Agro- waste to Bioenergy Production in India

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Abstract

The transition towards sustainable energy sources is imperative for mitigating environmental degradation and addressing energy security concerns. In the context of India, where biomass constitutes a significant portion of renewable energy potential, understanding its availability and utilization is paramount. The Biomass Resource Atlas of India serves as a comprehensive tool for assessing biomass resources, offering insights into regional and seasonal availability. However, despite substantial biomass generation, its utilization for power generation remains limited, primarily due to traditional agricultural practices like the burning of crop residues. Through advanced assessment techniques, including forestry, agriculture, animal husbandry, and municipal waste analysis, the potential for biomass energy production can be accurately estimated. Moreover, biomass characterization techniques, such as proximate and ultimate analysis, provide essential data on combustion properties, aiding in efficient energy utilization. Additionally, thermo-physical properties like calorific value contribute to understanding biomass's energy potential. By harnessing biomass for bioenergy production, not only can India mitigate greenhouse gas emissions and reduce air pollution caused by agricultural residue burning but also promote sustainable land management practices. Furthermore, integrating biomass energy into the energy mix can enhance rural livelihoods, foster economic development, and contribute to India's climate change mitigation goals. Embracing biomass energy thus presents a promising pathway towards achieving ecological sustainability and addressing India's energy needs in an environmentally responsible manner. In conclusion, the utilization of biomass for bioenergy production in India holds immense potential for promoting ecological sustainability and addressing energy demands. By implementing advanced assessment and characterization techniques, coupled with policy support and technological innovations, India can significantly enhance its renewable energy portfolio while fostering environmental stewardship and socioeconomic development.

Keywords- animal husbandry, ecosystem, environmental sustainability, Biomass Assessment Techniques, Calorific Value

Introduction

The imperative shift towards sustainable energy sources is increasingly recognized as vital for mitigating environmental degradation and addressing pressing energy security concerns worldwide. In the specific context of India, a country with burgeoning energy demands and a rich repository of renewable resources, the exploration and utilization of biomass stand out as a significant pathway towards achieving these dual objectives[1]. Biomass, derived from organic materials such as agricultural residues, forest residues, animal waste, and municipal solid waste, holds immense promise as a renewable energy source due to its abundance, renewability, and potential for carbon neutrality when managed sustainably[2]. Ecological considerations underscore the urgency of transitioning towards renewable energy sources, particularly in a country as ecologically diverse and populous as India. The degradation of ecosystems, loss of biodiversity, and disruptions to natural processes pose profound challenges to environmental sustainability. The burning of agricultural residues, a prevalent practice in many regions of India, not only contributes to air pollution but also results in the loss of valuable organic matter and nutrients essential for soil health and fertility. This unsustainable practice exacerbates ecological degradation, undermines agricultural productivity, and perpetuates a vicious cycle of environmental harm. Moreover, the rampant extraction of traditional fuels like fossil fuels and wood biomass exerts immense pressure on fragile ecosystems, leading to deforestation, habitat destruction, and soil degradation. Such ecological disruptions not only threaten the survival of countless plant and animal species but also jeopardize essential ecosystem services upon which human societies depend, such as clean air, water purification, and climate regulation. In this ecological context, the exploration and utilization of biomass for energy production offer a promising avenue for reconciling energy needs with environmental imperatives. By harnessing organic waste materials and residues from agricultural, forestry, and municipal sources, India can mitigate the adverse ecological impacts associated with conventional energy sources while promoting sustainable land management practices[3,4]. Furthermore, the adoption of biomass energy technologies can help alleviate pressure on natural ecosystems by reducing reliance on finite fossil fuel resources and curbing deforestation rates. Incorporating ecological perspectives into the discourse on biomass energy underscores the interconnectedness of human well-being and environmental health. By prioritizing ecological sustainability in energy planning and policymaking, India can forge a path towards a more harmonious relationship between society and nature, safeguarding ecosystems for future generations while meeting the nation's growing energy demands[5].

Biomass availability for power generation (BP) depends upon two major factors:

- Total production of Biomass (TB)
- Alternate use of Biomass, such as fodder, domestic cooking and other economic uses (AB)

BP=TB-AB

Earlier estimation of Biomass Available in a region was a cumbersome process based on surveys, field visits, censors and statistical data but recently Biomass Resource Atlas of India has been generated that can be directly accessed to estimate available Biomass in any part of the country[6].

Biomass Resource Atlas of India

It's an electronic Atlas which provides information on available biomass resources in the country with special reference to their potential for generation of power (Figure 1). This result is a product of collaborative work involving the Ministry of New and Renewable Energy (MNRE) under the Government of India, CGP Labs, and the Indian Institute of Science (IISc). Bangalore, RRSC (Regional and Remote Sensing Centre, ISRO), Coir Board and Agricultural Universities. The Salient Features of the Biomass Resource Atlas:

- It maps current biomass wealth of our country
- Provides information about regional and seasonal availability of Biomass at different levels such as state, district and taluka etc.

- It also depicts a map adhering to standard data, including boundaries, towns, roads, and rivers.

Important Conclusions:

- About 40 crops were studied for both the seasons.
- It provides information about wasteland and forest reserves too
- Annually, 120-140 million tons of biomass residues are generated in surplus and 16000 MW of energy has been produced from it by 2004.

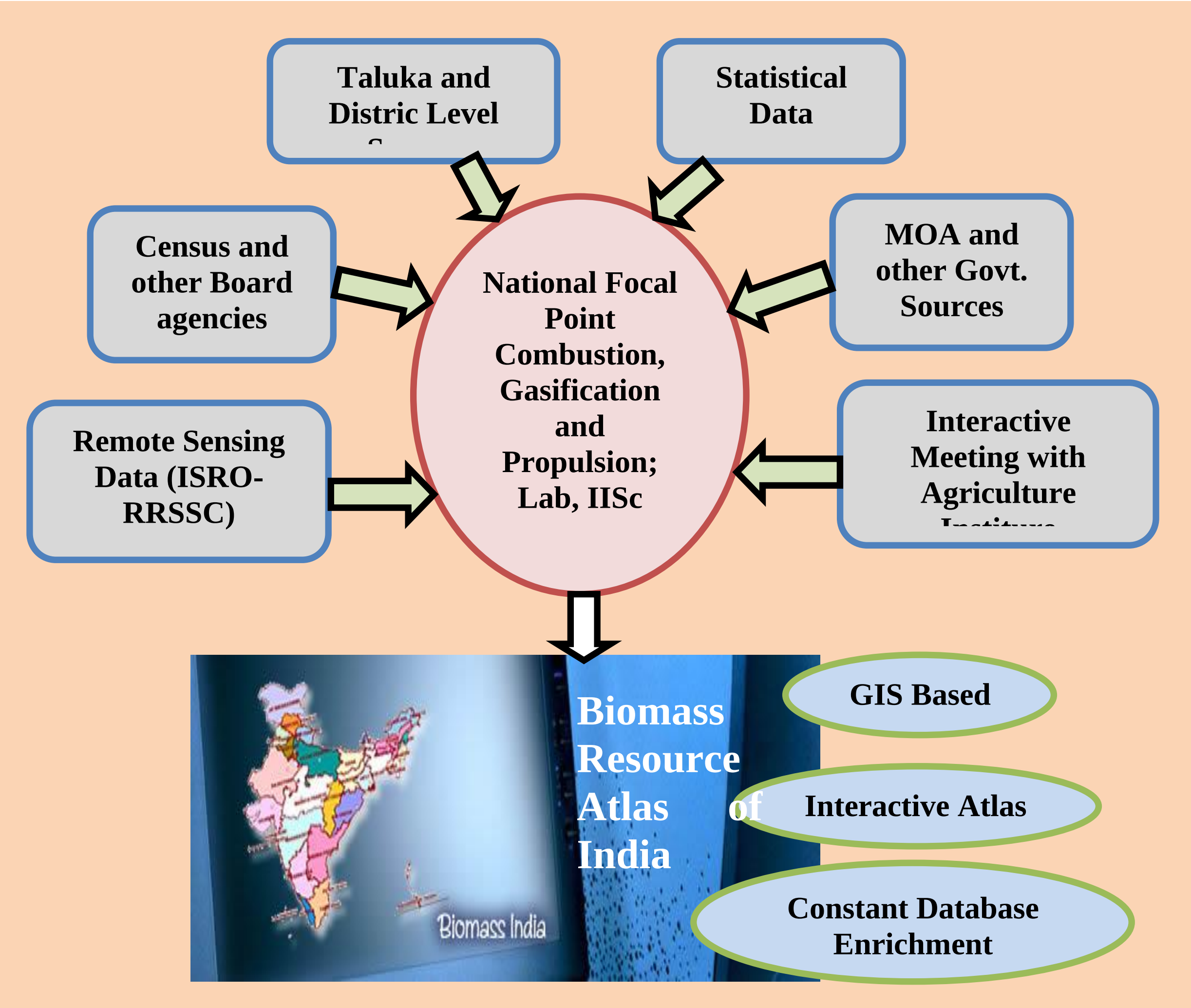


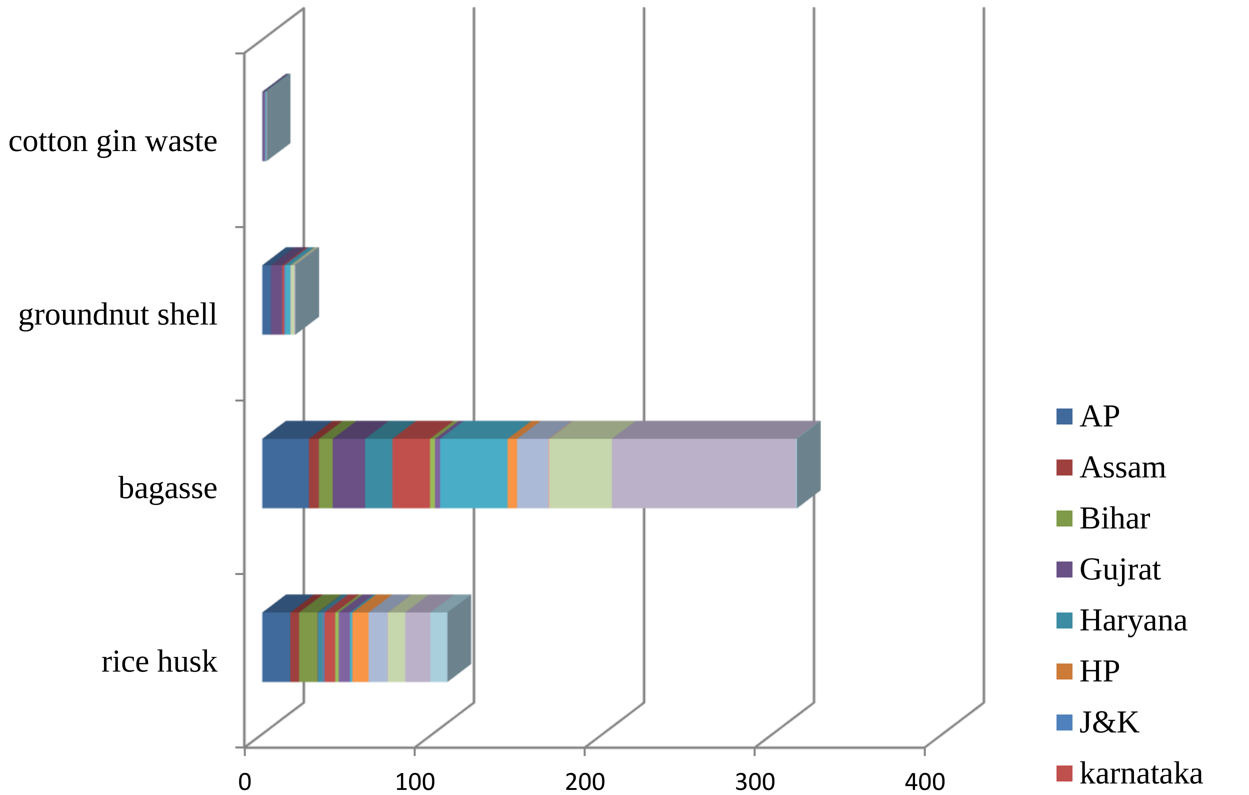
Figure 1. Generation of Biomass Resource Atlas of India

Biomass Resource Atlas of India assessed the biomass potential based on agro-residues to be 16, 000 MW in 2000-04. Up to March 2010, capacity of only 1220 MW have been installed which accounts for 7.6 % of total existing potential[7]. Major Agro-residue generation across states (in million tonnes) depicts in Figure 2.

How to use Biomass Resource Atlas to know Biomass Resource of your Region?

We can use biomass resource atlas to know biomass wealth of any part of our country .To access the atlas we can use the internet and follow the steps given below:

- Go to the web page: www.labcgpl.iisc.ernet.in
- It will take you to Biomass Atlas V2.0: Home
- For Biomass Atlas: To know Biomass Report of Particular Taluk, Click within the border of the taluk to get the Report. Click here to view the Atlas
- For biomass table: Select the respective State, District and Taluk to get the



	rice husk	bagasse	groundnut shell	cotton gin waste
AP	16.5	27.4	5.1	0.18
Assam	5.13	5.91	0	0
Bihar	10.93	8.1	0	0
Gujrat	0.32	19.1	6.6	0.51
Haryana	2.52	15.97	0	0.19
HP	0.14	0	0	0
J&K	1.06	0	0	0
karnataka	6.28	22.15	1.06	0.13
kerala	2.1	2.87	0	0
MP	6.47	2.99	0.54	0.77
Maharashtra	1.51	39.7	3.28	0.5
Orissa	9.46	5.55	0.03	0
Punjab	11.25	18.24	0	0.18
Rajasthan	0.23	0.72	0.19	0.09
TN	10.08	36.82	2.14	0.07
UP	14.75	108.26	0.55	0
WB	10.1	0.63	0	0

Figure 2: Major Agro-residue generation across states (in million tonnes) for the year 1997

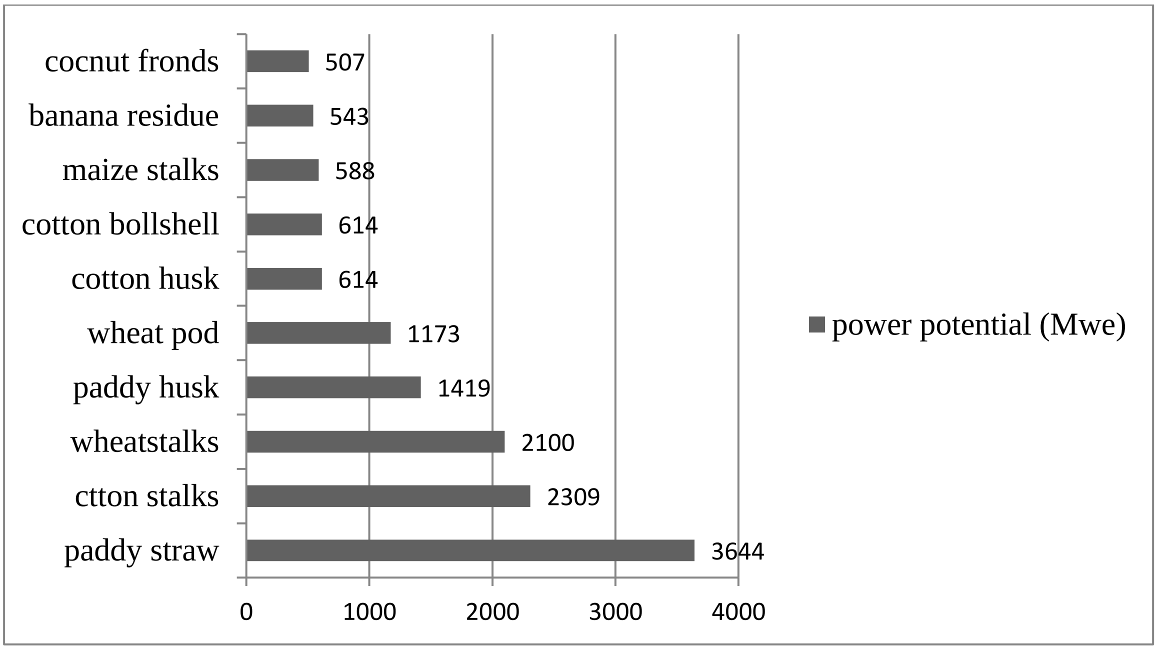


Figure 3: Power generation potential of main biomass residues

The figure 3 clearly shows that the paddy straw generated in our country has the high power generation potential of 3644 MW in comparison to paddy husk(1439 MW) but still the straw is the most underutilized agro-residue and is mostly burnt in the field itself to prepare field for sowing of next crop of wheat[8].

Biomass Assessment Techniques:

Biomass is highly dispersed source of energy and to fully tap its potential we first need to assess the quality and quantity of the available Biomass (Table 1). For quantitative analysis of the available biomass the following techniques are in practice and for qualitative assessment, Biomass Characterization Techniques are used[9].

Table 1: Biomass Assessment Technique for Specialized Field

Specialized Field Employed	**Biomass Estimated**
Forestry and Remote-Sensing	Woody biomass and tree based oil se
Agriculture	Agricultural residues
Animal husbandry	Animal wastes
Municipal bodies	Municipal wastes

Industries	Industrial waste

Assessment and Utilization of Biomass Resources for Energy Production: A Comprehensive Analysis

- **Agricultural Crop Residue**

1. **Residue production (R, tons/year) = Grain production (tons/year) x RPR**

Residue Product Ratio (RPR): indicates the amount of residue that becomes available after separation of useful product (Table 2).

Surplus agricultural residue available for energy production is much lower when compared to the total amount of residue production because:

2. **Collection efficiency factor (C):** Often it is not possible to collect the entire agriculture residue; some of it is lost during the collection. Thus we need to define a collection efficiency factor (ranging from 0 to 1)
3. **Alternate uses (X):** use such as animal feed mulching, roof thatch etc.

Surplus agriculture residue available for energy production, A
A = R X (C-X)

- **Animal Waste**

1. Potential animal dung (AD) = (Number of animal) x (Dung productivity)

where, Potential animal dung (AD) is in (kg/ head/day on dry basis). The amount of dung available for biogas production may be significantly(Table 3). Lowerthan the potential estimated due. The are two important factors influencing the availability of surplus dung available for biogas production; as below:

1. **Collection efficiency factor(C):** All the dung is not collected .
2. **Alternate uses of dung (X):** dung is dried and used as a fuel, fertilizer or mixed with clay to plaster walls and floor of the house

Surplus dung available for energy production (SD): SD = AD x (C – X)

- **Forest Residue**

Estimation of woody biomass is a two -step process:

Step I: **Map preparation**: to determine the spatial extent of the various ground cover types.

Techniques which are used for map preparation include satellite imageries:

1. **Low Spatial Resolution Imagery**: They provide overview data with low level of accuracy for ground cover typing and broad vegetation types.
2. **High Spatial Resolution Imagery**: Fine details could be studied by using satellite imagery with higher spatial resolution or aerial photography.

Step II: Ground inventory preparation: sample areas are selected representing various ground cover types and primary measurements are taken to calculate sustainable woody biomass yield in tons/year. Sustainable woody biomass yield is the amount of biomass which could be obtained from the forest without cutting the tree and generally includes detached parts of plants, twigs and fallen leaves, fruits and flower. For estimation of annual sustainable yield following formula is used : **ASY = 2 x G S/ R**

where, ASY is Annual Sustainable Yield in ton/year GS is Growing Stock in tons and formula for its calculation is given below:

GS = Area of the forest (ha) x Productivity (m3 of biomass/ha) x Density of biomass

where GS is in tons/m^3, R is rotation age for various trees (2-3 years for fast growing agroforestry trees to 60-100 years for high forest trees).The actual annual sustainable yield from the forests may not be fully realized due to various factors like lack of accessibility, machine efficiency etc. Therefore we need to define an collection efficiency factor(C, ranging from 0 to 1) to calculate extractable sustainable yield (ESY): **ESY = C x ASY**

To determine the excess woody biomass available for energy generation, we need to assess the current utilization of biomass for other purposes (X) in tons per year(Table 5). Biomass serves various functions, primarily as lumber and building material.

Surplus woody biomass availability (F, tons/year) = ESY – X

Table 2: Residue Product Ratio (RPR) for some important Crops

Rice	Husk	0.2
	Stalk	1.5
	Straw	1.5
Wheat	Pods	0.3
	Stalks	1.5
Maize	Cobs	0.3
	Stalks	2

Table 3: Average dung production in Indian subcontinent

Animal	**Dung Production (kg/head/day, weight)**	**Volatile Substance(kg/head/day)**
Dairy Cattle	2.87	2.64
Non-dairy Cattle	1.50	1.38

Problem 1: To Calculate Extractable Sustainable Yield (ESY) of a Biomass Resource

A forest with an area of 2000 ha has an annual productivity of 75 m3/ha. Its rotation age is 50 years and density is 0.8 tons/m3 (wet basis). Calculate Extractable Sustainable Yield (ESY) of the forest, if the efficiency factor for extraction **is 0.6.**

Solution:

First, we need to calculate the growing stock

GS = 2000 (ha) x 75 (m3/ha) x 0.8 (tons/m3) = 120000 tons

ASY = 2 x 120000/50 = 4800 tons/year

ESY = 0.6 x 4800 = 2880 tons/year

Biomass Characterization

The determination of the different constituents of biomass requires analytical methods such as proximate analysis and ultimate analysis that. Such studies are important to predict combustion properties of the biomass(Figure 4).[10]

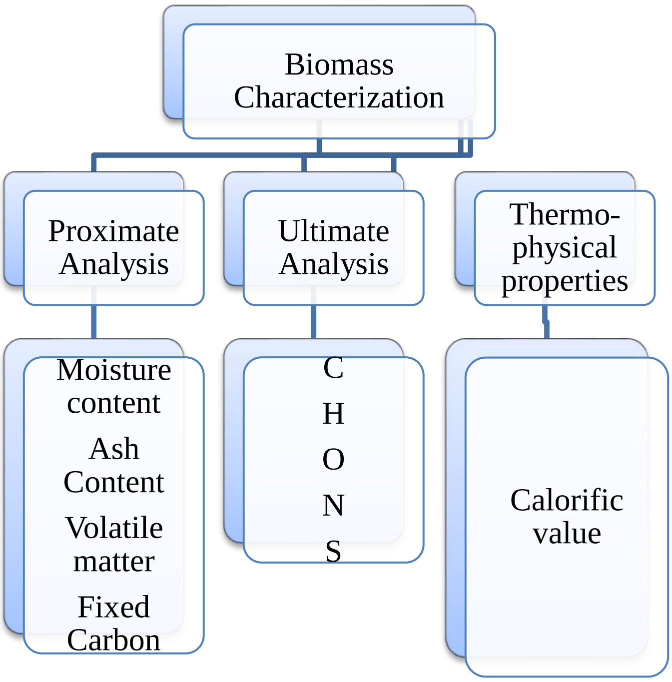


Figure 4: Outline of Biomass Characterization

Proximate Analysis

The proximate analysis aims to determine the primary components of biomass that directly affect its combustion properties, including:

Table 4 (A),(B),(C).(D) Depicts the proximate analysis.

A. Moisture content within the biomass,

B. Quantity of volatile substances,

C. Fixed carbon (char) content, and

D. Quantity of ash present.

Table 4. A. Determining of Moisture Content

Moisture Content	Moisture content is highly variable in biomass and has the large influence on the combustion chemistry and energy balance. Moisture content can be described by two ways; dry basis and wet basis. • Dry basis moisture (M_{db}) → Mass of water in the feedstock/ unit mass of dry water. • Wet basis moisture (M_{wb}) → Water to the total wet

	weight, dry matter plus water.
Instrument Used	Hot Air Oven (Figure 5)
Working Principle	The sample with an intial mass M_i is placed in a drying oven in which a temperature of 104°C is maintained. Every 6 hours the change in mass is noted and the process is continued till the mass becomes constant (M_e). $$\text{Moisture content [m]} = \frac{M_i - M_e}{M_e} * 100\ \%$$

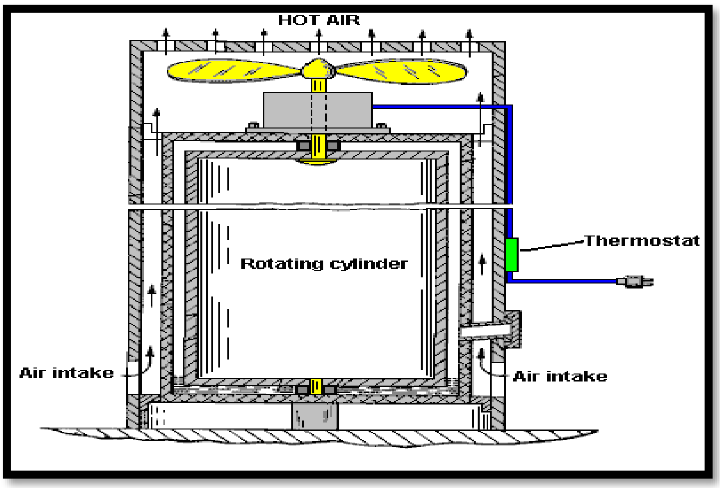


Figure 5: Schematic lay out Hot Air Oven

Table 4. B. Determination of Amount of Volatile Matter

Volatile Matter	The volatile matter in biomass refers to the carbon component that, when heated, transforms into vapor. In nearly all forms of biomass, the volatile matter, determined by the carbon-to-hydrogen ratio, is high, typically constituting around 70-80% of the dry biomass weight.

Instrument	Hot Air Oven
Working Principle	The quantity of volatile matter is assessed by subjecting a dried, ground sample of biomass, initially weighing Mi, to a two-stage heating process. First, the sample is heated in a closed crucible within an oven set at 600°C for 6 minutes, then it undergoes further heating in an oven at 900°C for another 6 minutes. $\text{Amount of volatile matter, u (in percent)} = \text{loss in the weight, L}$ $L = \frac{M_i - M_e}{M_i} * 100\ \%$

Table 4.C. Determination of Amount of Ash

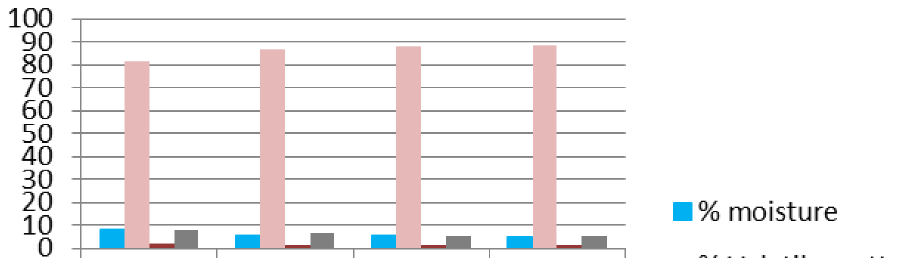
Ash	Ash is the noncombustible component of the biomass. The higher the amount of ash in a fuel, the lower is the calorific value of the fuel.
Instrument Used	Muffle Furnace (Figure 6)
Working Principle	The amount of ash is determined by heating a dry sample of biomass in a crucible in a furnace which is kept at 900°C. The amount of residues left is weighed. $\text{Amount of ash [a]} = \frac{M_i - M_e}{M_i} * 100\ \%$

Figure 6. Muffle Furnace

Table 4. D. Determination of Fixed Carbon Content:

Fixed Carbon Content	Carbon content of the Biomass Sample after separation of Volatile matter and Ash content is known as Fixed carbon.
Basis of Calculation	Determination of amount of fixed carbon is by use of mass balance calculations. The amount of volatiles is the difference between 100 and the sum of the moisture content [m], the amount of ash [a] and the amount of volatiles 'u' in the sample of biomass calculated as; $[c] = 100\ \% - ([m]\% + [a]\% + L\ \%)$ where, [m] = The moisture content in percentage [a] = Amount of ash content L = Amount of volatiles [c] = Amount of fixed carbon M_i = Initial mass M_e = Constant mass after heating certain time

Table 5: Proximate analysis of some woody biomass



	Sheesham	Eucalyptus	Mango	Sagwan
% moisture	8.53	5.62	5.55	4.86
% Volatile matter	81.4	86.76	87.88	88.28
%Ash Content	2	1.25	1.5	1.5
Fixed Carbon	8.1	6.37	5.07	5.36

PROXIMATE ANALYSIS OF WOODY BIOMASS SAMPLE

Ultimate Analysis

The ultimate analysis involves the estimation of the important elements of biomass such as: C, H, O, N and S. An automatic CHNS-O analyzer can also be used for this purpose (Table 6 & 7).

Table 6: Ultimate analysis.

Instrument	The CHNS(O) Analyzer is employed to ascertain the proportions of Carbon, Hydrogen, Nitrogen, Sulphur, and Oxygen in organic substances, utilizing the "Dumas method." This method entails the rapid and complete oxidation of the sample through "flash combustion." The CHNS(O) Analyzer is utilized to determine the ratios of Carbon, Hydrogen, Nitrogen, Sulphur, and Oxygen in organic materials, employing the "Dumas method." This technique involves quickly and fully oxidizing the sample via "flash combustion." Then, the combustion residues are separated using a chromatographic column and detected using a thermal conductivity detector (T.C.D.), which generates a signal

	proportional to the concentration of each element in the mixture (Figure 7)
Working Principle	The main components of CHNS include an autosampler, combustion reactors, chromatographic column, and T.C.D. detector. Within the integrated chromatographic column, compounds are transformed and released as NO2, CO2, SO2, and H2O, subsequently identified using the Thermal Conductivity Detector. The equipment undergoes calibration by analyzing standard compounds and calculating K-factors. This process guarantees utmost reliability of the outcomes since the combustion gases are not divided or diluted but are directly directed into the integrated Gas Chromatographic (GC) system. As a result, simultaneous determination of CHNS can be accomplished in under 10 minutes.. This method finds greatest utility in finding out percentages of C, H, N, S, (O) in organic compounds which are generally combustible at 1800^{o}C. This techniques for the determination of CHN \ CHNS \O is precise, accurate, fast and convenient. (Figure 8) .
User Instructions	Sample must be pure and all contaminants must be removed. Sample weight should be in between 4-5 mg. Liquid samples should have constant weight.

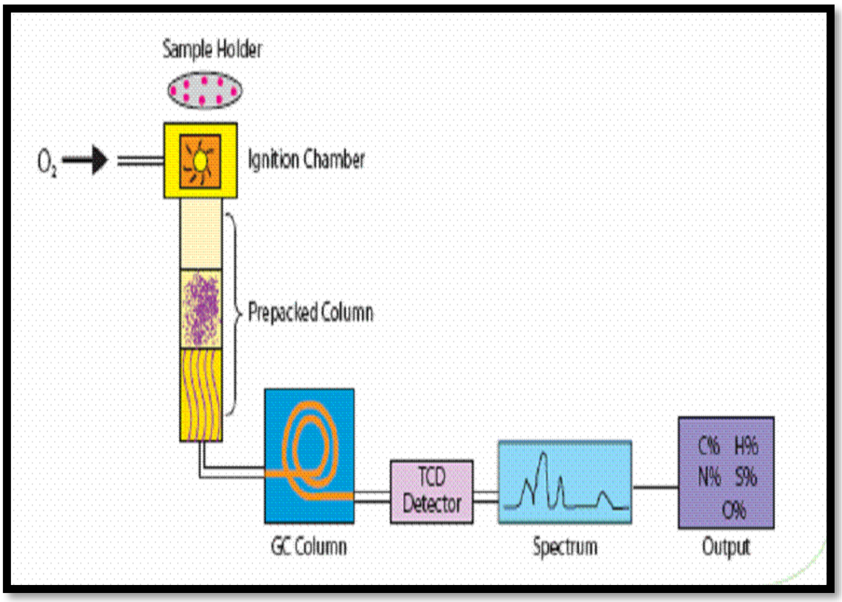
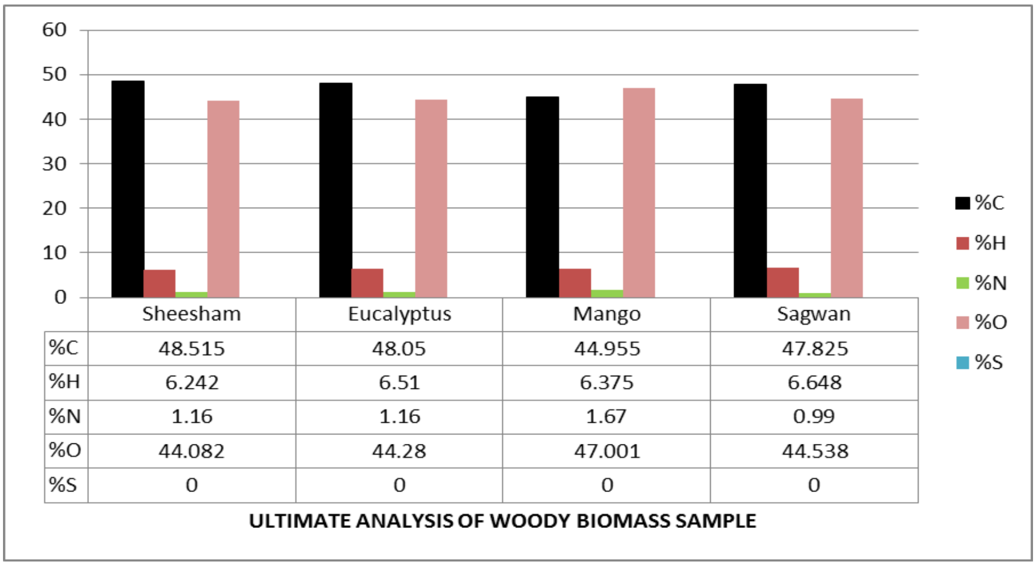


Figure 7. Basic Layout of the analyzer

Figure 8. CHNS Analyzer

Table 7. Ultimate analysis of some woody biomass



	Sheesham	Eucalyptus	Mango	Sagwan
%C	48.515	48.05	44.955	47.825
%H	6.242	6.51	6.375	6.648
%N	1.16	1.16	1.67	0.99
%O	44.082	44.28	47.001	44.538
%S	0	0	0	0

Thermo-Physical Properties

Key thermo-chemical characteristics of biomass fuels that influence combustion include calorific value, density, thermal conductivity, and thermal diffusivity[11].

Here we will discuss only Calorific Value while other properties will be dealt in subsequent units (Table 9).

Table 9. Determination of Calorific value

Calorific Value	The calorific value refers to the overall heat generated when a specified mass of fuel undergoes complete combustion with pure oxygen. It is alternatively referred to as the heating value of the fuel.
Instrument	Bomb Calorimeter
Theory	During the combustion of a fuel, hydrogen reacts with oxygen to form water. When water vapor is included in the exhaust gases, the latent heat of vaporization is dissipated.. Therefore, this amount of heat cannot be utilized for any practical application. As a result, when assessing the calorific value of a fuel, accounting for the presence of water vapor in its vapor form, it is termed as Net Calorific Value (NCV) or Net heating value (NHV) or Lower Heating Value (LHV). Should these vapors

	be condensed, the latent heat of water vapor can then be harnessed for practical applications. Therefore, when this portion of heat is included in the net calorific value, the result is the Gross Calorific Value (GCV) or Gross Heating Value (GHV) or Higher Heating Value (HHV). Units commonly utilized for calorific values encompass Calorie, Kilocalorie, British Thermal Unit, and centigrade heat unit. The Net Calorific Value (NCV) is derived by deducting the latent heat of condensation of water vapor from the Gross Calorific Value (GCV). Each part by weight of H2 generates 9 parts by weight of H2O. $$\lambda_v = 2442.5 \frac{kJ}{kg} (at 25^o C)$$ $$NCV = GCV - 9 * \left(\frac{H}{100}\right) * 587 = GCV - 0.09 * H * \lambda_v$$ where, H = % of hydrogen in the fuel. λ_v = latent heat of water vapor
Working	A sample of air dried biomass with known mass is burnt in an atmosphere of oxygen in a stainless steel high pressure vessel, known as the bomb. This bomb is placed in a calorimeter which is highly polished vessel containing a known amount of water with a known temperature. The combustion products CO_2 and H_2O are allowed to cool to the standard temperature. The resulting heat of combustion is measured from the accurate measurement of the rise in the temperature of water in the calorimeter, the calorimeter itself and the bomb. The calorific value so estimated is the gross calorific value.

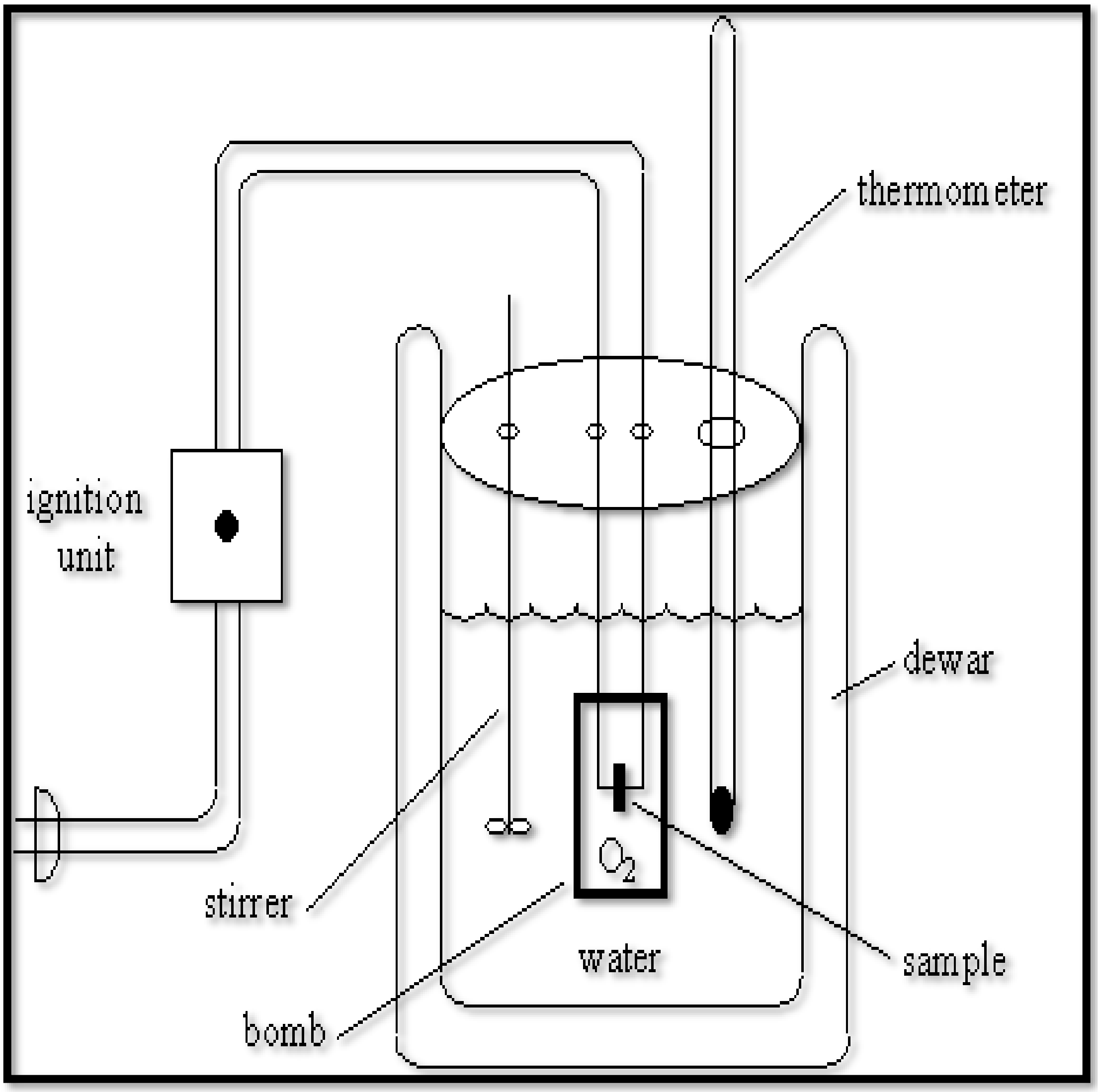
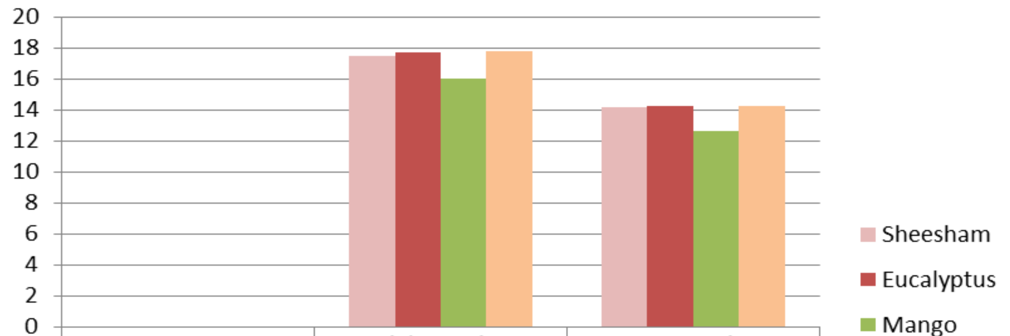


Figure 9: Basic Components of a Bomb Calorimeter

Source: http://www.chem.hope.edu/~polik/Chem345-2000/bombcalorimetry.htm

The Comparison between (High heating values & Low heating value) of woody biomass depicts in the table 10.

Table 10: Comparison of heating values of woody biomass



	High Heating Value(HHV)	Low Heating Value(LHV)
Sheesham	17.5	14.2
Eucalyptus	17.67	14.23
Mango	16	12.6
Sagwan	17.75	14.24

HEATING VALUES OF DIFFERENT WOODY BIOMASS

Note: Hydrogen does not have any contribution in calorific value. The calorific value of wood is thus influenced by its carbon content and resin-like components[12].

Conclusion

To summarize, India's biomass reserves present a hopeful opportunity for generating sustainable energy. Through advanced assessment methods and technological innovations, coupled with supportive policies, India can leverage biomass to mitigate environmental degradation, enhance energy security, and foster socioeconomic development, thus paving the way for a greener and more sustainable future.

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