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A Review on Production, Properties and Current Status of Biomass Energy in India

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Abstract: The ever growing population coupled with large number of developmental activities has led to resource scarcity in many parts of the country. A judicious choice of energy utilisation is required to achieve growth in a sustainable manner. It is estimated that about 70% of population still live in rural areas resulting in to tremendous demand on resources such as fuel wood, agricultural residues, etc. to meet the daily fuel requirements. The dependence on biomass resources to meet the daily requirement of fuel, animal fodder, etc. in rural areas is more than 85% while in urban area the demand is about 35%. Although biomass is a term that is closely associated with ecology, it can also be defined and described in terms of energy. The biomass energy is one of the primary sources of energy for many activities. It is considered as the source of renewable energy since the primary source of this energy is plenty in this world. Most biomass comprises carbon, hydrogen, oxygen, nitrogen, and other alkali metals, which provide a large amount of energy when burnt. Organic materials like agricultural wastes, wood, and municipal wastes can be recycled for the production of biofuels. The present paper deals with the sources, production technologies, types and properties of biomass energy. The current status of bioenergy in India is discussed in detail.

Key words: Biomass, biofuel, biochar, briquettes, black liquor.

Introduction: The energy that is generated from biomass is called biomass energy. All organic matter can produce biomass energy when reactions are done with it. These can be wood, leaves, pellets, fecal wastes, and other organic matters[1]. Technically speaking, biomass energy was discovered back during the ages when humans used to live in caves. Marco Polo, in the 13th century, described the use of biomass for the production of fuel after taking inspiration from the Chinese who used to cover sewage tanks to generate biogas [2]. Biomass energy can be both renewable and non-renewable. The first source of energy in the production of biomass is the sun. The plants convert solar energy by photosynthesis into chemical energy as food and subsequently uses it in their growth, which is later converted to fuel. The energy derived from biomass can be processed directly by burning to produce heat, or converted directly into electricity, or can also be processed to produce biofuels in an indirect manner [3,4].

Plants that are a rich source of Biomass energy and hence considered for Biofuel production. There are several plants that can be considered as a rich source of biomass energy and hence are often considered for the production of biofuels [5]. Some of them include wheat, switchgrass, sunflower, cotton seed, mustard oil, corn, canola, sugarcane, soy plants, jatropha, palm oil, and many more. These plants are often cultivated in large fields for the production of biofuels[6].

Way to Produce biomass energy:

Thermal conversion:

One of the primitive ways of producing biomass energy is to burnthe organic material and utilize the heat energy produced from it. The thermal conversion of biomass involves heating the feedstock so that energy is released, the feedstock is dehydrated, or the biomass is stabilized[7]. The common source of biomass feedstock is the municipal solid wastes and also waste from lumber mills and paper factories. The different processes of thermal conversion are direct firing, pyrolysis, co-firing, gasification, as well as anaerobic decomposition [8]. Before the biomass is burnt, they are needed to be dried. The chemical process of drying biomasses is called torrefaction[9]. In this process,the biomass is heated to a temperature of 200 to 320°C. The biomass not only loses all its moisture, and also loses the ability to absorb it. After torrefaction, the biomass is converted into a black dry material, which is then compressed to form briquettes[10]. Briquettes are highly hydrophobic, thus enabling them to be kept in moist places. Also, the briquettes have high energy density and can easily be burnt by direct firing or co-firing[11].

Biofuel: Biomass is considered a renewable source of biofuels like biodiesel and ethanol. Such biofuels are used to power vehicles and machines in several countries like Austria, Sweden, and the United States of America. Ethanol is produced by the fermentation process of biomasses that are rich in carbohydrates, such as corn, wheat, and sugarcane. Biodiesel can be made by combining this ethanol with animal fat, vegetable oil, and recycled cooking fat. Biofuels do not produce as much energy and, therefore, not as effective as gasoline. However, they can be mixed with gasoline, and this mixture can be used to power automobiles and pieces of machinery used in several industries. By using such mixture, the emission of harmful gases, as observed in the case of fossil fuels, is greatly minimized[12].

Biochar: Biochar is a byproduct of the pyrolysis process of biomasses. Itis considered to be a valuable source of energy for agriculture and other environmental uses. When biomass rots or burns, it releases large amounts of carbon dioxide and methane into the atmosphere. However, such emissions are prevented, and the process of charring these biomasses can retain the carbon content. When these biochars are added back to the soil, they can still absorb carbon from the surroundings. They can act as sequestered carbon sinks, which is beneficial for maintaining the quality of the soil it has been found that addition of biochars to the soil helps in increasing the quality and quantity of agricultural production[13].

Black Liquor: Black liquor is a toxic byproduct in the production of paper from wood. Till the 1930s, this black liquor is considered as an industrial waste product and was dumped into the nearby water bodies. However, later it was found that the black liquor can retain almost 50% of the carbon content of the source material. Later it was used as a power source in several mills with the help of the recovery boiler. It was also tried to be gasified so that it can be used to generate electricity[14].

Hydrogen Fuel Cells: Hydrogen fuel cells are produced from biomasses and are used in batteries for generating powers and fuel machines and vehicles. These cells are mainly used for automobiles driven in remote locations, like wilderness areas or in spacecraft. Hydrogen fuel cells can be considered as an alternative source of energy for vehicles. In current times, these cells are used as a source of power for boats, buses, submarines, and forklifts. Testings are going on for their usage in airplanes as well[15,16].

Biomass Resources

In its simplest form, the biomass is the organic matter in trees, agricultural crops and other living plant material. It is made up of carbohydrates-organic compounds that are formed in growing plant life. Biomass is solar energy stored in organic matter. As trees and plants grow, the process of photosynthesis uses energy from the sun to convert carbon dioxide into carbohydrates (sugars, starches and cellulose). Carbohydrates are the organic compounds that make up biomass.

When plants die, the process of decay releases the energy stored in carbohydrates and discharges carbon dioxide back into the atmosphere. Biomass is a renewable energy source because the growthof new plants and trees replenishes the supply [17]. The use of biomass for energy causes no net increase in carbon dioxide emissions to the atmosphere. As trees and plants grow, they remove carbon from the atmosphere through photosynthesis. If the amount of new biomass growth balances the biomass used for energy, bioenergy is carbon dioxide "neutral." That is, the use of biomass for energy does not increase carbon dioxide emissions and does not contribute to the risk of global climate change. The biomass is generally termed for the following:

- land and water based vegetation
- organic wastes
- photosynthetic organisms.

The primary step in the buildup of biomass is photosynthesis. In photosynthesis, sunlight is absorbed by chlorophyll in the chloroplastsof green plant cells and is utilized by the plant to produce carbohydratesfrom water and carbon dioxide. Biomass can be categorised broadly aswoody, non-woody and animal wastes. Biomass is also characterized as natural resources and derived resources. We will briefly discuss them.

Woody Biomass: All the biomass from forests, agro industrial plantations, bush trees, urban trees and farm trees are termed as woody biomass. Woody biomass is generally a high valued product because it has diverse uses such as timber, raw material for pulp and paper, pencil and matchstick industries, and cooking fuel.

Non-woody Biomass: Non-woody biomass is referred to as crop residues like straw, leaves and plant stems (agro wastes), processing residues like saw dust, bagasse, nutshells and husks, and domestic wastes (food, rubbish, sewage). Many of these are harvested at the village level and are essentially used either as fodder or cooking fuel.

Animal Wastes: Animal wastes constitute the wastes from the animal husbandry. Animal dung is a potentially large biomass resourceand dried dung has almost the same energy content as wood. About 150 Million tons (dry) of cow dung are used for fuel each year acrossthe globe, 40% of which is in India. The efficiency is only about 10% when dung is burnt to produce heat. The important example is cook stoves used in the rural areas[18]. The efficiency of conversion of animal residues could be raised to about 60% by digesting anaerobically (to produce biogas).

More commonly, biomass resources are also classified as follows:

Natural Biomass Resources: Biomass resources include wood and wood wastes, agriculture crops and their waste by products.

Agricultural Waste: Begasse, soya husk, cotton straw, rice husk, arhar stalk, wheat straw, and peanuts, peanut stalk, etc.

Derived Biomass Resources: Municipal solid waste, animal wastes, waste from food processing and aquatic plants, etc.

Forest Products: Wood, logging residues, trees, shrubs and wood residues, sawdust, bark etc. from forest cleanings.

Energy Crops: Energy crops are short rotation woody crops, herbaceous woody crops, grasses, starch crops (corn, wheat, and barley), sugar crops (cane and beet), oilseed crops (soya bean, sunflower, safflower). These are the biomass materials, which can be used during the pyrolysis process and to produce the bio-oil. The amount of crop residues available for energy purposes will depend on the cultivation practices, recovery and storage technologies. The recovery and delivery costs of these residues to bioenergy will vary considerably, depending on the crop, lignin and cellulose content, climate, topography, cost of labour as well as the opportunity costs associated with using the biomass for energy instead of other purposes [6,17].

Composition of Biomass

Biomass wastes generally contain cellulose, hemi-cellulose and lignin. A detailed discussion of cellulose, hemi-cellulose, lignin chemistry is beyond the scope of this unit [19]. However, cellulose, hemi- cellulose and lignin percentages are given in Table.1

S.No.	Species	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Ash (%)
1	Soft wood	40-45	24-37	25-30	0.4
2	Hard wood	40-45	22-40	19.5	0.3
3	Rice straw	30.2	24.5	11.9	16.1
4	Bagasse	33.6	29	18.5	2.3

Table.1 Compositions of Biomass

Energy Content of Biomass

The energy content of biomass that can be obtained after transformation is an important characteristic of biomass. The energy content is measured as the heating value. For woody biomass resources, the moisture content of the wood is the main determinant of the available energy. For non-woody biomass, the ash content and the moisture content affect its energy value.

The moisture content is variable and depends on the extent to which the wood is dried. That is why the energy content of fuel varies from 10.9-21.3 GJ per ton, with an average of about 16.9 GJ for oven- dried wood (moisture content of 0 percent). One ton of air-dried wood (average 20% moisture content) has an energy value of about 13.5 GJ [20].

One of the interesting aspects of wood is that it can be used for fuel purposes without any treatment or modification except that of being cut into small pieces. This is because of its high volatility, high char reactivity, and low sulphur and ash content. Lignin is more abundant and has a higher degree of polymerisation in softwoods than in hard woods. Woods having higher lignin content and plenty of extractives will have a higher heating value. Cellulose and hemi-cellulose contain only around 17.5 MJ/kg while lignin has about 26.5 MJ/kg and extractives can approach 35 MJ/kg. Wood has another interesting property that it can be modified into various forms that are convenient to use as shown in Figure 1

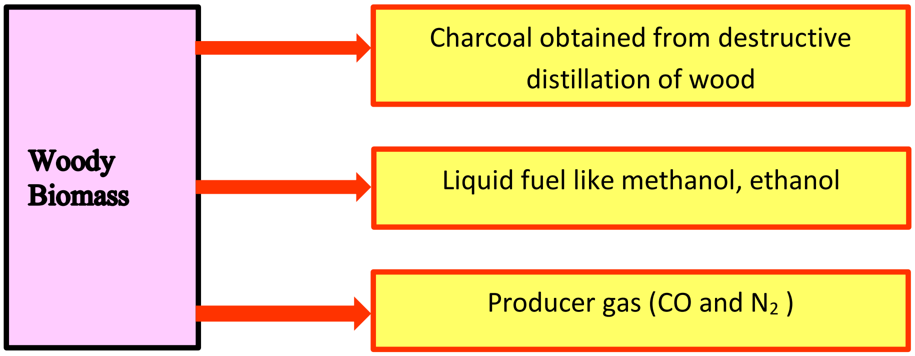

Figure 1. Conversion of Woody Biomass

It can be seen that woody biomass can be converted to charcoal, liquid fuels like Biomass Energy methanol and ethanol and producer gas (carbon monoxide and nitrogen). Charcoal is mainly made of carbon and is obtained by the destructive distillation of wood. It hasa relatively high-energy value of 28.9 GJ/ton. Producer gas is obtainedby the burning of carbon in a supply of air insufficient to convert itto charcoal.

The ultimate analysis of different plant residues in % of dry matter is given in Table.2 It is seen that the ash content varies considerably among the residues. The carbon content is typical of organic substrates, being between 40% and 50%. Hydrogen content at 5-6% and oxygen content mainly below 40% are nearly uniform[21]. Nitrogen content is a measure of the protein content of the residue. The nitrogen content is in most cases far below 1%, indicating that the residues have low protein content[3,18].

Residue	Ash	C	H	O	N	S
Wheat straw	6.53	48.53	5.53	39.08	0.28	0.05
Barley straw	4.30	45.67	6.15	38.26	0.43	0.11
Maize straw	5.77	47.09	5.54	39.79	0.81	0.12
Rice straw	17.40	41.44	5.04	39.94	0.67	0.13
Bagasse	3.90	46.95	6.10	42.65	0.30	0.10
Coconut shell Fibre	1.80	51.05	5.70	41.00	0.35	0.10
Potato stalks	12.92	42.26	5.17	37.25	1.10	0.21
Beet leaves	----	40.72	5.46	39.59	2.28	0.21
Wheat chaff	7.57	47.31	5.12	39.35	1.36	0.14
Barley chaff	5.43	46.77	5.94	39.98	1.45	0.15

Table.2 Analysis of plant residues (Percentage of dry matter)

Biomass has nearly twice as much of hydrogen and nearly an order of magnitude more oxygen per carbon atom than coal. The calorific value and heat utilisation efficiency of various fuels are given in Table.3

Fuels	Heating values (kcal/kg)	Fuel Utilization Efficiency (%)
Firewood	4,708	18.9
Vegetable waste	3,500	12.0
Dung cake	2,092	11.2
Soft cake	5,772	26.6
Charcoal	6,930	25.7
Kerosene	9,122	50.8

Table.3 Calorific value and heat utilisation efficiency of various fuels

Characterisation of Biomass

Since biomass differs greatly in their chemical, physical and morphological properties, they make different demands on the method of their utilization and consequently require different types of technologies. Most important properties, which may affect the gasification/ pyrolysis, are calorific value, moisture content, ash content, volatile matter, fixed carbon, ash melting point and bulk density. The moisture content, ash content, volatile matter and fixed carbon content of a particular fuel can be determined by proximate analysis of the fuel [4,19].

The method of gradation takes into account the comparative effect of different properties of the fuel in the gasification process. A brief description is given below.

Effect of Calorific Value

As the calorific value increases, the amount of gas produced at the normal temperature and pressure increases. This simply means that with the increase in calorific value, the material consumption also decreases.

Effect of Moisture Content

With increasing moisture content, the calorific value of wood decreases and correspondingly the amount of gas produced at normal temperature and pressure (NTP) and fraction of useful components decrease. For practical consideration, the wet biomass has also bad flow and handling characteristics and gives inconsistent operation, especially for biomass having 25% moisture on wet basis. High moisture contents reduce the thermal efficiency since heat is used to drive off the water and consequently this energy is not available for the reduction reactions[22]. Therefore, high moisture contents result in low gas heating values. Moisture content is defined on the wet basis as well as dry basis. The moisture content on the dry basis is defined as follows:

$$MC_{dry} = \frac{\text{Wet weight} - \text{Dry Weight}}{\text{Dry weight}} \times 100\%$$

Alternatively, the moisture content on a wet basis is defined as:

$$MC_{wet} = \frac{\text{Wet weight} - \text{Dry Weight}}{\text{Wet weight}} \times 100\%$$

Effect of Ash Content

With increasing ash content, the removal of the ash from the gasifier becomes more power consuming and fraction of useful components also decrease. If the ash content is very high, the biomass can be taken as unsuitable for gasification because due to removal of large amount of ash, material flow problems in the gasifier can arise**.**

Effect of Volatile Mafler

The volatile matter helps in the complex reactions of gasification but if the volatile matter content is high, tar formation is also high. Taris one of the products of thermal decomposition of solid fuels. The taryield is therefore related to the volatile matter in a fuel.

Effect of Fixed Carbon

With increasing fixed carbon, the amount of gas produced and the calorific value of the producer gas so obtained increase. The conversion of carbon to CO which is one of the main components of producer gas is the result of many complex reactions taking place during gasification.

Effect of Ash Melting Point

The ash melting point is essential to determine to maximum temperature that can be achieved at any zone in the gasifier. Whenthe temperature of any zone the gasifier exceeds the ash melting temperature, there are chances of clinker formation. The clinkers once formed can cause breakdown of the ash removal mechanism of the gasifier.

Effect of Bulk Density

Bulk density is one of the important factors for designing of a gasifier to obtain proper material flow. Biomass with very low bulk density have problem of proper fall through different zones of gasifier. The bulk density varies significantly with moisture content and particle size of the fuel. The average bulk density of few biomassesis given in Table.4

Fuel	Bulk Density(kg/m^3)
Wood	300-550
Charcoal	200-300
Peat	300-400

Table.4 Average Bulk Density of Biomass

Environmental Effects of Biomass

The use of biomass energy provides a number of environmentalbenefits. Some of them are:

- It can help mitigate climate change
- It can reduce acid rain
- It can prevent soil erosion and water pollution
- It can minimize pressure on landfills
- It can provide wildlife habitat
- It can help maintain forest health through better management.

The use of biomass will greatly reduce the greenhouse gas emissions. Biomass releases carbon dioxide as it burns, but the plants also need CO_2 to grow[23]. This creates a closed-carbon cycle. All the CO_2 released during the combustion of biomass materials is recaptured by the growth of these same materials. Thus, with biomass combustion there is no net increase in carbon dioxide released into the atmosphere. In addition, substantial quantities of carbon can be captured in the soil through biomass root structures, creating a net carbon sink [1,5]

Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs. Ministry of New and Renewable Energy has realised the potential and role of biomass energy in the Indian context and hence has initiated a number of programmes for promotion of efficient technologies for its use in various sectors of the economy to ensure derivation of maximum benefits. For efficient utilization of biomass, bagasse based cogeneration in sugar mills and biomass power generation have been taken up under biomass power and cogeneration programme[24].

Biomass power and cogeneration programme is implemented with the main objective of promoting technologies for optimum use of country's biomass resources for grid power generation. Biomass materials used for power generation include bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, groundnut shells, saw dust etc.

Potential

As per a recent study sponsored by MNRE, the current availability of biomass in India is estimated at about 750 million metric tonnes per year. The Study indicated estimated surplus biomass availability at about 230 million metric tonnes per annum covering agricultural residues corresponding to a potential of about 28 GW**.** This apart, about 14 GW additional power could be generated through bagasse based cogeneration in the country's 550 Sugar mills, if these sugar mills wereto adopt technically and economically optimal levels of cogeneration for extracting power from the bagasse produced by them.

Technology

Combustion The thermo chemical processes for conversion of biomass to useful products involve combustion, gasification or pyrolysis. The most commonly used route is combustion. The advantage is that the technology used is similar to that of a thermal plant based on coal, except for the boiler. The cycle used is the conventional rankine cycle with biomass being burnt in high-pressure boiler to generate steam and operating a turbine with the generated steam. The exhaust of the steam turbine can either be fully condensed to produce power, or used partly or fully for another useful heating activity. The latter mode is called cogeneration. In India, cogeneration route finds application mainly in industries.

Cogeneration in Sugar and Mills: Sugar industry has been traditionally practicing cogeneration by using bagasse as a fuel. With the advancement in the technology for generation and utilization of steam at high temperature and pressure, sugar industry can produce electricity and steam for their own requirements. It can also produce significant surplus electricity for sale to the grid using same quantity of bagasse. For example, if steam generation temperature/pressure is raised from 400ºC/33 bar to 485ºC/66 bar, more than 80 KWh of additional electricity can be produced for each ton of cane crushed. The sale of surplus power generated through optimum cogeneration would help a sugar mill to improve its viability, apart from adding to the power generation capacity of the country[25]**.**

Deployment of Biomass Energy programme in India:

The Ministry has been implementing biomass power/co-generation programme since mid-nineties. Over 800 biomass power and bagasse/ Non-bagasse cogeneration projects aggregating to 10205.61 MW capacity have been installed in the country for feeding power to the grid. States which have taken leadership position in implementation of bagasse cogeneration projects are Maharashtra, Karnataka, Uttar Pradesh, Tamil Nadu and Andhra Pradesh. The leading States for biomass power projects are Chhattisgarh, Madhya Pradesh, Gujarat, Rajasthan and Tamil Nadu[26].

Central Financial Assistance and Fiscal Incentives

CFA for Briquette/Pellet manufacturing and Biomass (non- bagasse) based projects (Valid upto 31 March 2026).

Project Type	**Capital Subsidy**
Briquette/Pellet Manufacturing plants	Rs. 9 Lakh per MTPH (metric ton/hour) manufacturing capacity (maximum CFA of Rs 45 Lakhs per plant)
Biomass (Non-bagasse) cogeneration projects	Rs. 40 Lakhs/MW (on Installed Capacity) (maximum CFA of Rs. 5 Crores per project)

Service charges to Implementing/inspection agencies:

i) Implementing agency (IA) i.e. IREDA shall be provided a service charge @1% of total CFA.

ii) Performance Inspection Agency shall be provided service charge of:

(a) Rs. 25,000 per metric ton per hour (maximum Rs. 1 Lakh perproject) for Briquette/Pellet manufacturing plants, and

(b) Rs.1 Lakh/MW (Maximum Rs.5 Lakh per project) for Biomass(non-bagasse) cogeneration projects

Current Status:

As on 31.10.2022, a total capacity of 10205.61 MW has been installed in Biomass Power and Cogeneration Sector.

Installed Capacity of Biomass IPP–1871.11 MW

Installed Capacity of Bagasse Cogeneration–7562.45 MW Installed Capacity of Non-Bagasse Cogeneration-772.05 MW[27,28].

Conclusion: Biomass has always been an important energy source for the country considering the benefits it offers. India produces about 450-500 tones of biomass per year. It is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. About 32% of the total primary energy use in the country is still derived from biomass. Ministry of New and Renewable Energy has realised the potential and role of biomass energy in the Indian context and hence has initiated a number of programmes for promotion of efficient technologies for its use in various sectors of the economy to ensure derivation of maximum benefits. The Ministry has been implementing biomass power/co-generation programme since mid-nineties. Over 800 biomass power and bagasse/ Non-bagasse cogeneration projects aggregating to 10205.61 MW capacity have been installed in the country for feeding power to the grid. There is just a need to allocate necessary resources for improving these technologies and development of plan for widespread dissemination. On the biomass energy sector Indian government committed to increasing the share of non – fossils fuel in total capacity to 40% by 2030.

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