

# **Energy Estimation and Analysis of Agricultural Biomass Species & Land Requirement Calculation for 20000 kWh/day Power Plant**

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**ABSTRACT:** With global fossil energy sources depletion, there is a vast need to develop the alternative sources of energy. If the country wants to meet its energy demand, to depend less on importing energy and to minimize greenhouse gas effect and to keep environment safe then it should use renewable energy sources. Other Renewable sources of energy such as Wind energy, Solar energy developing with subjecting pace. But, as their availability at all instances is not considered possible. Biomass considered as an important source of power production due to its wide availability. Among all the renewable energy sources biomass is an important source of power generation due to its abundant availability. In the present work, the biomass from agricultural plant residues of different species is taken from locally available fields in Andhra Pradesh such as dried cotton (*Gossypium*), Red gram (*Cajanus Cajan*), Groundnut (*Arachis Hypogaea*) husk, Maize (*Zea Mays*) and Green Gram (*Vigna Radiata*). By using all the available scientific equipment and methods, the Calorific values, Volatile matter content, the amount of Ash per unit mass of Biomass of each species and Ash fusion temperatures are also determined. The area of land required to produce Biomass for 20000 kWh/day of energy generation for 15 villages is also estimated.

**KEYWORDS:** Text Alternative sources, Agricultural plant residues, Calorific values, Proximate analysis, Land requirement and Energy generation for 15 villages.

## **I. INTRODUCTION**

**Importance of Agricultural Biomass:**

In India, more than 67.1% of the electricity is produced power plants fired by fossil fuels. With limited availability of coal, the future energy demand may suffer. So for the security of future energy supply, the alternate power source is essential. As conventional fuels are limited and emit maximum amount of greenhouse gasses to the atmosphere, it should be minimized or replaced by other energy sources. Biomass can be the most promising energy source due to its wide availability. The current availability of biomass in India is estimated at about 650 MMT per year. The annual potential to produce clean energy from Biomass from agricultural, forestry and bagasse from sugar mills is about 23,000 MW. Currently, India's energy from biomass is very mediocre, annual capacity of 4833.33 MW is produced. Hence there is a lot of scope to install energy plants based on biomass. By evaluating energy values from each species and proper proximate analysis, agricultural species with most calorific value may be used as replacement of low grade coal as well.

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## II. LITERATURE SURVEY

[1] Authors Narsimhulu Sanke, Dr. D.N. Reddy reported that biomass fuels can be used in gasifier without changing its orientation and technology. The conversion of gasification is by thermo chemical reactions of a fuel with oxidizer under sub-stoichiometric conditions, the energy in biomass being realized in the form of combustible gases. [2] Author Dora Sarfo reported that Bamboo can be used as a source of bioenergy livestock. The native tree species of Ghana *Bambusa v. Vulgaris* and *V. Vittara* tested for fuel properties. Test were carried in a combustion chamber with 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 content were done their energy values were also compared with energy crops such as *Miscanthus x giganteus* and *Panicum virgatum*. [3] Authors A. Sharma, E. Terrell, C.S. Theegala experimented on the Biomass gasification of plant biomass products include Feedstocks were Pine, hardwood pellets, chipped bark, alfalfa, switchgrass, sugarcane bagasse, corn, dairy manure and poultry litter. Results were generated by using High heat value ASTM test, moisture content by ASTM D4442-07 standard test method and ash content was determined by using ASTM 2007a method. [4] Authors J.P.Yadav, Bharat Raj Singh primarily relied on the rice husk for replacing the fuel used in rice mill. Here coal and rice husk mixed and used as fuel. They determined the Calorific value and boiler efficiency. Concluded that 32.139 MJ/kg and 15.217 MJ/kg are the calorific values of coal and husk. [5] Authors Melchor C. Maranam, Marie-Pierre Laborie used direct combustion and conversion into cellulose ethanol for optimizing bioenergy production. Infrared spectroscopy for determining the chemical composition is used and co-relation between wood composition and energy values were established. [6] Shoaib Mehmood, Bale V. Reddy, Hossam Gabbar are the authors who investigated impacts of biomass co-firing system performance and gaseous emissions. The proximate analysis was done on the selected biomass species. System performance at different parameters for different combinations of fuel at two co-firing conditions was determined. [7] Author Anil K. Rajvanshi mainly concentrated to detect flaws in the current status of gasification technology. By vast testing he stated that coal and wooden biomass the most preferred fuels for gasification. [8] Author Melese Tesfaye Firrisa reported the calorific values of rapeseed for different locations in EU and also estimated the total crop residue and seed production per hectare of land in multiple geographical regions. [9] Author Baburaj Kanagarajan reported the bulk densities of different agricultural crops and its impact on the economical transportation to the power plant. He refer that biomass fuels require more space for storage and given data about mass per energy of Rye and alfalfa crops. [10] Authors Ezekiel Kiptoo Kipyego, Dr. P.N. Kioni reported the combustion characteristics of Macadamia nut shells by grounding shells to standard mesh size -72. The analysis determined it has a higher heating value of 21.12 M/kg, 72.1% volatile matter, 13.1% of moisture content and 1.6% of ash with 800°C as combustion chamber temperature. [11] Thomas Johannes Hugo, J.H. Knoetze and J.F. Gorgens were authors studied Thermochemical upgrading of Sugarcane bagasse. They identified the optimal decomposition temperatures for hemicellulose and cellulose were identifies as 290° C and 345° C respectively. [12] V. Alderucci, A. Giordano, A. Iovino, N. Giordano and V.D. Phillips were authors conducted studies on the biomass available in Hawaiian Islands, Results indicate that of Sicily biomass has  $236 \times 10^6$  total annual energy requirement.

## III. PRESENT WORK, APPARATUS AND PROCEDURE

For the present project work, 2 different components (new branch, main branch, cobs of Maize and shell husk of Groundnut) were taken from residues of five agricultural plant species of most grown varieties in Andhra Pradesh were taken. These plant species are *G. Hirsutum* variety (local name: Cotton), *Cajanus* variety MRG 66 (local name: Red gram), *Zea Mays* variety DHM 103 (local name: Maize), *Arachis Hypogaea* variety Kadiri-4 or K-150 (local name- groundnut) and *Vigna radiata* variety LAM M2 (local name: Green gram). Considering all the components of selected biomass samples were taken for proximate analysis and Calorific value determination. By keeping these samples sun dried at fields and kept a cross-ventilated room for 20-30 days, the equilibrium in moisture contents of these components was attained. Before experimental work dried samples were grinded into powder. Proximate analysis is deemed for characterizing biomass samples. The quantitative analysis of the distribution of constituent products obtained when the sample is heated under designated conditions is called proximate analysis. As

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per ASTM test, proximate analysis separates the constituents into four categories: a) Moisture, b) Ash, c) Volatile matter and d) Fixed carbon.

Moisture content determination: One gram of each -72 mesh size samples was air dried and then were taken in shallow silica disc and put in a muffle furnace which is shown in Fig. 3.1. The temperature inside muffle furnace was maintained at 785 - 800 °C. The muffle furnace used for this experiment have a measuring range of temperature 0-1100 °C with a resolution of 1 °C and accuracy of  $\pm 5$  °C . The biomass samples were kept in maintained temperature in the muffle furnace and heated till their complete combustion usually half an hour. Then the residues obtained were measured with the help of electronic balance for each sample and expressed in a percentage similar to moisture content.

Determination of Volatile matter: One gram of air dried powdered sample of size -72 mesh was taken in a volatile matter crucible (made of silica) and kept in the muffle furnace maintained at the required temperature of 900°C. The sample was soaked at this temperature for seven minutes and then crucible was taken out from the furnace and cooled in air. Weight loss in the sample was recorded by using an electronic balance having a sensitivity of 0.001grams. The percentage loss in weight – moisture present in the sample gives the volatile matter content in the sample.

$$\text{Volatile Matter (wt.\%)} = \% \text{ loss in weight (wt.\%)} - \text{moisture content (wt.\%)}$$

Calculation of fixed carbon content: The value of fixed carbon content can be calculated by subtracting the aggregate percentages of moisture, volatile matter and ash from 100. Fixed carbon content is the quantity of solid carbon residue that remains after the combustion of the sample with the removal of volatile matter. The value of fixed carbon content helps for evaluating the productivity of biomass fuel. At lower combustion temperature it improves reactivity of fuel.

$$\text{Fixed Carbon Content (Wt. \%)} = 100 - \text{Wt \% ( Moisture + Volatile matter + Ash)}$$

Calorific value determination: The calorific values of the biomass samples were measured in a Bomb calorimeter apparatus by the method outlined in reference. In this test an over dried sample briquette of weight 1gm (approx.) was taken in a bomb and oxygen gas was filled into this bomb at a pressure of 25-30 atm. The sample was then fixed inside the bomb and rise in temperature of water was noted with the help of Thermometer.

$$\text{Gross Calorific value} = (\text{W.E X T}) / \text{W}_0 - (\text{fuse wire} + \text{thread connections})$$

Where, W.E = Water equivalent of apparatus

T = Maximum rise in temperature in ° C

W<sub>0</sub> = Initial weight of briquette sample.

Ash fusion temperature determination: Ash fusion temperature plays a significant role in selection of fuel because at high-temperature fuel ash creates slag better known as clinker. That can pose a mechanical problem in combustion process associated with the boiler which largely influences boiler design and efficiency. Deposition of ash at high-temperature region causes slagging and fouling problems in the boiler. Hence, ash fusion temperature determination plays a crucial role in the selection of fuel which includes i) Initial deformation temperature (IDT), ii) Softening temperature (ST), iii) Hemispherical temperature (HT). IDT is the temperature, at which first change in shape occurs and the temperature at which the sample starts shrinking and the corners of the sample melt is called ST and the temperature at which the cubical sample becomes hemispherical in shape is called HT. The Ash fusion Temperature, softening Temperature, Hemispherical temperature and Flow temperature) of all the ash samples, obtained from the presently selected non-woody biomass species were determined by using Leitz Heating Microscope.

Determining Bulk densities: The bulk density of fuel gives an idea about the weight of that fuel to be provided sufficiently in a given volume of the boiler. It influences the transportation and storage costs largely. The combustion devices also largely influenced by bulk density. Higher, the bulk density lesser, will be the transportation cost. It is expressed as the weight per unit volume of material, expressed in kg/cubic meter. The bulk densities of the biomass samples were calculated according to the ASTM E873-82 standard. Each biomass sample of -72 mesh size powder was taken in a cubic container of dimension 65mm × 65 mm × 65 mm made of mild steel. Each sample was fully packed in the container and leveled at the top surface. The weight of the samples filled in the container was measured with the

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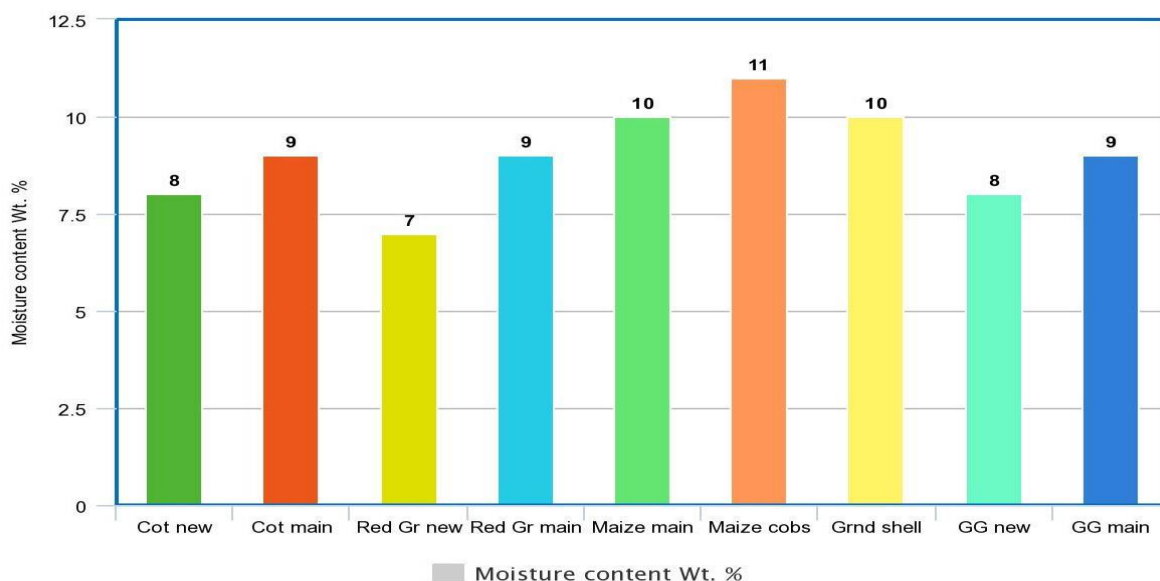
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help of electronic balance of sensitivity 0.01gm. Then bulk density was calculated by the weight obtained from electronic balance and initially measured dimension of the container.

$$\text{Bulk Density} = \text{Wt. of the sample packed in container (kg)} / \text{Volume of the container (m}^3\text{)}$$

## IV. EXPERIMENTAL RESULTS

Proximate Analysis Results: : It is found that the moisture content of corn cobs is highest (11 Wt. %) followed by Corn main branch and Groundnut shell husk (10 Wt. %). The Red Gram possess lowest moisture content of about 7 Wt. %. The moisture samples of other Biomass samples were also compared. The moisture content of the agricultural biomass has several factors influencing on them including the cross winds of the room in which they are stored, humidity in the air and time period of drying in number of days as well.



Graph 1 shows Moisture content of agricultural biomass species

The Ash content of the groundnut shell husk is highest among the rest (11 Wt. %), while cotton possess the lowest ash when compared with all the other agricultural biomass species (4.97 Wt. % for new branch and 5.1 Wt. % for the main branch respectively). Green gram (GG) plant also gave some interesting results in which its ash content Wt. % are as low as Cotton stacks from the below graph (Green gram new branch 5.6 Wt. % and Main branch has 6.1 Wt. %). Red Gram and maize cobs has ash content from 7 to 8.5 Wt. % from the graph 2.

The Volatile matter content of Red Gram main branch is highest (74 Wt. %) and Groundnut shell husk has the lowest with 63 Wt. %. Most of the plant species have similar volatile matter content with very close averages per each test cycle. Cotton has the second highest amount of Volatile matter after Red gram main branch (Cotton main new branch 71 Wt. % and Main branch 72.19 Wt. %).

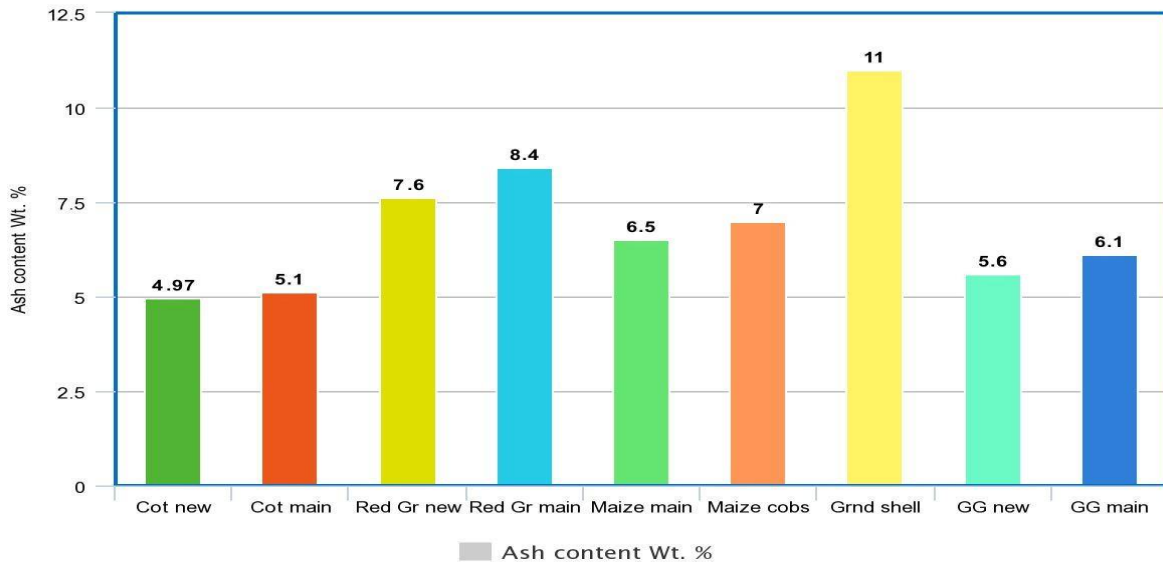
Fixed carbon is the solid combustible residue that remains after a biomass specimen is heated and the volatile matter is expelled. The fixed carbon content of the Green gram new branch and main branch is highest (22.9 Wt. % for new branch and 22 Wt. % for main branch).

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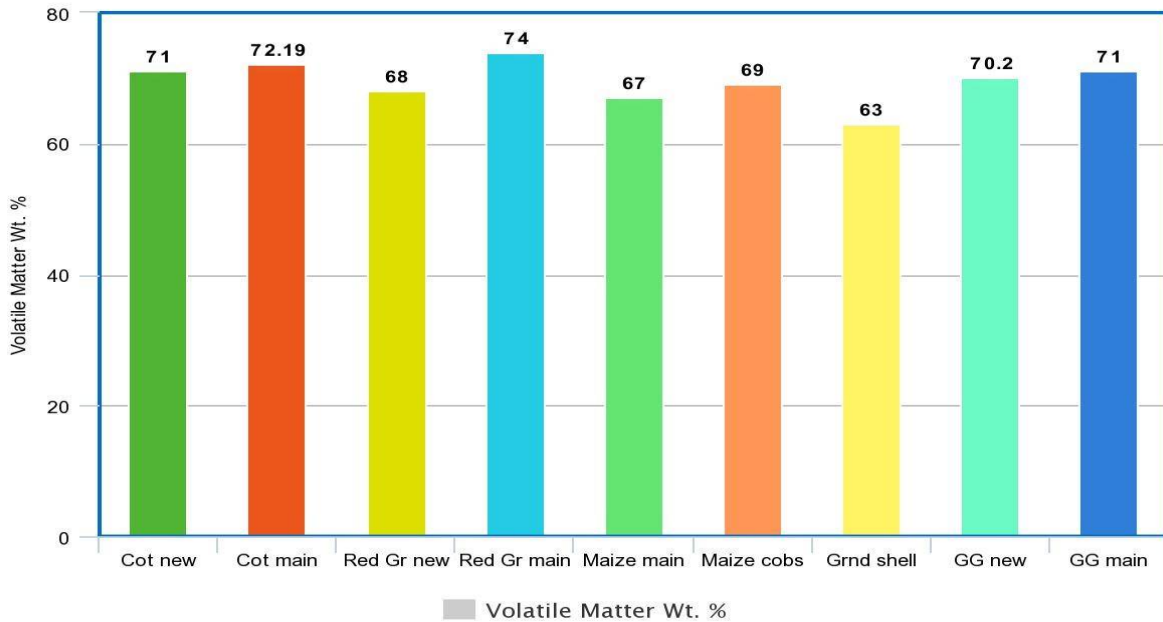
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Graph 2 shows Ash content of Agricultural biomass species



Graph 3 shows Volatile matter content of agricultural biomass

Red gram and Maize have similar fixed carbon content. Red gram new branch has 13.2 Wt. % and main branch has about 12.3 Wt. %. Maize has least fixed carbon values compared with other. (Maize main branch 12.21 Wt. % and Maize cobs have 12.9 Wt. %) from graph.

The Heating Value determines how much fuel is required in the power plant. Higher the Calorific Value lesser the amount of the coal required per unit of Electricity. Higher Calorific value also means the lower cost of logistics, storage and ash disposal. Moisture is the main factor that influences the Calorific value of the fuel. The moisture is in two

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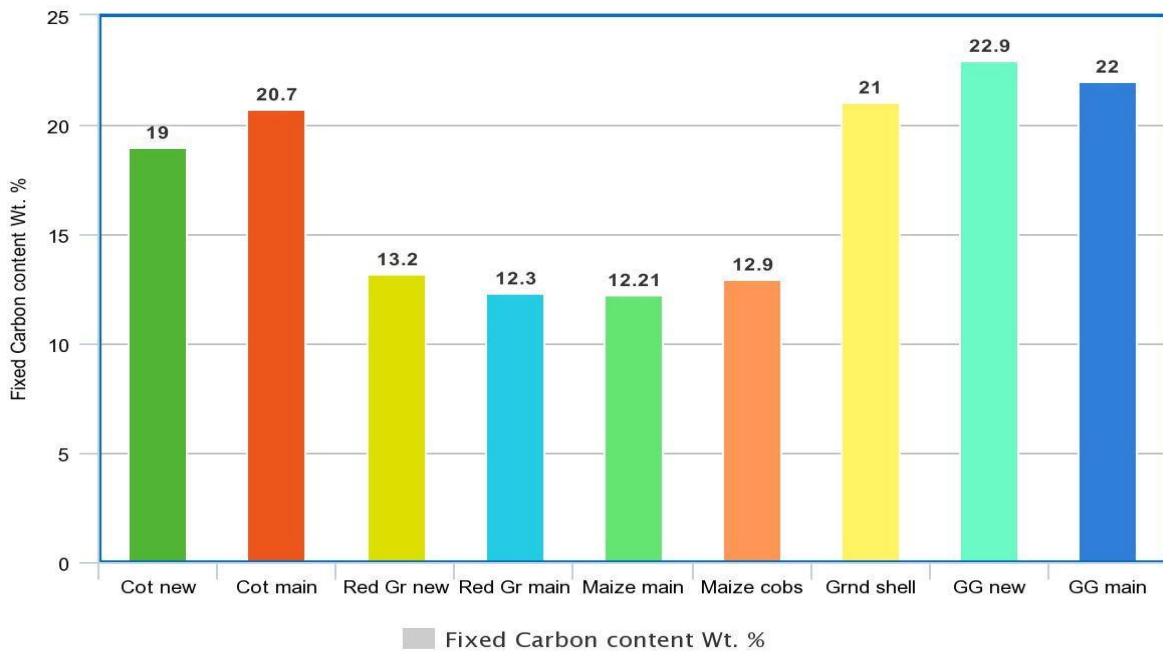
forms. First is the inherent moisture which is entrapped within the structure of biomass branches. Second is the external moisture that is outside of structure.

For example,

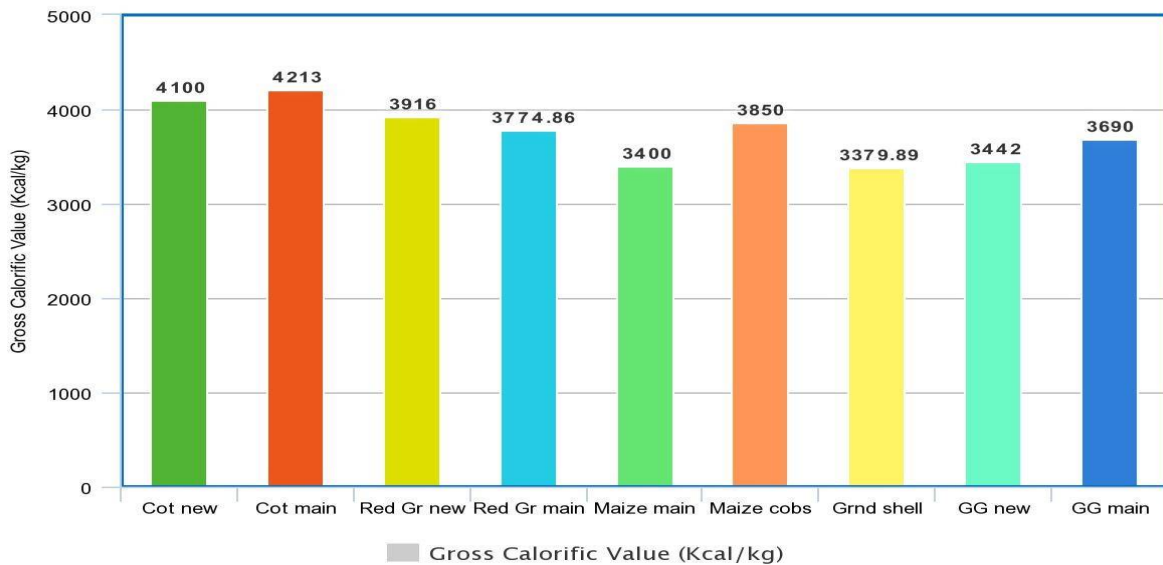
$$\text{Calorific value} = (W.E X T) / W_o - (\text{fuse wire} + \text{thread connections})$$

$$\text{GCV of Cotton new branch} = (1987 \times 0.5981) / 0.29 = 4100 \text{ kcal/kg}$$

Similarly GCV for all the other agricultural biomass species were calculated.



Graph 4 shows Fixed Carbon content of Agricultural biomass species



Graph 5 Shows Gross Calorific Value of Agricultural biomass species

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The crop residues with lowest moisture have highest Calorific values certainly. The Cotton has the highest calorific value (For New branch is about 4100 Kcal/kg and even higher values of 4213 Kcal/kg for main branch). Maize main branch and groundnut shells has the lowest calorific values of 3400 Kcal/kg and 3379.89 Kcal/kg.

Determination of Bulk Densities: Bulk density is an important property which decides the cost associated with transportation and storage capacity.

Biomass & Part of plant	Bulk Density (Kg/m <sup>3</sup> )
<b>Cotton</b>	
New Branch	247
Main Branch	256
<b>Red Gram</b>	
New Branch	198
Main Branch	205
<b>Maize</b>	
Main Branch	196
Maize Cobs	188
Groundnut Shell Husk	265
<b>Green Gram</b>	
New Branch	213
Main Branch	221

Table 1 shows Bulk densities of Agricultural biomass species

The Ash fusion temperatures of five biomass species were measured using Leitz Heating Microscope.

Ash of Biomass Samples	Ash Fusion Temperatures in °C		
	IDT	ST	HT
<b>Cotton main branch</b>	990	1140	1212
<b>Red Gram main branch</b>	960	1125	1145
<b>Maize Cobs</b>	810	840	1084
<b>Groundnut shell</b>	1109	1134	1161
<b>Green Gram main branch</b>	932	1052	1109

Table 2 shows Ash Fusion temperatures of Agricultural biomass species

It was found that Initial Deformation Temperature (IDT) varies from 810 to 1109 °C, Softening Temperatures (ST) ranges from 840 to 1140 °C and Hemispherical Temperatures (HT) ranges from 1084 to 1212 °C. The IDT of Groundnut shell husk found to be of highest value and Maize cobs are found to be of lowest value from the table 4.3. The ST of Maize cobs was the lowest varied between 840-850 °C of two different samples and Cotton has the highest ST value. The HT values of Cotton was found to be highest and with 1084 °C Maize at the lowest value. For safe boiler operation, the IDT of the ash of the fuel should be at least 150 °C more than the boiler operation temperature. The value of IDT of the entire selected sample is found to be above the boiler operating temperature except maize cobs stood at 810 °C.

Calculation of Land and Agricultural Biomass Requirement for Power generation: Here, the biomass residue per hectare of G. Hirsutum variety of Cotton is taken. The Biomass residue yield of Cotton G. Hirsutum was about 1.1 t/ha, the energy value is about 4100 kcal/kg.

Total energy value per hectare = 1100 kg × 4100 kcal = 4510000 kcal/kg

Converting kcal to MJ by using the formula:  $0.0041868 \times E_{Kcal} = E_{MJ}$

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For Cotton new branch =  $0.0041868 \times 4510000 = 18869.84$  MJ/ha

Component	Biomass Production (t/ha)	Energy value (MJ/ha)
Cotton new branch	1.1	18869.84
Cotton main branch	1.6	28203.5072

Table 3 shows Biomass production and Energy values per hectare of Cotton crop

The Energy values for each other agricultural Biomass species carried in the similar way. In general, the Thermal and overall efficiencies of a power plant are considered as 30% and 85% respectively. The total energy production in MJ per hectare of land is found by adding the energy values of the two components (main branch and new branch) of cotton plant.

$$18869.84 + 28203.5072 = 47073.3472 \text{ MJ/ha}$$

The energy output by taking thermal efficiency of 30%, is  $47073.3472 \times 0.3 = 14122.00416$  MJ/ha

Then the net output by considering overall efficiency of 85%, is  $14122.00416 \times 0.85 = 12003.703536$  MJ/ha

Then by multiplying factor of 0.0002778, the above energy value can be converted in MWh/ha as shown below.

$$12003.703536 \times 0.0002778 = 3.33462 \text{ MWh/ha}$$

Hence, the land required for supplying electricity from Cotton plant biomass for whole year

$$= 7300/3.33462 = 2189.15 \text{ ha}$$

The biomass requirement for supplying electricity from the Cotton biomass species for the whole year can be found by multiplying land required for supply of electricity from cotton plant for whole year with yield residue per hectare of land.

$$2189.15 \times (1.1 + 1.6) = 5910.71846 \text{ tons of cotton plant biomass}$$

Biomass species	Land Requirement (ha)	Biomass req. (tonnes)
Cotton	2189.15	5910.718
Red gram	2579.50	6448.76
Maize	808.237	6870.01
groundnut	1325.10	7288.07
Greengram	2577.68	6830.86

Table 4 shows Land requirement and Biomass requirement

If plant leaves and roots included, the land requirement to achieve required biomass is considerably reduced.

## V. CONCLUSION

The calorific value of Cotton plant is highest of all other specimens taken in the experiment with 4100 Kcal/kg and 4213 Kcal/kg for new branch and main branch. All the calorific values of the tested agricultural biomass species when compared with India's most used E and F grade coal shows relatively equal energy values, of which 3360-4200 Kcal/kg and 2400-3360 Kcal/kg for E and F grades respectively. This agricultural biomass can be used as a feed with blend of coal or as individual to reduce most of the fuel mining costs and imports as well.

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