replace those produced by petroleum refinery (NREL, 2006). Biopower is harnessed from the burning and combustion of biomass to produce heat and

electricity. Thermal conversion is classified as combustion, co-firing, pyrolysis and gasification based on the conditions of combustion.

Combustion is also referred to as direct firing and is the most common conversion method in use. Direct firing is the burning of biomass in the presence of excess oxygen either for direct heat, to produce steam by boiling water or produce liquids and gases based on varying oxygen and temperature conditions. According to DemibraS (2005), biomass residues are now widely used in many countries to provide centralized, medium and large-scale production of process heat for electricity. This heat is used to boil water in boilers to produce steam. The steam produced can be used in industrial processes or can be used to turn steam turbines for the production of electricity. Boilers have the capacity to produce about 20-50 MW of electricity. Biomass is the second largest source of energy in the United States next to hydropower (NREL, 2006). The main problems associated with biomass in direct firing are slagging, fouling and corrosion of the boiler surface. This is due to the ash formed during combustion and its chemistry.

Co-firing involves the use of biomass to replace some amount of coal in existing coal power plants. This reduces the amount of greenhouse gases produced and improves the quality of emissions without compromising the efficiencies of the existing system (Scurlock *et al.*, 2000). Biomass has more oxygen than fossil fuel and coal and therefore burns more efficiently but this also lowers its lower heating value (LHV).

Pyrolysis is a process that involves burning but here the amount of oxygen involved is very limited or almost excluded. At temperatures of 500 ^oC and limited oxygen conditions, thermal destructive distillation of the biomass occurs (Blasi *et al.*, 1999). During pyrolysis, there is

production of charcoal (solid), bio-oil (liquid), and fuel gas products. This thermal degradation process of cellulose goes through two main types of reactions; a gradual degradation, decomposition and charring on heating during the lower temperatures; and a rapid volatilization accompanied by the formation of laevoglucosan on pyrolysis at higher temperatures. For the biomass with higher cellulose content, the pyrolysis rate became faster while the biomass with higher lignin content gave slower pyrolysis rate (Gani and Naruse, 2007).

Gasification uses biomass gasifier systems where the solid biomass is converted into gases. These flammable gases can be used to turn gas turbines or gas and steam turbines together in a system called combined – cycles to produce electricity (NREL, 2006). When a biomass is burnt in the absence of oxygen or a third of the oxygen required for efficient combustion, tar, char and gases are released. It is a long process that consists of solid drying and pyrolysis, cracking and oxidation of tars and gasification of chars (Zanzi, 2001). These are termed synthesis gas or syngas. They can be used to turn gas turbines to produce electricity. Syngas is more efficient than the solid biomass from which it was produced; because it mixes more easily with oxygen during combustion. Whiles smaller sized particles is favourable for a higher Lower Heat Value and yield, application of steam to the process also improves the quality of the gas produced (Lv *et al.*, 2004).

2.2.2 Biochemical conversion

They are biological systems that are employed to convert the chemical energy in biomass into biofuels. These conversion processes are relatively cheaper and more efficient than most thermal processes and they are ideal for wet and liquid biomass. Variations in oxygen concentrations and the microbial organisms used are employed. Fermentation processes are employed where microorganisms are used to convert the sugars in the biomass into gases and liquids. The biomass, once broken down into starch and sugars are in turn converted to alcohol. Starchy crops like corn, potatoes, barley, wheat and all cellulosic materials are sources of sugar that can be converted into alcohol. The most commonly produced alcohol for biofuel are methanol and ethanol with the latter being the most commonly used one. Though it can be used alone in some diesel engines as fuel (E100-100% Ethanol), some modifications are needed and it is mostly used in different combinations with diesel oil. Production of alcohol out of crops like corn, wheat and others are however a source of concern due to its competition with direct human consumption as food. There are fears of food shortages and competition for land. Research is therefore being done on a large scale to find alternative grasses that can be fermented into alcohol. Switchgrass, *Miscanthus* and several other perennial weedy grasses that can grow on poor soils are being investigated for this purpose (Fields *et al.*, 2008).

In the production of biogas, anaerobic digestion is employed in the use of microorganisms to breakdown biomass in digesters but in this case the most important product is methane which can be used directly to produce energy or converted to hydrogen for use. The solid waste remaining can also be used as compost to enrich soils whiles the effluents can be recovered. Environmentally, anaerobic digestion is one of the most effective conversion process since no carbon dioxide nor hydrogen sulphide gases are produced during the process (Albertson *et al.*, 2006). One of the main restrictions to the use of this process however is the cost especially with the equipments. Some researchers have found that using a pond instead of an expensive digester can effectively absorb all pollutants while at the same time producing water insoluble methane at a cheaper cost (Oswald, 1996; Oswald *et al.*, 1994). Anaerobic digestion is an effective way of treating waste generated by man whiles getting energy as well.

Municipal waste or human waste is converted into energy in this way.

2.2.3 Esterification

Chemo-thermal processes are employed converting vegetable oils, animal fats and recycled greases into what is called biodiesel. It is basically the transesterification of triglyceride oil with monohydric alcohols. All forms and types of oils, including used cooking oil, are chemically transformed for use in diesel engines and other machinery in place of fossil fuels. The monoalkyl esters of these fats and oils are what is called biodiesel and can be burned in diesel engines without any need for modification. (Sharif-Hossain *et al.*, 2008; Vieira *et al.*, 2006)

2.3 CHEMICAL PROPERTIES

There is a lot of chemical heterogeneity in biomass and it is a chemically complex form of renewable energy resource (Biomass Program, 2006). For plant biomass, carbon dioxide from the atmosphere combines with water molecules to form carbohydrates through a process called photosynthesis using solar energy. Several other complex and simple compounds are also formed as by-products. These give the various chemical variations found in biomass.

2.3.1 Organic composition

Plant biomass has both organic and inorganic composites. Carbon constitutes nearly 5051% of the total biomass of plants (Vessia, 2006; Nemestothy, 2008; Smith *et al.*, 2002). Hydrogen, Oxygen, Nitrogen, Carbon with a little Sulphur and Chlorine are the usual components of the organic portion of a carbonaceous material. Some alkali and alkali earth metals are also present in various quantities in the organic compounds (BEC, 2006). The main complex organic compounds are cellulose, hemicellulose, lignin and then there are waxes, resins e.t.c.

Lignocellulose (made up of cellulose, hemicellulose and lignin) is the most abundant biomass on earth (Detroy and St Julian, 1983). The hemicellulose, cellulose and starch in the plants are made up of five and six carbon sugars which on combustion release energy for use with carbon and hydrogen being the combustible components. They can also be broken down into their sugar monomers and these form the basis for fermentation and anaerobic digestion conversion processes. Lignin is a tough, glue-like substance that keeps plant cell walls from falling apart, a cementing material between cell walls with an amorphous chemical composition and structure. Lignin has coniferyl alcohol as the building block and its combustion releases a large amount of energy that can also be harnessed. There are also extractives present in biomass that affect its heating values. They tend to raise the higher heating values of biomass (DermibaŞ, 2005). Table 2.1 shows the proportions of each of these in representative biomass with their carbon contents and higher heating values (HHV). High lignin content however negatively affect the fermentation of biomass to alcohols. Lignin is currently seen as one of the chief barriers to producing ethanol from grasses and woody plants, a preferable alternative to making ethanol from corn kernels or other food sources (Miller, 2008). Oxygen content in the biomass also has a negative effect on the net heating value (Vessia, 2006).

Table 2.1. Diomass	composition and	chemical properties	
	No. Add a		

			the second second			
Biomass	Bermuda Grass	Poplar	Pine	Refuse Fuel	Carbon	HHV
Component	(herbaceous)	(woody)	(woody)	(waste)	Content	[MJ/kg]
-	[% mass]	[% mass]	[% mass]	[% mass]	[% mass]	-
Cellulose	32	41	40	66	40-44	17

Hemicellu	llose 40	33	25	25	40-44	17
Lignin	4	26	35	3	63	25
Protein	12	2	1	4	53	24
Ash	5	ΚN		17	0	0

Source : Global Climate & Energy Project, 2002

2.3.2 Inorganic composition/Ash content

The ash from the combustion of the biomass usually consist of the inorganic constituents of the biomass. In ash analysis of biofuels, eight elements are important to ash characterization in the inorganic phase. They are Aluminim, Calcium, Potassium, Phosphorus, Sodium, Iron, Silicon and Magnesium (Paulrud, 2004). The ash concentration ranges from less than 1% in softwoods to 15% in herbaceous biomass and agricultural residue (Agblevor and Besler, 1996). Wood usually has less ash (11-25 g/kg) than grass (42-66 g/kg). The quality of the ash content of biomass however poses a problem for users in diesel engines, steam boilers and turbines. This is because the metals tend to catalyse the formation of char which when suspended in the fuel lead to the release of ash and alkali that can corrode these systems and also cause slagging and fouling. Slagging is the formation of deposits on surfaces exposed to radiant heat whiles fouling is the formation of deposits on heat recovery surfaces in furnaces and boilers (Cassida et al., 2005). The concentration of alkali metals, sulfur, chlorine and silica in the fuels appear to be the best indicators of the tendency of fuels to slag. Alkali contents of 1.4 lb MBtu⁻¹ is given as the slagging potential (Miles *et al.*, 1995; McLaughlin et al., 1996). In biodiesels, gas filtration can be used to reduce the effects of the ash content (Agblevor and Besler, 1996). The ash content of biomass is essential for the

heating value as it decreases with an increase in ash content (Vessia, 2006). This is because the ash represents the part of the biomass that does not burn to give energy.

2.4 PHYSICAL PROPERTIES

The biomass used in the production of bioenergy comes in various forms and shapes. They may be solid, liquid or gas. Wood, crops and their residues are solid, black liquor and vegetable oils are liquids whiles municipal waste decomposes to release gases.

2.4.1 Moisture Content

The moisture content of biomass plays an important role when it comes to its conversion to energy. It determines the conversion process to be employed and the end products. Various biomass to energy conversion processes exist and the physical form of the biomass best determines which process is suitable. This is likely the most important determinant of the overall biomass heating value during combustion. Due to their varying forms, moisture content of biomass has a wide range. Air dried biomass typically has about 15-20% moisture whiles oven dry biomass has 0% (Scurlock, 1999). Coal on the other hand has a moisture content variation between 2-30%. Biomass therefore needs to be dried but not beyond a certain level since that also leads to the production of syngas with less hydrogen (Vessia, 2006). Therefore the lower the moisture content of the biomass, the more desirable it is as a biofuel. As the moisture content increases, the Effective Heating Value (EHV) decreases until the moisture content reaches a critical value of 87% at which the energy of evaporation becomes equal to the EHV. The critical moisture content of the various biomasses is at 50-55% after which an increase in moisture content leads to significant decreases in EHV. This is shown in Figure 2.1 where the moisture contents of four softwood species are compared to the effective heat value. The evaporation of water may also retard combustion temperature and prevent it from reaching the optimum temperature. This may lead to the formation of undesirable products like creosote and tars that will affect the operations and efficiencies of the boiler. In addition, most biomass gasifiers are designed to operate on feedstock with low moisture contents of around 10-20% (BEC, 2006). Most plant biomass are therefore dried before use in boilers, a process that involves a lot of time and energy. A biomass with lower moisture content at harvest is therefore desirable.



Figure 2.1: The relation between moisture content and EHV [kWh/m3] (Source: Vessia, 2006)

2.4.2 Ash content

Ash content directly affects heating value. The ash content is made up of the inorganic constituents that do not burn to produce heat (Bakker and Elbersen, 2005). Therefore as the ash content of a biomass increases, the heating value decreases and vice-versa (Vessia, 2006). With low ash content, a biomass causes fewer problems when used in boilers and this is also dependent on the quality of the ash produced in terms of the constituent chemical elements. The ash content of biomass is affected by the plant type, plant fraction, growing conditions, harvesting time and method, handling systems, pretreatment and conversion systems (Bakker and Elbersen, 2005).

2.4.3 Gross Calorific value

Calorific value is one of the most important determinant of the quality of a fuel. Gross calorific value (G.C.V) is the quantity of heat liberated when a unit mass of fuel is combusted at constant volume in oxygen saturated with water vapour and the products of combustion contain carbon dioxide, sulphur dioxide, oxygen and nitrogen (Faculty of Mechanical Engineering, K.N.U.S.T). Calorific value of various fuel sources vary. Whiles fossil fuels have rather high and varied calorific values; coal 15-30 GJ/kg and oil 42-45 GJ/kg, biomass feedstock fuels have low calorific values that fall within a short range; 15.4-20.5 GJ/kg. bioethanol has 27 GJ/kg whiles biodiesel has 40 GJ/kg (Table 2.2).

2.4.4 Energy Density

Energy density is a term used for the amount of energy stored in a given system or region of space per unit volume. Bulk density of materials is directly proportional to their energy density. The bulk density of biomass is generally low compared to fossil fuel and coal. Biomass therefore has a comparatively lower calorific value than fossil fuels and coal. Bulk density also

varies among the various biomass. Bamboo chips have lower bulk density than wood chips (Papadopoulos *et al.*, 2004).

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Table 2.2 Chemical Characteristics of selected feedstocks

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Ç		heating value (gross, unless specified; GJ/t)	Ash (%)	sulfur (%)	potassium (%)	Ash melting temperature [some ash sintering observed] (C)
2	corn stover	17.6	5.6	8	2	FI
	sweet sorghum	15.4	5.5	1	1	2
	Sugarcane bagasse	18.1	3.2- 5.5	0.10- 0.15	0.73-0.97	
	Sugarcane leaves	17.4	7.7			
_	Hardwood	20.5	0.45	0.009	0.04	[900]
Bioene <mark>rgy</mark> Feedstocks	softwood	19.6	0.3	0.01		
	Hybrid poplar	19.0	0.5- 1.5	0.03	0.3	1350
	Bamboo	18.5-19.4	0.8- 2.5	0.03- 0.05	0.15-0.50	
	switchgrass	18.3	4.5- 5.8	0.12		1016
	miscanthus	17.1-19.4	1.5- 4.5	0.1	0.37-1.12	1090 [600]
	Arundo donax	17.1	5-6	0.07		
Liquid Biofuels	bioethanol	28		< 0.01		N/A
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	biodiesel	40	< 0.02	< 0.05	<0.0001	N/A
	Coal (low rank;	15-19	5-20	1.0-	0.02-0.3	~1300
	lignite/subbituminous)		1	3.0		
Fossil Fuels	Coal (high rank;	27-30	1-10	0.5-	0.06-0.15	~1300
	bituminous/anthracite)		6	1.5		
	Oil (typical distillate)	42-45	0.5-	0.2-		N/A
			1.5	1.2		

Source: Jonathan Scurlock, 1999.

2.5 ENERGY CROPS

These are crops that are purposely grown for the production of energy in one form or another. They may yield starchy crops which are later fermented into ethanol; like corn, wheat, sugarcane or the whole crop may be used especially in the combustion process. Some of the crops that are being used or researched for use are switch grass (*Panicum virgatum*), *Miscanthus spp*, *Arundo donax* (giant reed) (Lewandoski *et al.*, 2003), cane and several grass. Rice husk, bagasse and other agricultural residues are also being used as biofuels. Some of the factors influencing the propagation of energy crops are land use, biomass production, cost (both monetary and environmental) of production, fuel characteristics like heating value, ash content and alkali index (BEC, 2006). Some basic characteristics required of 'ideal' energy crops are stated in Table 2.3 which also gives a comparison between corn, miscanthus and short rotation crops:

2.5.1 Miscanthus (*Miscanthus x giganteus*)

One important energy crop in Europe and the U.S. is *Miscanthus*. The most common one under study is a hybrid; *Miscanthus x giganteus*. It is a perennial grass that gives a high yield of biomass per hectare. It is being grown for both combustion and fermentation processes to

produce ethanol. According to literature, *Miscanthus* meets all the ecological criteria required for an ideal biomass energy crop (Table 2.3). Its pyrolysis also yields oil that can be used as a renewable fuel and chemical feedstock (Yorgun, 2003).

Table 2.3 Ecological Characteristics of the ideal biomass energy crop

Characteristics of the ideal biomass energy crop rotation	Corn	Short-	Miscanthus
	C	oppice	
C ₄ photosynthesis	+	1	+
Long canopy duration		+	+
Perennial (no need for annual tillage or planting)		+	+
No known pests or diseases			+
Rapid growth in spring to out compete weeds	- and	+	+
Sterile prevent "escape"	n/a	5	5+ 3
Stores carbon in soil (soil restoration and carbon tool)	D.	+22	+ Sequestration
Recycles nutrients back to roots in fall (low Fertiliser requirements)		192	+
Low nutrient content(very clean burning)			+
High water use efficiency			+
Dry down in field(zero drying costs)	?		+
Good winter standing (harvest when needed;zero Storage costs)	5	+	
Utilizes existing farm equipment	+	-	+ Alternative
markets (high quality paper,	1	BA	
building materials and fermentation)	10	+	+
Source: Heaton et al, 2002.			

2.5.2 Switchgrass (Panicum virgatum)

It is a herbaceous crop that has been adopted mainly in the U.S as an energy crop. This is due to its growth characteristics, high ethanol yield, and desirable combustion properties (Mclaughlin *et al.*, 1996). By the late eighties, most states in the United States were testing switchgrass for its energy properties (Wright, 2004).

2.5.3 Bamboo

Bamboo is a member of the grass family though they are woody in nature. There are about 1250 species of bamboo in the world with a height of 10-40 cm (Scurlock et al., 2000). Although they are native to the tropics, they have been known to survive in temperate regions as well. Bamboo is said to have some desirable fuel characteristics like low ash content and low alkali index with a lower heating value higher than most agricultural residues, grasses and straw but also lower than many woody biomass (Scurlock et al., 2000). Table 2.2 gives the biomass fuel characteristics of some energy crops including bamboo. Among the genera and species, bamboos exhibit no great differences in the chemical and physical-mechanical properties. There are however some anatomical differences due to differences in vascular bundles and this may affect properties like strength, density, bending behaviour, splitting and shrinkage. The culm is made up of about 60% parenchyma, 40% fibre and 10% conducting tissue. Bamboo has about 50-70% cellulose, 30% hemicellulose and 20-25% lignin. This indicates that it has a comparative composition to that of the species listed in Table 2.1 (Liese, 1992). The biomass of bamboo, in terms of productivity, does not differ much from that of woody biomass (Hunter and Jungi, 2002). In a study conducted in India to study the biomass Bambusa bambos, aboveground biomass of the clumps gave an average of 2417 kg/clump with the highest biomass given by the live culm (82%), followed by the foliage and thorns (13%) with dead culms contributing about 5%. The average biomass per hectare was given as 241.7 Mg/ha (Kumar *et al.*, 2005). Bamboo comes in varying culm sizes ranging from small 'fishing pole' sizes to large diameter species that can grow up to 100 feet (30 m) in 3 to 4 years (Hurter, 2002).

2.5.3.1 Bambusa heterostachya (Munro) Holttum 1946

Synonyms : Bambusa latispiculata (Gamble) Holttum 1946, Gigantochloa heterostachya Munro 1868, Gigantochloa latispiculata Gamble 1896.

They have light green or white green stripes. They have straight culms of about 8-16 m tall and 3-5 cm culm diameter. The nodes are prominent with internodes of about 30-80 cm long. They have regular flowering characteristics and bear cylindrical fruits of about 5-6 mm. Cultivation is mainly by seed. They thrive under lowland forest conditions.

2.5.3.2 Bambusa vugaris var vittata

Synonym: *Bambusa multiplex (Lour.) R,,uschel ex J.A. & J.H. Schultes 1830. cv.* 'Silverstripe'

Attractive yellow culms striped green, widely planted as an ornamental. They grow in clumps and tolerate low light conditions. They can grow to a height of about 15- 20 m, with a culm diameter of about 8 cm. The yellow colour starts to fade when harvested. They thrive on infertile soils and close to water bodies as well. Flowering is extremely rare (Anon, 2010).

2.5.3.3 Bambusa vulgaris Schrader ex Wendland 1810.

Synonym: Bambusa arundinacea (Retz.) Willd. ,Bambusa auriculata Kurz , Bambusa balcooa Roxburgh 1832

It is the most common bamboo species in Ghana and in most parts of the tropics. They are green in colour, grow in dense clumps and can reach 15-20 m in height. The culms can increase

to a diameter of 4-10 cm with a wall thickness of 7-15 mm (Rao *et al.*, 1998). They have woody culms and produce new culms on yearly basis (Anon, 2010).

Roots easily shoot out at the nodes and they can be easily propagated by using culm branch cutting, rhizome and layering. They have irregular flowering nature. About 5 cm per month growth was observed at Subri plantations in Western region, Ghana. They grow well in all types of soils (Personal Comm. Lyndar Sanchebe, Subri plantations, 2007).

2.5.4 The situation of bamboo in Ghana.

Bamboo in Ghana is found mainly in the wild and lacks any serious management practices. It is difficult to get information of the amount of bamboo biomass available even in the plantations because stock taking has not taken place. Bamboo is also found scattered all over the country on farmlands, reserved forest and off-reserve. Though a permit is required for the extraction of non-timber forests products, offenders are hardly penalized since the main focus is on timber. In the last few years, two bamboo plantations have been established in the Western and Eastern regions of Ghana. There are four native species; *Bambusa v. vulgaris, Bambusa v. vulgaris, Bambusa v. vulgaris* is the main species found in Ghana, the two plantations have embarked on the introduction of other species from other parts of the world, mainly Asia. In April 2003, 18 new and improved bamboo species were introduced to Ghana from the U.S. Data on the current availability status of bamboo is scanty and unreliable. The two bamboo plantations in the country have also introduced several species mainly from Asia.

The International Network on Bamboo and Rattan (INBAR) together with other stakeholders quite recently built a classroom block with bamboo as the first wholly modern bamboo housing

structure in the country. Bamboo is mainly used in the production of furniture, artifacts and handicrafts, cooking utensils, toothpicks, roofing, fencing and as firewood in Ghana

There are several industrial concerns in the country that are using biomass as fuel in boilers to facilitate their production process. These sources are however mainly residues and waste from their own activities. At Samaboi in the Western region, samartex sawmill uses their residues and waste to generate enough electricity for the factory, residence of workers as well as the host village; Samaboi (Personal communication, Samuel Danso, Samartex sawmill, January 2008). Some sawmills in Kumasi also burn their wood residues to operate their drying kilns. The potential of bamboo as a dominant biofuel has however not been explored. Bamboo could easily be planted to supply a constant source of biofuel for these industries. Several woody species like Acacia spp. and others have been recommended and planted in Ghana as a source of firewood. Bamboo can be added to this list as well. Other plant and grass species are being explored around the world for their use as a source of bioenergy. However, bamboo with its fast growing characteristics coupled with a wide range of soil adaptability presents a potential source of energy for both industrial and domestic use particularly in the production of electricity. Below are some traditional Ghanaian tree species being used for energy production in the form of corewood and sawdust and their fuel characteristics.

		JAN	E		
Botanical	Local	Qgw	Qgw	Qnw	Moisture
Name	Name	MJ/kg	MJ/kg	MJ/kg	Content

Table 2. 4: Calorific values and moisture content of sawdust from sawmills.

	Mixture	17±1	20±1	16± 1	15±1	
Cylicodiscus gabunensis	Denya	17 ± 1	20± 1	15± 1	15±3	
Triplochiton scleroxylon	Wawa	15.4 ± 0.8	19±1	14± 1	21±4	
Khaya ivorensis	African Mahogany	16.8± 0.9	19± 1	15± 1	15±3	
Milicia excelsa	Odum	17.4±0.9	20± 1	16±1	14± 2	
Albizia Ferruginea	Awiemfo samina	18.1±0.9	19±1	17± 1	4± 1	
Tecton <mark>a grandis</mark>	Teak	17.5±0.9	20± 1	16±1	13±2	

Where Q = Calorific Value; n = Net; g = Gross; d = Dry; w = Wet Source: Resources Catalogue Final Report, Energy Commission of Ghana (2003).

CHAPTER THREE 3.0 MATERIALS AND METHODS

BADY

3.1 PREPARATION OF SAMPLES

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The three species (*Bambusa v. vittata, Bambusa v. vulgaris and Bambusa heterostachya*) of bamboo samples were harvested from Subri Plantations in the Western Region of Ghana in November 2007. All three species had been planted in March 2003. The samples were quickly wrapped with plastic coverings and placed in jute sacks for subsequent transportation to Kumasi. Sample culms were taken from the upper, lower and middle portions of each culm. These were each cut into small pieces of about a centimeter square, mixed together and ground into powder form. Nodes and internodes were mixed from the upper, middle and lower portions of the culm for each species. A mesh size of 2 mm and 1 mm was used for the final sieving of samples. The powdered samples were then sealed into plastic bags and labeled. The tests were carried out at three laboratories in Kumasi, in the Ashanti Region of Ghana. The calorific values were determined at the laboratories of Mechanical Dept. of KNUST whiles ultimate analyses were done at the chemistry and mineral laboratory of the Soil Research Institute of CSIR, Kumasi. All other tests were done at the Instrumentation laboratory of the Chemistry Dept of KNUST.

3.2 PROXIMATE ANALYSIS

3.2.1 Moisture content determination.

Methods

Immediately after grinding, samples were taken to the laboratory for the determination of the moisture content. 2 g of each sample was weighed and placed in different crucibles. The crucibles had already been dried and weighed. These were then labeled and placed in the oven which was kept at a temperature of 105 °C. Each crucible and sample were taken out of the oven regularly and weighed. A gradual decrease in weight was observed and the drying and weighing continued until there was no observed change in the weights after several weighings.

The samples were taken out and kept in a dessicator for them to cool down and weighed. The final weights were then recorded.

This was duplicated for each species (Appendix 1).

The formula for calculating the moisture content is given by:

Moisture content (dry basis) = $(M_1 - M_c) - (M_2 - M_c) \times 100\%$

$$(M_2 - M_c)$$

Where:

 M_1 = Initial weight of sample and crucible

 M_2 = Final weight of sample and crucible

 $M_c =$ Weight of crucible

The average of the three samples was taken as the moisture content of the species.

3.2.2 Ash Content Determination

Method

Two grams of bamboo powder of each species was measured into an already weighed crucible and carried by a forceps into a furnace burning at a temperature of 400 °C. The samples were left in the furnace until complete ashing took place and were finally taken out. The crucible and ash were transferred to a dessicator and weighed immediately it cooled down. The test was duplicated for each species (Appendix 2). The ash content is given by: Ash content = (Weight of ash and crucible – weight of crucible) $g \ge 100\%$ (Weight of final sample and crucible-weight of crucible)

3.2.3 Gross Calorific Value

Method

A crucible was weighed and 0.7 g of the various species were measured out. Each sample was put in a crucible. The crucible containing the sample was fixed in the seating in the bomb cover. A piece of ignition wire, touching the surface of the sample, was attached to two terminals. 15 mls of distilled water is poured into the base of the bomb which is then filled with oxygen up to 25 atm. A volume of 240 mls of water was poured into the calorimeter vessel which in turn was placed in a water filled jacket. A thermometer was inserted through the cover of the bomb and the latter placed in the calorimeter vessel. Once the power was turned on, temperature readings were taken at 1 min intervals. For the first 5 min, there was no change in temperature. After that the temperature began to rise (called the Firing point) and went on increasing. Readings were then taken every minute until there was no more increase in the temperature. After this, temperature readings were taken for every minute for 5 min. The values were plotted on a graph. Two lines were drawn to intercept the curve on the graph; one from the firing point and the other from the maximum temperature. The temperature at the mid-point of a line joining the two interceptions was then determined and taken as the 'rise in temperature' in the following formula used to calculate calorific value in KJ/kg:

 $W_f \ge Q = (W_{w+}W_a)$ (rise in temperature) ⁰C x 4.2

Where

 W_{f} = weight of fuel in kg

 W_w = weight of water in the calorimeter in grams

 W_a = 'water equivalent' of the apparatus (0.482 g) Q =

calorific value in KJ/kg

Values were then converted to GJ/t (Appendix 3).

3.3 CHEMICAL ANALYSIS

Flame photometer was used in the determination of the Potassium content of the three species. The photometer was used to measure the quantity of Potassium based on the flames that was emitted from the sample. For Phosphorus and Sulphur (in the form of sulphate), spectrometry was employed whiles the Atomic Absorption Spectrography (AAS) was used in the determination of the heavy metals Lead and Iron. Agentometric titration was employed in the determination of chlorine using sliver nitrate to precipitate the chloride whiles the dry combustion method was used in the determination of carbon.

3.3.1 Extractives

3.3.1.a Toluene-alcohol extraction.

A volume of 200 mls each of toluene and 98% ethanol were added to 15 g of bamboo sample packed in a polyester sack in a round bottom flask and attached to the soxhlet apparatus and condenser. The mixture was then heated and refluxed until the condensate was clear and free of colour. The sample was then dried in the oven at 105

°C and weighed regularly until a constant weight was achieved and this weight was recorded. The toluene-alcohol mixture was recovered and the residue was put in a petri dish, dried in an oven and the weight of extractives taken. The procedure was repeated again for each species (Appendix 4).

3.3.1.b Alcohol extraction

A volume of 400 mls of 98% Ethanol was added to toluene-alcohol soluble extractive free bamboo samples in a round bottom flask, attached to a soxhlet and condenser and heated. It was refluxed several times until the condensate was clear and clolourless. The alcohol was recovered and the residue was washed and dried in an oven and the extractives weighed. The procedure was duplicated for this solvent (Appendix 5).

3.3.1.c Hot Water extraction

To the bamboo sample free of toluene-alcohol and alcohol soluble extractives, 400 mls of distilled water was added and heated in a round bottom flask attached to a sohxlet apparatus and a condenser. It was heated and refluxed several times until the condensate was clear and colourless. The sample was dried in an oven until constant weight was achieved. The distilled water was recovered and the residue was heated in an oven until completely dry and then weighed. The procedure was done in duplicate for each sample (Appendix 6).

3.3.2 Lignin determination

A gram of moisture and extractive free sample was taken and put in a beaker and 15 ml of 72% sulphuric acid was added whiles stirring. The stirring continued for about 1 min. The mixture was allowed to stand for two hours with frequent stirring at intervals. After 2 h the mixture was poured into a one litre conical flask. 360 mls of distilled water was added to it with some being used to rinse the beaker. At a reduced concentration of 3%, the mixture was boiled for 4 h using

a reflux condenser. The mixture was allowed to settle and then filtered. A crucible was dried and weighed and the residue was transferred to it after it had been washed with 500 ml of hot water to remove the acid. It was then dried in an oven at 105 °C for 2 h, cooled in a dessicator and weighed as lignin. This procedure was duplicated for each species (Appendix 7).

3.3.3 Holocellulose determination

An amount of dried soluble-extractives free samples was taken and to this 180 ml of distilled water, 6.0 g ethanoic acid, 8.6 g sodium acetate and 6.6 g sodium chlorite were mixed. Digestion of the mixture was done in a 250 ml conical flask under a reflux condenser in a water bath of temperature 70 °C in fumehood. The mixture was digested for 3 h and allowed to cool. After filtration, the residue was washed with 100 ml of distilled water in five 20 ml portions. The sample was then dried in an oven at 105 °C until constant weight was achieved. The weight was taken and the experiment was duplicated for all the three species (Appendix 9).

3.3.4 Cellulose determination

One and half grams of the sample that is free of solvent soluble extractives was taken and put in a 250 ml beaker that was then put in a water bath at 25 °C. Accompanied by vigorous stirring, 100 ml of 17.5% NaOH was added to the sample. This was left to stand alone for 30 min with the occasional stirring. After this, 100 ml of water at 25 °C was added, stirred and left for another 30 min. After this the mixture in the beaker was filtered and the cellulose which remained as the residue was washed with 9.5% NaOH solution. This was followed by 100 ml of distilled water at 25 °C in five 20 ml portions. Further washing was done using 40 ml of 10% acetic acid and after that more distilled water. Sample was then dried in an oven at 105 °C to achieve a constant weight. This was done for all three species in duplicates (Appendix 8).

3.3.5 Hemicellulose (Pentosans) determination

Holocellulose is made up of hemicelluloses and cellulose. Based on the tests done above on the basis that cellulose is insoluble in 17.5% NaOH, the difference between the holocellulose and the percentage of cellulose will give the percentage of hemicelluloses.

CHAPTER FOUR 4.0 RESULTS AND DISCUSSION

The proximate, ultimate and elemental ash analysis are usually the tests done to determine the properties of fuel materials. The results obtained from our various tests will be compared to that of other species chosen as biomass plants around the world and where available, that of coal, a non-plant solid fuel. The data for these species was obtained from PHYLLIS, a biomass database compiled by the Energy Research Centre of the Netherlands, ECN. Other data was obtained from Scurlock *et al*, 2000 who did similar work on different bamboo species in the United States of America and similar work done in Laos by Danneman *et al* (2007) on two *Dendrocalamus* spp, two *Bambusa spp*, two *Gigantochloa* spp and *Thyrostachys siamensis* of bamboo.

4.1 Proximate Analysis

Table 4.1: Fuel analysis of B. v. vulgaris, B. v. vittata and B. heterostachya							
	Bambusa	Bambusa	Bambusa	v.vulgaris			
v.vittata	heterost	tachya					
Fuel pr	operty	WJSAI	UF NO				
Moisture c	content	12.39	16.02	9.84			
(%	b)						
Ash co	ntent	2.96	2.45	1.2			
(%)							

Higher Calorific value	17.29	17.24	17.84
(GJ/t)			



Table 4.2: Comparison of selected fuel properties of bamboo with other bioenergy Crops

Fuel property (Bamboo range of 3 hyllostachys spp) ^a	Bamboo (species not given) ^b	Bamboo (species not given) ^c	Miscanthus (Miscanthus x giganteus) ^d	Switchgras (Panicum virgatum) ^e	S
Gross heating	19.1-19.6	15.85	18.96	17.1-19.4	18.3	value
(dry, GJ/t)			(Contraction of the second se	12		
Moisture	~	5	R		FF.	
Content(%)	8.4-22.6	10.4	2.94	15-40) 15	
(Samples as received after	(at harvest?)	(after drying) shipping)	(at harvest?)	(at harvest)	7	
Ash content(%)) <1.0	3.98	2.04	1.5-4.5	4.5-5.8	
0.1.1	6	11/10	100			
Sulphur Content(%)	0.03-0.05	N/A	0.15	0.1	0.12	

^aScurlock *et al*, 2000.Table 2. ^bEl Bassam (1998) Table 3.8 ^cC.E.Pugh 1981,laboratory report for Northeast Louisiana University, cited in Woods(1996). ^dData for *Miscanthus* from Scurlock (1999). .^eData for switchgrass from Mclaughlin *et al* (1996)

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Table 4.3 : Statistical data for moisture content, Ash content and Calorific value of *B. v. vulgaris, B. v. vittata and B. heterostachya* from this study

Source	Moisture content	Ash content	Calorific value	
F-ratio	68.6724	51.55	2690	
Mean	13.27	2.20	17.457	77
Standard Deviation	2.55	0.7196	0.27293	
Variance	6.51	0.51786	0.07449	
Co-effiecient of Variation	4.14%	7.96%	0.052%	No. 1
Least Square Difference (LSD)	2.0145	0.5447	0.02899	MOM

4.1.1 Moisture content

Moisture content of plant species varies according to location, season, age and the location of the sample in the species. The moisture content of the three bamboo species under study which were of the same age, from the same location and harvested at the same time showed variations that are statistically significant from ANOVA calculations at 10% significance level (Table 4.3). Bambusa v. vulgaris had 12.10%, Bambusa v. vittata had 16.30% and Bambusa heterostacya 11.41%. The least square difference for this experiment was 2.0145. This is lower than the 3.63 difference between the means of *B. v. vulgaris* and *B. v. vittata* which implies that the difference in the moisture contents of the two species is significant. However the difference is not as wide as the 6.18 between B. v. vittata and B. heterostachya which marks a significant difference in the mean moisture content of the two species. Coefficient of variance gives an indication of the pooled error in an experiment with values less than 20% considered as acceptable. The co-efficient of variance for the moisture content in this study is 4.14%, far lower than the acceptable 20% which confirms the reliability of the experiments carried out and the precision with which the treatments can be compared. The relevance of moisture content in biomass energy production is enormous. Since plants need water to survive, they usually contain a lot of water at harvest. In the combustion process, a lot of the heat energy that is derived from the burning of the biomass is used in the evaporation of this water (2444 kJ/kg of water at 25 °C) therefore reducing the Effective Heat Value (EHV) of the biomass (Vessia, 2006). The water in the biomass however needs to be evaporated before combustion can proceed. Lower moisture content at harvest is therefore desirable in biomass since it will reduce the energy needed for drying. The mean moisture content of these three species is 13.27% with a standard deviation of 2.55 which is relatively lower when compared with 35% to 44% found in five bamboo species in Laos (Dannenmann *et al*, 2007) and comparable to 8.42% to 22.61%

in three bamboo species in the U.S. (Scurlock, 2000). Of the three species in this study, *Bambusa heterostachya* has the lowest moisture content and is therefore more desirable as a biofuel for the combustion process. From Table 4.2 however, all three compete well with energy crops like *Miscanthus* and switchgrass.

4.1.2 Ash content

The results of ash content that were obtained for B. v. vulgaris (2.96%), B. v. vittata (2.45%) and *B. heterostachya* (1.2%) has a variance of 0.5178 with a co-efficient of variance of 7.96%. The variation in ash content of the three species is therefore quite small but statistically very significant even at 10% level of significance. Whiles that of B. v. vittata and B. v. vulgaris are quite close together, the ash content of *B. heterostachya* is almost twice lower than the other two and this is also shown in Figure 4.2. This will widely impact on the choice of species for the combustion process in energy generation. Low ash content is desirable in the combustion process therefore *B. heterostachya* shows more superior quality in relation to suitability for this purpose. Its value is close to that of softwoods (0.3%), hardwoods (0.45%) and hybrid poplar (0.51.5%) (Scurlock, 2000). Though that of B. v. vulgaris and B. v. vittata are higher, they compare favourably with the ash contents of energy crops like *Miscanthus* (1.5-4.5%) and switchgrass (4.5-5.8%) as can be seen from Table 4.2. The mean ash content for the three species is 2.17 with a standard deviation of 0.7196. This compares favourably with the 2.5% for bamboo in general but comparatively higher than that found for three *Phyllostachys spp* of bamboo that showed an ash content of less than 1% (Scurlock,

2000). It is, however, within the range of 1.91%-4.99% of five other bamboo species (Dannenmann *et al*, 2007). Also, compared to other biomass materials like cane (3.5%) and

bagasse (3.8%) and also coal (17.7%) all on dry basis (PHYLLIS), all three bamboo species can compare favourably as a biomass feedstock. The variance in the ash content values of *B*. *v. vulgaris* and *B. v. vittata* is 0.0584, giving them closer ash content values than that between *B. v. vulgaris* and *B. heterostachya* which 0.7313, the highest variation between any two species under study. The least significant difference analysis also confirms that the difference in the mean ash content values of *B v. vulgaris* and *B.*.

v. vittata is statistically insignificant. However the difference between *B. heterostachya* and the other two species far exceed the LSD, showing statistically significant differences in their ash contents. Figure 4.2 gives the ash content of several other biomass crops against which the three species under study compares with favourably.



Figure 4.2:Graphical representation of ash contents of various grasses and coal inPercentages(%). (values for miscanthus, switchgrass, cane, coal and bagassefromPHYLLIS database. B.v. vulgaris, B.v. vittata and B. heterostacya datafrom currentstudy.from current

4.1.3 Gross Calorific value

The heating value of woody materials is usually low and uniform with a range of 15-20 GJ/t. The calorific values of the three species in this study also fall within this range; 17.84 to 17.24 GJ/t. Analysis of variance shows that the variation in the calorific values of B. v. vulgaris (17.28 GJ/t), B. v. vittata (17.24 GJ/t) and B. heterostachya (17.84 GJ/t) is significant and hence the different species are significantly different in terms of their calorific values. The variance and standard deviation between the calorific values of B. v. vulgaris and B. v. vittata is small, 0.00057 and 0.02385 respectively. LSD analysis however shows that the difference in the mean calorific values of these species is statistically significant though by only a small margin. Whiles the LSD is 0.03, the difference in the mean of the two species was 0.04. However the differences between the mean calorific values of the two species compared with B. heterostachya is almost twice that. The difference between the means of B. v. vulgaris and B. heterostachya is 0.56 and between *B heterostachya* and *B. v. vittata* 0.6 The mean calorific value for the three species is 17.455 GJ/t which is low but close to the range for bamboo in general; 18.5-19.4 GJ/t. It is however closely at par with that of switchgrass (18 GJ/t) and miscanthus (17.94 GJ/t). Therefore these three species can be said to be good candidates as energy crops in terms of calorific value. It is an important factor in the selection of an energy source because it is a determinant of direct

heat value.

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	EthanolToluene extractives	Ethanol extractives	Hot-water extractives	Lignin Holocell	Cellulose ulose	
F-ratio	240.54	5.5	0.1349	1390.9	13.52	256.0615
Mean	5.15	7.37	1.62	27.47	42.00	71.53
Variance	8.2025	0.7756	0.0514	13.804	3.0408	5.88
Stan <mark>dard</mark> Deviation	2.864	0.8807	0.2267	3.72	1.74	2.42
Coefficient of Variance	1.03%	8.80%	7.47%	0.65%	1.86%	0.33%
Least Square Difference	1.22	2.062	2.2091	0.5721	2.47	0.7620

Table 4.5 Statistical data on wet c	chemical analysis of B. v.	vulgaris, B. v. vittata and B.
heterostachya .		



4.2 Biochemical Analysis

	Bambusa vulgaris vulgaris	Bambusa vulgaris vittata	Bambusa heterostachya	Miscanthus	Switchgrass	Bamboo
Compound				\cup .		
Lignin	22.06	29.4	30.92	17.0	13-20	24-26
Cellulose	44.33	40.67	41.33	44.0	44-51	41-49
Holocellulose	74.08	68.28	72.20	h.,	-	-
Hemicellulose	29.75	27.28	30.87	24	42-50	24-28
Extractives	9.8	12.4	19.3		17.0	

Table 4.4 : Chemical Analysis of the selected bamboo species and other energy crops.

Sources: Data for *B. v. vulgaris, B. v. vittata* and *B.heterostachya* from current study. Data for Miscanthus and switchgrass fromWorld watch Institute.Biomass database Data for Bamboo from Higuchi, 1957

4.2.1 Extractive content

Extractive content is a parameter that directly affects the heating value of a biomass (Demibras, 2002). The ethanol and toluene-ethanol soluble extractives are substances that do not form part of the integral structure of the bamboo material and are primarily the waxes, fats, resins, and some gums, as well as some water-soluble substances (Xiabo, 2004). Heating values increase with an increase in extractive content. According to Nemestothy (2008), the higher heating value of resins, oils and the other extractives in wood is around 38 MJ/kg. The percentage of extractives soluble in each solvent is given in Table 4.6. Analysis of variance shows that the variation in ethanoltoluene soluble extractives is very significant, implying the ethanol-toluene soluble extractives are very significantly different in the three species under study. The standard deviation between the values of *Bambusa v. vulgaris* and *Bambusa heterostachya* was the

highest at 3.3297 followed by that between B. heterostachya and Bambusa v. vittata at 2.6125. The standard deviation between B. v. vulgaris and B. v. vittata was however very low, 0.7628, indicating low variations in their ethanol-toluene soluble extractives. Treatment pair analysis shows that the difference in the means of B. v. vulgaris and B. v. vittata (1.45), which is slightly higher than the LSD value (1.22), is statistically significant. The means of *B. heterostachya* and B. v. vulgaris gave a difference 6.65, a value far in excess of the LSD value just like that between B. heterostachya and B. v. vittata which was high at 5.2. The differences in these pairs were therefore highly significant. Xiabo (2004) had 2.86-7.34 % for ethanol-toluene extractives of varying ages of *Phyllostachys pubescens* and Mahanim et al (2003) had 2.95 to 4.45% for two Gigantochloa species. The variations in the ethanol soluble extractives in the three species are statistically insignificant at 10% level of significance. However, on comparing pairs of treatments, the difference between *B.heterostachya* and *B. v. vulgaris* was found to be the only significantly different pair using LSD analysis. That means at that level of significance, the difference in ethanol soluble extractives in the three species is so insignificant that they can be assumed to be the same. Between B. v. vulgaris and B. heterostachya however, the standard deviation (1.0779) was about twice that between B. v. vulgaris and B. v. vittata as well as B. heterostachya and B. v. vittata. The overall difference in the hot water soluble extractives in the three species is statistically insignificant and confirms the null hypothesis, meaning that the difference in species does not influence the amount of hot water soluble extractives in the three bamboo species. This is further confirmed by LSD analysis performed on treatment pairs where the difference in all pairs of species proved to be statistically insignificant.

Variations between pairs of species were also low for all the combinations of species. *B. heterostachya* showed a higher level of extractives for all three solvents making it a more

desirable biofuel species in comparison to the other two. It is also higher than those of switchgrass which has 17.0 % as extractives (Table 4.3).

Species	Toluene- Ethanol soluble (%)	Ethanol Soluble (%)	Hot Water soluble (%)	B.heterostachya —9.1 8.4 1.8
B. v. vulgaris	2.1	6.3	1.4	4.2.2 Cellulose
It is <i>B. v. vittata</i> compound in bioma	3.8 ss because it is usual	7.3	the 1.7	major combustible
wood has a high hea	ting value of approxi	mately 19.5 M.	J/kg, though lowe	er than those of lignin
and extractives (Ne feedstock. However	mesthoty, 2008). He because of its highe	eating values for a second sec	or cellulose may	differ based on the nposition, the overall
calorific value tends	to hinge on the cellul	ose content. Hig	<mark>gh cellulose conte</mark>	ent is therefore needed
for a species to be a heterostachya which	a viable energy crop h have 39.0, 40.0 an	. In light of th d 38.1% of ce	is, <i>B. v. vulgaris</i> Ilulose respective	s, B. v. vittata and B. ely can be said to be
slightly lower than n	nost biomass that gen	erally contains	40- 50% cellulose	e (EERE, Nemesthoty
2008). The analysis species is insignifica	of variance shows the structure of variance shows the structure of the str	hat the variation el of 1% and ce	n in the cellulose ellulose can there	e content of the three fore be assumed to be
the same regardless	of the species. How	ever at 5% and	d 10% levels of	significance, the null
hypothesis is void significant. The star	and variations in ce	llulose content	due to the difference of <i>B</i> .	erences in species is <i>v. vulgaris</i> and <i>B. v.</i>
vittata was 1.734 wł	niles the variance was	3.0067. Least	Square Differenc	ce analysis shows that
the difference in th	e means of these tw	vo species is s	tatistically signif	ficant. The standard

Table 4.6: Proportion of Extractives in Bamboo in Different Solvents of extraction.

deviation and variance for *B. v. vulgaris* and *B. heterostachya* were 1.9389 and 3.7592 respectively. Treatment pair analysis using LSD showed significant difference in the means of the cellulose content of the two species. The standard deviation and variance of *B*. *heterostachya* and *B. v. vittata* however were quite low showing a low variation in the cellulose contents of the two species. This is confirmed by the least square difference analysis of the pair which shows that the difference in their mean values is statistically insignificant. The mean cellulose content of the three species is 42.0%, quite close to that of two *Gigantochloa* species with 46.14 to 56.45% (Mahanim *et al*, 2003) and 41.71-47.14% for *Phyllostachys* species (Xiabo, 2004).

4.2.3 Lignin

B. v. vulgaris showed a lignin content of 22.06%, *B. v. vittata* 29.42% and *B. heterostachya* 30.92%. Analysis of variance shows that the different lignin contents in all three species vary significantly from each other. In other words, lignin content variation among the three bamboo species is very relevant. Statistical analysis showed that the variation between the lignin content of *B. v. vulgaris* and *B. v. vittata* has a standard deviation of 1.734 and a variance of 3.0067. Based on the least square difference, the difference in the mean lignin content of the two species was found to be statistically significant. This was the same for the two species of *B. v. vulgaris* and *B. heterostachya* which had a higher difference between the difference in their means and the LSD value. The difference in their lignin contents is therefore very significant. Lignin contents of *B. v. vittata* and *B. heterostachya* also varied significantly and had a standard deviation of 0.7596 and a variance of 0.5769, the least values among the treatment pairs. The mean lignin value for the three species is 27.47% with a standard deviation of 3.72. This is comparable to that of several bamboo species (Table 4.5) and that of *Phyllostachys. bissetii*

(26.2-28.5%), *P. bambusoides* (24.3-27%) and *P. nigra* (25.2-28.5%)(Scurlock *et al*, 2000). The results are however higher than that of switchgrass (17%) and other grasses but slightly lower than wood. *B. heterostachya* has higher lignin content of the three species though only a little higher than *B. v. vittata*. This makes the former a desirable species as an energy crop. Studies have shown that for thermochemical conversion of biomass to energy, high lignin content is desirable though the extent of its effect is not well known (Boateng *et al*, 2008, Cassida *et al*, 2005).



1	No.	%Ethanol-	2	200	~	
	%ash	Benzene	%lignin	%celllulose	%pentosan	Total
Species		0	2		1	_
Ph <mark>yllostachys</mark> nigra	2.0	3.4	23.8	42.1	24.1	<mark>9</mark> 5.61
P.heterocyla	1.3	4.6	26.1	49.1	27.7	108.82
P.reticulata	1.9	3.4	25.3	41.0	26.5	98.15
Data from Higuchi (1	957)	SA	NE T	10 1		

Source: Scurlock, 2000

4.2.4 Holocellulose

It is made up of the alpha cellulose and hemicelluloses of the plant. Statistically, the variation in the holocellulose component of the three species is very significant. The holocellulose content therefore varies significantly from species to species. The coefficient of variation for holocellulose in this study was 0.33%, indicating a very small error in comparing treatments. The variance and standard deviation of the values of *B*.

v. vulgaris and *B. v. vittata* were the highest at 8.4625 and 2.909 respectively. The difference in the mean lignin values of the two species was statistically significant. The standard deviation and variance of *B. v. vulgaris* and *B heterostachya* were the lowest at 0.9158 and 0.8387 respectively. The LSD, which was 0.7620, however showed that the two treatments (species) vary significantly in terms of holocellulose content. *B. v. vittata* and *B heterostachya* have a standard deviation of 1.9734 among their values and a variation of 3.8942. The LSD analysis also proved that the difference in the lignin content of the two species was significant statistically. The mean of the holocellulose content of the three species in this study is 71.525% with a standard deviation of 2.42. This is comparable to the 63.14 to 71.95% found in *Phyllostacys spp* (Xiabo, 2004), 63.04-79.64% of two *Gigantochloa spp*, and those of the *Phyllostachys* species given in table 4.7. From Table 4.3, the holocellulose content of *Miscanthus* and switchgrass are lower than those of the three bamboo species under study.

4.2.5 Hemicellulose

Hemicellulose contains the same elements as cellulose but have shorter chains that also branches. These properties make them more readily combustible than cellulose. High concentrations of hemicelluloses are therefore desirable in plant species meant for the combustion process. *B. v. vulgaris, B. v. vittata* and *B. heterostachya* had 17.0, 19.0 and 24.9% respecively. Though that of *B. v. vulgaris* and *B. v. vittata* are slightly low, the hemicellulose content of *B.heterostachya* falls within the range of bamboo in general; 24-28%. This is also true of the three bamboo species shown in Table 4.7. Though that of miscanthus (24%) is in the same range, the hemicelluloses content of switchgrass (42-50%) is higher.

4.3 ULTIMATE ANALYSIS

Although the physical properties of biomass may be relatively uniform, the chemical element contents vary widely. In biofuel analysis, the six major elements; Carbon, Nitrogen, Hydrogen, Oxygen, Sulphur and Chlorine are tested for in the ultimate analysis to give their composition in the biomass. In this study the composition of all with the exception of Hydrogen and Oxygen were determined due to limited facilities.

Table 4.8 Results of ultimate and elemental analysis of *B. v. vulgaris*, *B. v. vittata* and *B. heterostachya*.

Ultimate analysis (% dry matter)

	B. vulgaris	B.vittata	B. heterostachya
_	48.5	49.0	48.5
3	0.79	0.40	0.49
1950	Trace	Trace	Trace
1	0.16	0.12	0.20
	WJSANE	NO	>

Elemental analysis

Pb (ppm)	5.0	4.33	2.33

Fe (ppm)	33.83	33.00	33.33	
K (%)	0.21	0.07	0.07	
P (%)	0.13	0.05	0.03	
		107		

4.3.1 Carbon

The carbon content found in the three species were 48.5, 49.0 and 48.5% for *B. v. vulgaris, B. v. vittata* and *B. heterostachya* respectively. These fall within the close range of 48.5% to 50% on dry basis for bamboo (Nemestothy, 2002). This is also at par with most biomass materials with an estimated average of 45-55% carbon content (Vessia, 2006). The three *Phyllostachys* species Scurlock *et al* worked on had a carbon content of 50.58% to 52.28%. Coal has 49.8% carbon content; *Miscanthus* has 47.9%, bagasse 45.9%, switchgrass 47.8% and cane 47.7% all on dry basis (PHYLLIS). Carbon is the major constituent of biomass and its combustion increases the heating value therefore high carbon content is desirable in biofuels.

4.3.2 Nitrogen

The nitrogen content of the three species showed a marked difference between *Bambusa v. vulgaris* which had 0.79% as compared with *Bambusa v. vittata* and *Bambusa heterostachya* which had 0.40% and 0.49% on dry basis respectively. Three *Phyllostachys spp* of the bamboo family also have a nitrogen content of 0.21% to 0.60% Scurlock *et al*, 2000). C,ane has 0.5%, *Mi,scanthus* has 0.54%, coal has 1%, 1.73% for bagasse and switchgrass 1.17% on dry basis (PHYLLIS). *Bambusa v. vittata* and *Bambusa heterostachii* have comparatively lower nitrogen content than *Bambusa v. vulgaris*. A lower nitrogen content in biomass is desirable. During

combustion, the nitrogen present combines with oxygen to form oxides of nitrogen. The problem of nitrous oxides from biomass combustion has been the source of research and worry for both environmental researchers and policy makers. Nitrous oxides are said to have almost the same climate warming effect as carbon dioxide. Therefore, as we push towards biomass to reduce carbon dioxide released into the atmosphere, we inadvertently introduce another source of environmentally unfriendly gas, which according to scientists is a more powerful greenhouse gas than carbon dioxide. This was a research finding from a group of scientist including Paul Crutzen, a Nobel Prize winner (Smith, 2007). The relatively lower nitrogen contents of the two test species is therefore a very promising quality as a biofuel especially in the combustion process.

4.3.3 Chlorine

The chlorine content of the three bamboo species is relatively low. Scurlock *et al*, (1999), found that the three *Phyllostachys* species they worked on had a chlorine content ranging from 0.002% to 0.34% and these were quite acceptable in biomass systems. With chlorine contents of 0.16, 0.12 and 0.20% respectively, *B. v. vulgaris*, *B.*

v. vittata and *B. heterostachii* have appreciably lower values that makes them good feedstock candidates when compared with Miscanthus which has 0.18% and Cane 0.292% (PHYLLIS). Chlorine affects high temperature corrosion of boilers and low contents are desirable in biomass feedstock meant for systems producing electricity (Scurlock *et al*, 1999).

4.3.4 Sulphur

Only traces of sulphur were detected in all three species under study in this research which makes them more promising than switchgrass which has 0.12% (McLaughlin *et al*, 1996) and

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miscanthus 0.1% (Scurlock, 1999). This is because sulphur is an undesirable element in biofuels and especially in the combustion process. According to Filho and Badr (2004), bamboo generally has lower nitrogen and sulphur contents compared with coal and other fossil fuels thereby leading to the release of minimal amounts of their oxides on combustion. Since their oxides are environmental pollutants, this is a desirable characteristic in bamboo in the combustion process. Their oxides are also corrosive and cause problems in boilers.

4.3.5 Ash analysis

The potassium, phosphorus, lead and iron contents of the three species were analysed. The ash content of three *Phyllostachys spp* studied by Scurlock *et al*, (2000) contained 0.158-0.475 % of potassium in the form of oxide (dry matter) compared to 0.07 to 0.21% of the three *Bambusa* species under study. This is also lower than most biomass and grasses (Scurlock *et al*, 2000). Potassium and other alkali metals are used to measure the alkali index of the ashes produced by a biomass. Lower alkali content is desirable in a biomass destined for combustion and all three species had relatively low values. Concentrations of the heavy metals lead and iron are small; 33.00-33.83 ppm for iron and 2.33-5.0 ppm for lead.

4.4 PRODUCTIVITY AND COST OF BAMBOO PRODUCTION.

From the tilling of the land, planting, maintenance and lopping, about 350 Ghana Cedis may be required in the forest areas to plant one hectare of bamboo. Use of machines for felling may raise the cost to about 400 Ghana Cedis per hectare (Personal communication, Mr Lyndar Sanchebe, Subri Plantations, 2007). About 500 to 100 culms can be grown per hectare based on the spacing which is dictated by the species and its crowning characteristics. The basic planting spaces are 5 m x 5 m and 7 m x 7 m. Each culm can have about three offshoots per

year. This means that the number of bamboo culms planted may triple every year. Therefore a minimum of about 300 culms may be gained per year.

CHAPTER FIVE 5.0 CONCLUSIONS AND RECOMMENDATIONS

The three main attributes of fuels that determine their suitability for combustion or gasification are moisture content, total energy content and the ash content. The chemistry of the ash produced is also important (Mclaughlin et al, 1996). Based on the above parameters, there is a great potential for bamboo as an energy crop. Although the heating value of bamboo is lower than most liquid fuels and woody biomass feedstocks, it is in turn higher than most grasses and agricultural residues which are under consideration and being used as bioenergy sources. For all three species, these three parameters were comparable with all other biofuels already in the system. Comparatively lower moisture content, low ash content and reasonable calorific values qualifies them all as good bioenergy crops. The results show that although all three species have the potential for successful use in combustion or gasification processes as fuel crops, the exotic species *B.heterostachya* stands out as the most suitable species for combustion whiles the native species B. v. vulgaris and B. v. vittata showed inferior fuel characteristics in terms of combustion. B. heterostachya had a higher calorific value, lower moisture content and lower ash content and all these properties varied significantly among the species. With the exception of hot water extractives, all other parameters studied-cellulose, holocellulose, lignin, ethanoltoluene and ethanol extractives- showed significant differences between the three species. The ash content and chemistry are also suitable for use in boilers. The three Bambusa species have therefore proved to be equal or better when compared with other biomass species in Europe and U.S.A that are being used for the production of electricity and other energy sources

Bamboo shows differing chracteristics along the length of the culm and with age. This study was conducted on a whole culm basis on bamboo of the same species. Further studies therefore need to be carried out to determine the variation of fuel properties along the upper, middle and lower portions of the culm as well as among different ages preferably of the same species of bamboo used in this study. A follow up to this can be done by determining the volume of bamboo culms needed to produce certain quantities of energy in existing combustion systems. Because of the superior fuel characteristics shown by *B. heterostachya*; the only imported species in this study, other exotic species that have been introduced and are doing well silviculturally can be investigated. Other indirectly related studies that need to be done are the measurement of growth rate of bamboo in different parts of the country.



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APPENDICES

Species	Initial weight (g)	Final weight (g)	Percentage of moisture (%)
Bambusa v. vulgaris	2.02	1.80	12.22
Bambusa v. vittata	2.08	1.80	15.55
Bambusa heterostacya	2.03	1.85	9.73
	6.	1.4	

Appendix 1 (a): Determination of Moisture content (Test 1)

Appendix 1 (b): Determination of Moisture content (Test 2)

Species	Initial weight (g)	Final weight (g)	Percentage of moisture (%)
-	A.		111
Bambusa v. vulgaris	2.06	1.83	12.56
Bambusa v. vittata	2.05	1.76	16.48
Bambusa	2.10	1.91	9.95
heterostacya		22.27	
THE	culation of Average I	M	J.
Species	Average Ca	lculation A	verage Moisture Content (%)
	W JS	ANE NO	-
Bambusa v. vulgaris	(12.22 + 12.	.56) x1/2	12.39
Bambusa v. vittata	(15.55 + 16)	.48) x 1/2	16.02

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Appendix 2 (a). Deter	Appendix 2 (a). Determination of Ash Content (Test 1)					
Species	Initial weight (g)	Final weight (g)	Percentage of ash			
1			(%)			
Bambusa v. vulgaris	2.04	1.98	3.0			
Bambusa v. vittata	2.10	2.05	2.4			
Bambusa heterostachya	2.01	1.99	1.0			

Appendix 2 (a) : Determination of Ash Content (Test 1)

Appendix 2 (b): Dete	n of Ash con	tent (Test 2)	
Species	minati weight(g)	Final weight (g)	Percentage of
1	Initial		ash(%)
Bambusa v. vulgaris	2.12	2.06	2.91
Bambusa v. vittata	2.05	2.00	2.50
Bambusa 🛛 👘	2.13	2.10	1.40
heterosta <mark>chya</mark>	SEI		353

Appendix 2 (c) :	Sec. 7	
Calculatio	n of Ash content	
Species	Calculation of Average	Average Ash content
	111	
		(%)
Bamb <mark>usa v. vu</mark> lgaris	$(3.0 + 2.91) \times \frac{1}{2}$	2.96
Bambu <mark>sa v. vitta</mark> ta	$(2.4 + 2.5) \times \frac{1}{2}$	2.45
Bambusa <mark>heterostach</mark> ya	$(1.0 + 1.4) \times \frac{1}{2}$	1.20

Appendix 3: Determination of Gross Calorific value

9,0

Species	Calorific value	Calorific value	Calculation of	Average Gross
	(Test 1)	(Test 2)	Calorific value	calorific
				value(GJ/t)

- 14

Bambusa v.	17.28	17.29	(17.28+17.29)1/2	17.29
vulgaris				

Bambusa v. 17.23 17.25 (17.23+17.25)1/2 17.56 vittata

Bambusa 17.84 19.84 (17.84+17.84)1/2 17.84 heterostacya

- 1

1.1

Appendix 4 (a): I	Appendix 4 (a): Determination of Ethanol-Toluene soluble extractives (Test 1)					
Species	Initial weight(g)	Final wei (g)	ght	Weight of extractives (g)	Percentage of extractives (%)	
Bambusa v. vulgaris	13.35	13.00	1	0.35	2.6	
Bambusa v.	12.50	12.05	0.45	3.6 <i>vitt</i>	ata	
Bambusa	12.92	11.77	1.15	8.9 het	erostacya	

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1.15

Species	Initial Weight(g)	Final weight (g)	Weight of extractives (g)	Percentage of extractives (%)
Bambusa v.vulgaris	13.20	12.9	0.3	2.3
<i>Bambu<mark>sa</mark> 12.0</i> 0 11.	5 0.5 4.2 v.vittat	a	<	13
(Fr	12.8	11.61	1.19	9.3
Bambusa heterosta	исуа		E al	2/

Appendix 4 (c): Calculation of Ethanol-Toluene soluble extractives.

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Species

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Average percentage (%)

Bambusa v. vulgar	ris	(2.6 + 2.3) x 1/2	2.5	5	
Bambusa v. vit	ttata	(3.6 + 4.2) x 1/2		3.9	
Bambusa heterosta	асуа	(8.7 + 9.3) x 1/2	9.0 Ap	pendix 5 (a):
Determination of I	Ethanol soluble	e Extractives (Test 1)	1.00	-	
Species	Initial weight(g)	Final weight (g)	Weight of extractives (g)	Percentage of extractives (%)	
Bambusa v. vulgaris	13.35	12.52	0.83	6.2	
Bambusa v.	11.50	10.66 0.84	7.3 vit	tata	
	11.70	10.72	0.98	8.4	
Bambusa heterosta	асуа				
	5	100	1 A		
	5			B	
Appendix 5 (b): L	Determination of	of Ethanol soluble Ex	tractives (Test 2)	1	
Species	Initial	Final weight	Weight of	Percentage of	
	weight(g)	(g)	extractives (g)	extractives (%)	
Bambusa vulgaris	12.95	12.12	0.83	6.4	
Bambusa vittata	13.00	12.04	0.96	7.4	
Bambusa	11.00	10.08	1.01	9.5	
neterostacya	11.90	10.70	1.01	0.5	
5	(c):Calculation	on of ethanol soluble	20		
,	extractiv	es.	NO		
Species		Average	Average ethanol so	e percentage of luble extractives (%)	
Bambusa v. vulgar	ris	(6.2 + 6.4) x 1/2		6.3	

Bambusa v. vittata	(7.3 + 7.4) x ¹ / ₂	7.4
Bambusa heterostacya	(8.3 + 8.4) x 1/2	8.4

Appendix 6 (a): Determination of Hot water soluble extractives (Test 1)				
Species	Initial weight(g)	Final weight (g)	Weight of extractives (g)	Percentage of extractives (%)
Bambusa v. vulgaris	12.40	12.23	0.17	1.4
Bambusa v. vittata	11.50	11.30	0.20	1.7
Rambusa hatarost	11.20	11.02	0.18	1.6

Appendix 6 (b): Determination of Hot water soluble extractives (Test 2)				
Species	Initial weight(g)	Final weight (g)	Weight of extractives (g)	Percentage of extractives (%)
Bambusa v. vulgaris	11.90	11.75	0.15	1.3
Bambusa v. 1.7		Vittata	12.30	12.10 0.20
Bambusa heterostacya	11.40	11.17	0.23	2.0
TONE SAD				
Appendix 6 (c): Calculation of Hot water soluble extractives				

SpeciesAverage calculationAverage percentage (%)

Bambusa v. vulgaris	· · ·		<u> </u>	
	(1.4 + 1)	.3) x 1/2	1.4	
Bambusa v. vittat	a (17+1	7) $\times 1/2$	17	
	(1.7 + 1)	./) X 1/2	1.7	
	(1.8 + 2	2.0) x 1/2	1.9	
Bambusa heteros	tacya	1U5		
7 (a): Determination	of Lignin (Test 1)			
Species	Initial weight (g)	Weight of lignin (g) (oven dried)	Percentage of lignin (%)	
Bambusa v. vulgaris	1.113	0.244	21.92	
Bambusa v. vittata	1.040	0.306	29.42	
Bambusa hete <mark>rostacya</mark>	1.021	0.314	30.75	
		VZ	TES	
Appendix 7 (b).	mination of Lignin (T	est 2)	F.	
<u>Deter</u> Species	Initial weight (g)	Weight of lignin (g) (oven dried)	Percentage of lignin (%)	
Bambusa v. vulgaris	1.117	0.248	22.20	
Bambus <mark>a v. vittat</mark> a	1.040	0.306	29.42	
Bambusa heterostacya	1.023	0.318	31.09	
	WJSI	ANE NO	5	

Appendix 7 (c): Calculation of lignin content.

Species	Calculation of Averages	Percentage of lignin (%)
Bambusa v. vulgaris	(21.92 + 22.20) x 1/2	22.06
Bambusa v. vittata	(29.42 + 29.42) x 1/2	29.42
Bambusa heterostacya	(30.75 + 31.09) x 1/2	30.92

Appendix 8 (a): Determination of cellulose (Test 1)

Species	Initial weight (g)	Final weight (g)	Percentage of cellulose (%)
Bambusa v. vulgaris	1.5	0.656	43.73
Bambusa v. vittata	1.5	0.620	41.33
Bambusa heterostacya	1.5	0.600	40.00

Species	Initial weight (g)	Final weight (g)	Percentage of Cellulose (%)	
Bambusa v. vulgaris	1.5	0.674	44.93	
Bambusa v. vittata	1.5	0.610	40.67	
Bambusa heterostacya	1.5	0.620	41.33	

Appendix 8 (c) : Calculation of cellulose				
	Calculation of Averages	Percentage of cellulose		
Species		(%)		
	(43.73 + 44.93) x 1/2			
Bambusa v. vulgaris		44.33		
Bambusa v. vittata	$(41.33 + 40.67) \times 1/2$	41.00		
		11.00		
Bambusa heterostacya	$(40.00 + 41.33) \times 1/2$	40.67		
v				

Appendix 9 (a): Determination of holocellulose (Test 1)

Species	Initial weight (g)	Final weight (g)	Percentage of holocellulose (%)
Bambusa v. vulgaris	2.0	1.482	74.10
Bambusa v. vittata	2.0	1.360	68.00
Bambusa heterostacya	2.0	1.446	72.30

Appendix 9 (b): Determi	nation of holocellu	llose (Test 2)	1
Species Ir	iitial weight (g)	Final weight (g)	Percentage of holocellulose (%)
~	1	1.481	0
Bambusa v. vulgaris	2.0	NE NO	74.06
Bambusa v. vittata	a 2.0	UNE .	
		1.371	68.55
Bambusa			
heterostacya	2.0	1.442	72.10

Appendix 9	(c): Calculation	of holocellulose
rippondin j	\mathbf{v}). Culculution	or morecentarose

	Calculation of Averages	Percentage of holocellulose
Species		(%)
		5
Bambusa v. vulgaris	(74.10 + 74.06) x ¹ / ₂	74.08
Bambusa v. vittata	$(68.00 + 68.55) \times 1/2$	68.28
Bambusa heterostacya	(72.30 + 72.10) x 1/2	72.2
	SV. 11	

Appendix 10: Calculation of Hemicellulose

Species	Calculation of	Percentage of	
	Hemicellulose	hemicellulose	-
Bambusa v. vulgaris		An 1	
	(74.08 - 44.33)	29.75	
Bambusa v. vittata		R/Ft	8
-	(68.28 - 41.00)	27.28	
Bambusa heterostacya			
	(72.20 – 40.67)	31.53	
	That	175	
	- man of		

Appendix 11 : A	NOVA of Moistur	e Content		
Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation		freedom	squares	151
X	38.1956	2	<mark>19.09</mark> 78	68.67 <mark>24</mark>
Treatment	1 2		and the second sec	551
10	An	3		58
Error	0.8343		0.2781	
	- Hu			
Total	39.0299	SANE	7.806	

Appendix 12: ANOVA of Ash Content

Sources of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F-ratio or F _o
Treatment	3.0193	2	1.50965	51.55
Error	0.08785	3	0.0293	Г
Total	3.1072	5	15.536	

Appendix 13: ANOVA of Calorific value

Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation		freedom	squares	
Treatment	0.4467	2	0.2234	2690
Error	0.00025	3	0.000083	
Total	0.44695	5	0.08939	

Appendix 14: ANOVA of Cellulose

Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation	1	freedom	squares	
Treatment	16.4222	2	8.2112	13.5185
Error	1.8223	3	0.6074	
Total	18.2445	5	3.6489	1

Appendix 15:	A JOVA of Lignin		~	St.
Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation	- Hi	freedom	squares	
Treatment	89.94613	2 SANE	44.9731	1390.9197
Error	0.097	3	0.0323	

Total 90.0431 5	18.0086
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Appendix	16: AN	OVA of	Holocellulose
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Sources of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F-ratio or F _o
Treatment	29.369	2	14.6845	1.181692
Error	0.17205	3	0.05735	
Total	29.5423	5	5.90846	

Appendix 17: ANOVA of Ethanol-Toluene

Sources of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F-ratio or F _o
Treatment	/8 91	2	24.455	240.54
Treatment	10.71	ER	24.435	210.51
Error	0.305	3	0.102	2
Total	49.215	5	9.843	

Appendix 18: ANOVA of Ethanol

Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation		freedom	squares	
Treatment	4.62	2	2.31	5.5
Error	1.27 5.89	3	0.42	AN AN
Total	PR	5	1.178	
	ZW	SANE	NOY	

Appendix 19: A JOVA of Hot water

Sources of	Sum of squares	Degrees of	Mean sum of	F-ratio or F _o
variation		freedom	squares	

