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Biomass Fired Thermal Power Generation Technology- A Route to Meet Growing Energy Demand and Sustainable Development

Amarnath Bose*† and Devender Kumar Saini**
*Sustainability Cluster, School of Engineering (SOE), University of Petroleum and Energy Studies, Dehradun, India
**Electrical Cluster, School of Engineering (SOE), University of Petroleum and Energy Studies, Dehradun, India
†Corresponding author: Amarnath Bose; bose.amarnath@gmail.com

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ABSTRACT

Energy derived from biomass is a very promising energy alternative especially when we compare the same with fossil fuels (coal, liquid fossil fuels, etc.) as the plants can absorb the carbon dioxide during the photosynthesis process and therefore can reduce the greenhouse gas (GHG) emissions generated from fossil fuels. Further, the utilization of biomass in various biomass-based thermochemical conversion technologies could help to convert waste bio-resources into bio-energy. This review paper provides an overview of various types of available biomass resources along with their chemical composition and physical properties and their utilization for the generation of power (electricity) as an alternative to coal for power generation from a Thermal Power Plant or useful form of heat or fuels/chemicals for various other industrial processes. It includes the merits and demerits of biomass-fired thermal power plants with reference to efficiency, environmental emissions, and logistics, supply chain and storage for biomass. These review papers attempt to bring forward the effective methods which could be adopted for the efficient utilization of biomass for the purpose of power generation from biomass-based thermal power plants. Further, this could also help to substantially reduce green house gas emissions and carbon footprint and help to achieve sustainable development goals.

INTRODUCTION

Biomass is a renewable energy source, derived from plants. It is one of the oldest energy sources and is been used by humankind for the generation of energy for centuries. It is still the major energy source (mainly for cooking and boiling water) in several countries and regions. Biomass is considered a CO_2 -neutral fuel, as it releases no net CO_2 emissions if carefully managed. The plants absorb the amount of CO_2 released from biomass combustion during photosynthesis. Moreover, biomass fuels have less Sulphur and usually have less nitrogen compared to coal. Therefore, biomass fuels have great potential and are more environmentally friendly due to reduced greenhouse gases emission(s) in comparison to existing fossil fuel-fired power plants. Due to this reason, the use of biomass as a fuel in the scope of clean environment technologies has gained great interest in recent years (Jack & Oko 2018, Kumar 2017).

Climate change which leads to global warming is the most notable problem in the present scenario (Change 2014). The conventional sources of energy are natural gas, coal, and nuclear energy of which electricity from coal is the major source. Globally, China is the major consumer of coal, with 2,866 mtce, which accounts for 53.0% of the world's share. In the second place, India consumes 585 mtce, 0.4% less than last year (Ramirez Pons 2021). In India, about 60% of electricity is generated using coal (Mishra 2004, Reddy 2018) but the conversion efficiency is very low, and also during this conversion process, pollutants are released into the atmosphere which is hazardous to the environment (Goyal 2015). Since coal is in finite quantity so in the future it will come to extinction. By considering all these facts, an alternate source of energy could be a possible solution for sustainable development. Renewable energy is the solution to these problems. The increase in energy demand is directly proportional to the growth of the world population (Joshi & Beck 2018).

Due to increased concern over global warming and climate change (Walther et al. 2002), researchers are trying to discover alternative energy forms to replace conventional energy as a possible solution to counter the detrimental effects caused by fossil fuels. Biomass being carbon neutral has an advantage over other forms of renewable energy sources (Johnson 2009, Ragauskas et al. 2006). As per a report by Global Bioenergy Supply and Demand Projections (Tauro et al. 2018, Berndes 2002), biomass could make up to 60% of the overall renewable energy usage (Nakada et al. 2014). The world biomass demand by the year 2030 is expected to be 108 EJ (Nakada et al. 2014).

The world has vast amounts of biomass but much of them are unexplored. Various technologies are available to convert biomass into useful energy by thermochemical and biochemical processes. Among these technologies, the biomass-fired Steam Generator (Boiler) is the most common method and has shown the greatest potential for large-scale utilization of biomass energy, especially for power generation (Kumar 2017).

In India, public sector organization like National Thermal Power Corporation (NTPC) has demonstrated the co-firing of biomass (7% blending) along with coal in their Dadri plant in the state of Uttar Pradesh (MOP 2021).

In this review paper, a comparative analysis of various types of biomass fuels has been done along with the issues associated with the effective utilization of biomass in Thermo-chemical combustion technologies.

COMPARATIVE ANALYSIS OF ELEMENTAL COMPOSITION AND PHYSICAL PROPERTIES OF BIOMASS

Biomass-based power generation technologies are highly dependent on the type of Biomass fuel. Biomass is generally analyzed as feedstock, which exhibits a variety of forms and properties that can impact power generation output.

Depending on the type of the bio-residue, the Biomass feedstock may largely vary in its physical characteristics like homogeneity and ash or moisture content, which ultimately affects the cost per unit of energy produced, transportation cost, treatment, and storage cost & efficiency of the power generation technology. The various types of feedstock include rural feedstock like forest residue and wood waste, agricultural residues, energy crops, and biogas from livestock effluent while urban feedstock includes packing crates, pallets, wastewater, and sewage biogas, municipal solid waste, or food processing residues.

The feedstock is utilized to produce power through conversion technologies like thermochemical conversion processes, which include combustion, gasification, and pyrolysis, and biochemical processes like anaerobic digestion, etc.

Resources of Biomass Feedstock

Biomass feedstock is generally heterogeneous to operate and it is composed of fibrous structure along with moisture and lignin, carbohydrates, sugars, and ash. Lignocellulose is present in plant biomass or woodstock. The biomass feedstock resources that are used as fuel for heat/gas/electricity generation are categorized as follows in Table 1.

Elemental Composition of Various Types of Biomass

The Table 2 provides the detail of the elemental constituents of various types of Biomass residues based upon the proximate and ultimate analysis:

Table 2 provides us with detailed information on various types of biomass residual fuels which could be used in a steam generator of a Thermal Power Plant along with their percentage of carbon content which determines the calorific value and the percentage of ash & moisture content respectively.

Even though biomass fuels inherently have lower calorific value when compared with fossil fuels (coal, diesel, etc.), the "carbon neutral" concept puts biomass in a more advantageous position than fossil fuels. However, the high percentage content of moisture & physical characteristic of

Table 1: Biomass feedstock resources along with fuel analysis (M/s Sathyam Power Private Ltd.- 10 MW biomass-based power plant at Village Punjas, Tehsil Merta, Distt. Nagaur, Rajasthan, India).

S. No.	Constituents	Mustard	Jeera	Sindhi Saunf	Saunf	Cotton Stalk	Mehandi
1.	Moisture %	10.79	16	4.86	8.4	7.87	13.44
2.	Ash %	4.99	6.16	3.13	6.84	3.04	1.64
3.	Volatile matter %	65.76	77.2	81.4	78.57	82.27	78.72
4.	Fixed carbon (By difference)	18.46	0.65	10.61	6.19	6.82	6.16
5.	Carbon % by Mass	37.92	61.13	74.87	67.9	71.86	68.01
6.	Hydrogen % by Mass	6.87	5.5	5.49	5.5	5.48	5.5
7.	Oxygen % by Mass		10.85	10.25	10.64	10.28	10.26
8.	Nitrogen % by Mass	0.79	0.37	1.4	0.72	1.47	1.11
9.	Sulphur % by Mass	0.34	0.3	0.15	0.3	0.019	0.15
10.	Chlorine content % by Mass	0.16	0.14	0.07	0.16	0.007	0.014
11.	Oil content %	0.97					
12.	GCV	3760	2992	3200	3130	3925	3921

Table 2: Elemental compositions with physical properties for various types of biomass fuels (M/s Sathyam Power Private Ltd.- 10 MW biomass-based power plant at Village Punjas, Tehsil Merta, Distt. Nagaur, Rajasthan, India). Comparative analysis for elemental compositions with physical properties within biomass:

		Jeera Husk	Assaliya Husk	Sindhisva Husk	Saunf Husk
A.	PROXIMATE ANALYSIS				
1.	Gross Calorific Value (GCV) kcal.kg^{-1}	3739.18	3973.09	4077.38	3651.06
2.	Net Calorific Value (NCV) kcal.kg^{-1}	3617.7	3873.7	3971.7	3519.5
3.	Moisture (as received) [%]	5.28	4.32	4.61	5.72
4.	Total Ash [%]	5.62	4.96	3.89	6.98
5.	Volatile Matter [%]	79.25	83.82	79.49	80.22
6.	Fix Carbon [%]	9.85	6.89	12.01	6.31
7.	Chlorine content [%]	1.10	0.708	0.74	0.929
8.	Oil content [%]	0.482	0.628	0.082	0.766
9.	Ash Fusion temperature (°C)	1050	960	990	1055
10.	Calcium (Ca) [%]	0.549	1.82	0.6142	0.549
11.	Magnesium Oxide (MgO) [%]	0.285	0.281	0.465	0.2843
12.	Sodium (as Na_2O) [%]	0.361	0.1315	0.542	0.409
13.	Potassium (as K_2O) [%]	0.241	0.027	0.306	0.242
14.	Seed in the sample [%]	NIL	NIL	NIL	NIL
B.	ULTIMATE ANALYSIS				
15.	Carbon (as C) [%]	54.6	40.4	26.7	44.61
16.	Nitrogen (as N) [%]	2.8	0.87	3.61	2.17
17.	Sulphur (as S) [%]	1.7	1.3	0.71	0.55
18.	Hydrogen (as H) [%]	4.5	3.6	4.2	1.82
19.	Oxygen (as O) [%]	40.9	53.8	88.8	50.75

the ash which is produced in the steam generator should be a matter of concern & requires greater attention.

GLOBAL SCENARIO OF BIOMASS-BASED THERMAL POWER GENERATION

Bioenergy grew by an evaluated 5 percent in 2019, dropping behind the normal annual development from 2011. In Sustainable Developments Scenarios (SDS), bioenergy production of electrical energy will rise by 6 percent annually by 2030 (Kang et al. 2020, IEA 2018).

Table 3 and Fig. 1 provide the global scenario of the utilization of biomass resources in various countries for the generation of power (electricity) and thermal energy (heat) produced from captive power plants wherein a gradual increase in its utilization is observed among most of the nations.

INDIAN SCENARIO OF BIOMASS-BASED THERMAL POWER GENERATION

The percentage of biomass-independent power plants (IPP), Bagasse cogeneration, and non-Bagasse cogeneration power plant are shown in Fig. 2 wherein the percentage share of bagasse-based biomass cogeneration is most prominent.

The biomass installed capacity in key Indian states is shown in Fig. 3 and Table 4. Karnataka, Uttar Pradesh, and Maharashtra are among the Indian states leading in biomass-based power plants indicating that the larger states have a greater potential for the effective utilization of their biomass residues both forest and agricultural by-products.

The State-wise installed capacity of biomass ipp/bagasse cogeneration/non-bagasse cogeneration in India is shown in Table 4.

BIOMASS FUEL-FIRED THERMAL POWER PLANT

Among the many available technologies, the biomass-fired Steam Generator (Boiler) is the most common method and has shown the greatest potential for large-scale utilization of biomass energy, especially for power generation or the utilization of the heat produced during combustion of the biomass in a process like sugar manufacturing plant, etc. Fig.

Table 3: Technical features of biomass power and CHP plants around the world (IRENA 2015).

Country	Year	Efficiency	Capacity	
			Megawatt electric [MWe]	Megawatts thermal [MWt]
Austria	N/A		15	
Belgium	2010		24	
Denmark	2009		35	85
Finland	2002	29.9	14	28
Finland	2010	28.3	25	50
Finland	1996	23.2	17	48
Finland	1990		14	41
Germany	2002	16.5	9	
Germany	2004	19.4	20	65
Germany	2005	26.6	20	23
Germany	2009	19.0	8	30
Germany	2012		7	30
France	2010		30	
Hungary	2009		20	
Hungary	2010	31.5	50	
Ireland	2005	16.0	2.5	10
Ireland	2004	16.1	1.8	3.5
Netherlands	2002	29.9	25	
Portugal	1999	26.5	9	
Spain	2003	32.0	25	
Sweden	1982		65	129
Sweden	2009		83	200
United Kingdom	2000	32.0	38	
United Kingdom	2007	29.5	30	10
United Kingdom	2008	31.3	44	
United Kingdom	2009	36.0	14	
United Kingdom	2011		350	
United Kingdom	2012		50	
United Kingdom	2011		25	
United Kingdom	2011		40	
United Kingdom	2011		65	
United Kingdom	2012		100	
United Kingdom	2013		150	
United Kingdom	2012		295	
United Kingdom	2015		100	
Total			1905	

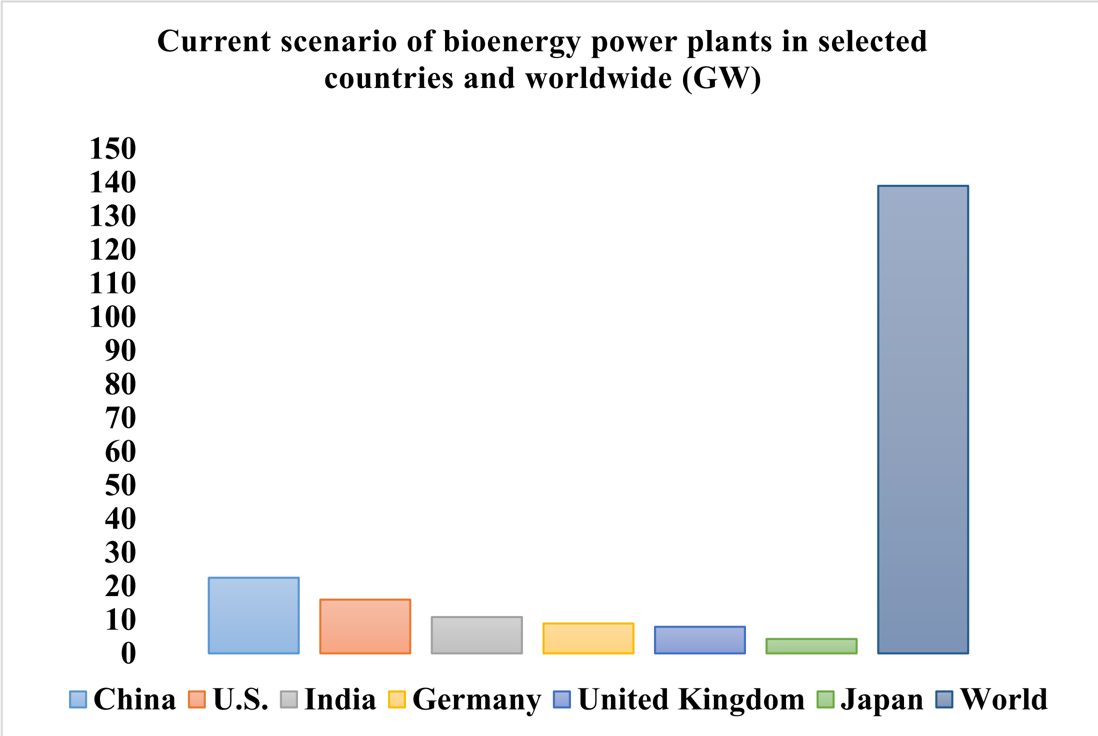

Fig. 1: Current scenario of bioenergy power plants in selected countries and worldwide (GW) (Paletto et al. 2019).

4 gives the detail of the process involved in Biomass-based Thermal Power

In the process shown in the figure above, the biomass feedstock enters the combustion chamber (furnace) of the steam generator (Boiler) along with air (O_2) and water (H_2O). During the combustion of the biomass feedstock, heat is produced which converts the water present inside the tubes of the boiler (water tube boiler) into steam. The steam is further routed to the steam turbine through the main steam pipeline, which makes the turbine rotor rotate. The generator, which is coupled with the steam turbine, produces electricity (Power) in this process. The hot flue gas exits the boiler into the atmosphere through the boiler chimney (De Jong & van Ommen 2014).

During the combustion process, the traditional Rankine cycle containing biomass getting burnt is utilized (oxidized) (Qiu et al. 2011, Drescher & Brüggemann 2007) to produce steam within a higher pressure boiler. The net power cycle efficiencies are approximately 23% to 25%. Steam turbine output is either completely condensed to generate power or partially or entirely utilized for several useful heating activities or in another process.

The energy conversion pathway shown in Fig. 4 is typical of a biomass-based Thermal Power Plant that was also taken as a case study in M/s Sathyam Power Private Ltd.- a 10 MW biomass-based power plant at Village Punjas, Tehsil Merta, Distt. Nagaur, Rajasthan, India.

BIOMASS THERMOCHEMICAL CONVERSION PROCESS- CHALLENGES

Fuel Efficiency

Biomass fuel(s) characteristically have higher moisture content and low calorific value, which leads to a decrease in the temperature resulting in lower process efficiency. Moreover, the presence of alkali and chlorine in biomass fuel causes slagging on the heating surfaces of the equipment used for conversion (boiler for direct combustion, pyrolyzer for pyrolysis, or gasifier in case of biomass gasification process) which further leads to corrosion of the equipment surfaces.

However, the intangible benefits associated with biomass fuel should also be considered which ultimately increases the profitability of the plant operator:

Biomass is a renewable form of energy source which is replenishable.

The cost of biomass residual fuel is very low compared to fossil fuel.

Table 4: State-wise installed capacity of biomass (Garg & Sharma 2020).

State/ Union Territories	Biomass Independent Power Production [In MW]	Bagasse Cogeneration [In MW]	Non-Bagasse Cogeneration [In MW]	Cumulative Installed Capacity (As of 31.12.2019)
1	2	3	4	5
Andhra Pradesh	171.2	206.9	105.57	483.67
Arunachal Pradesh	-	-	-	0
Assam	-	-	2	2
Bihar	12	100.5	12.2	124.7
Chhattisgarh	222.4	20	2.5	244.9
Goa	-	-	-	0
Gujarat	44.5	20.8	12	77.3
Haryana	19.4	102	89.26	210.66
Himachal Pradesh	-	-	9.2	9.2
Jammu &Kashmir	-	-	-	0
Jharkhand	-	-	4.3	4.3
Karnataka	137.3	1729.8	20.2	1887.3
Kerala	-	-	2.27	2.27
Madhya Pradesh	92.5	0	14.847	107.347
Maharashtra	217	2351	16.4	2584.4
Manipur	-	-	-	0
Meghalaya	-	-	13.8	13.8
Mizoram	-	-	-	0
Nagaland	-	-	-	0
Orissa	50.4	-	8.82	59.22
Punjab	138.5	161	173.95	473.45
Rajasthan	114.3	4.95	2	121.25
Sikkim	-	-	-	0
Tamil Nadu	218.7	750.4	43.55	1012.65
Telangana	60.1	98	2	160.1
Tripura	-	-	-	0
Uttar Pradesh	28	1929.5	159.76	2117.26
Uttarakhand	0.12	72.6	57.5	130.22
West Bengal	300	-	19.2	319.92
Total	1826.42	7547.45	772.047	10145.917

The environmental impacts especially associated with the environmental emissions are very low compared to conventional fossil fuel-based systems.

Thermochemical biomass-based technologies can very effectively utilize the agricultural & forest wastes by controlled combustion of the same which otherwise would be required to be burnt in the open in an uncontrolled manner leading to air pollution & deterioration of the environment.

Environmental Impacts

With reference to the emission of CO_2 and other Green House Gases (GHGs) for biomass-based power generating systems, since CO_2 produced during its combustion is absorbed during photosynthesis which greatly reduces CO_2 emissions per unit of energy produced.

Moreover, the calorific value of agro-residue pellets is comparable to bituminous coal. Thus, technically, it can

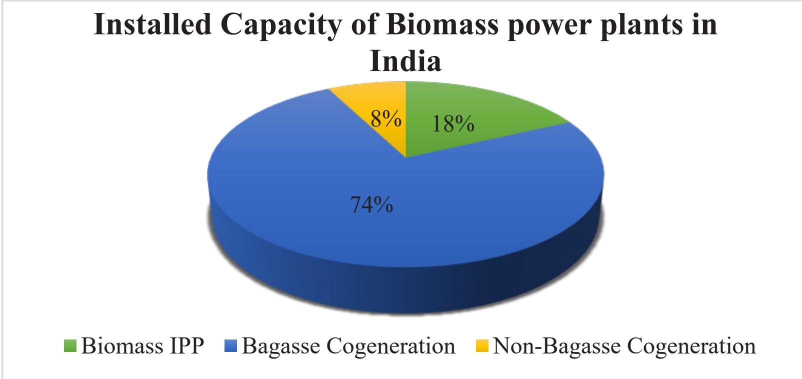

Fig. 2: Installed capacity of biomass power plants in India (Garg & Sharma 2020).

directly reduce the dependency on coal (fossil fuel) as an alternative to coal.

Additionally, systematic collection, segregation & rational distribution of biomass residue from the point of generation would also help to tackle the uncontrolled burning of agricultural residue in the open, which leads to the emission of GHGs in large quantities into the atmosphere. This can also help to control air pollution to a greater extent.

Supply Chain and Logistics of Biomass Fuel

The handling and delivery of biomass fuel are different compared to fossil fuel (especially coal) as it is large in vol-

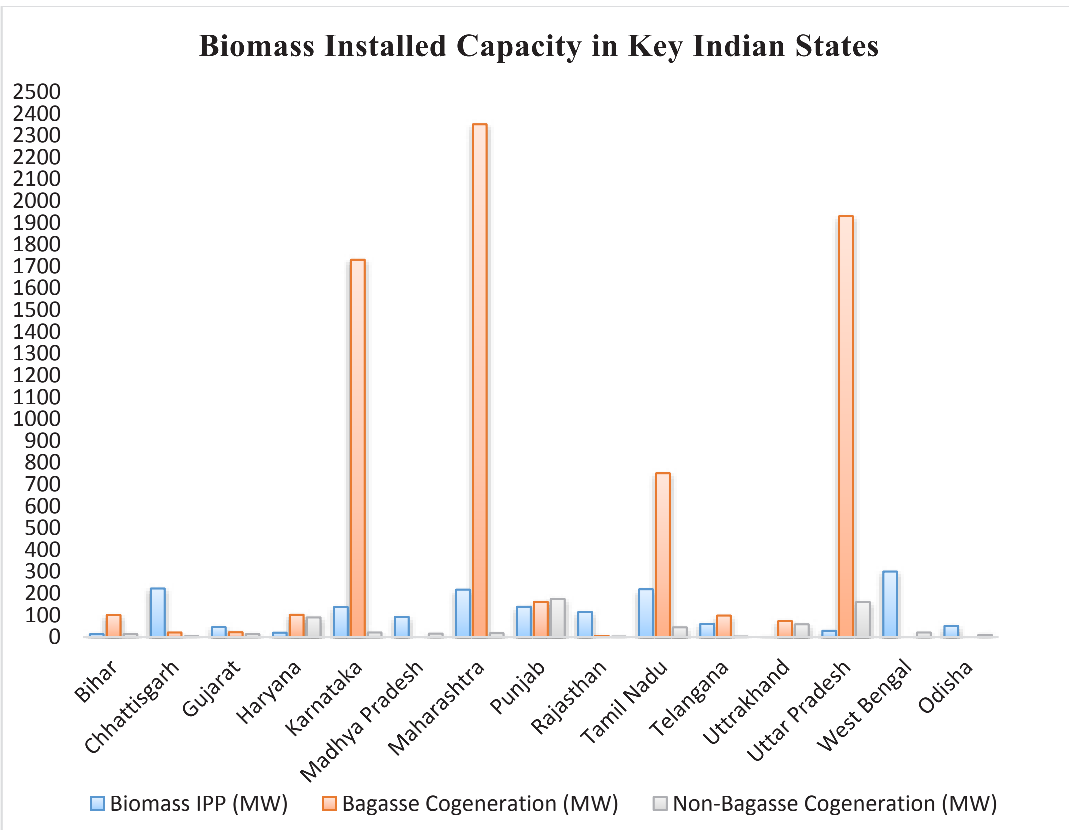

Fig. 3: Biomass installed capacity in the key Indian States (Garg & Sharma 2020).

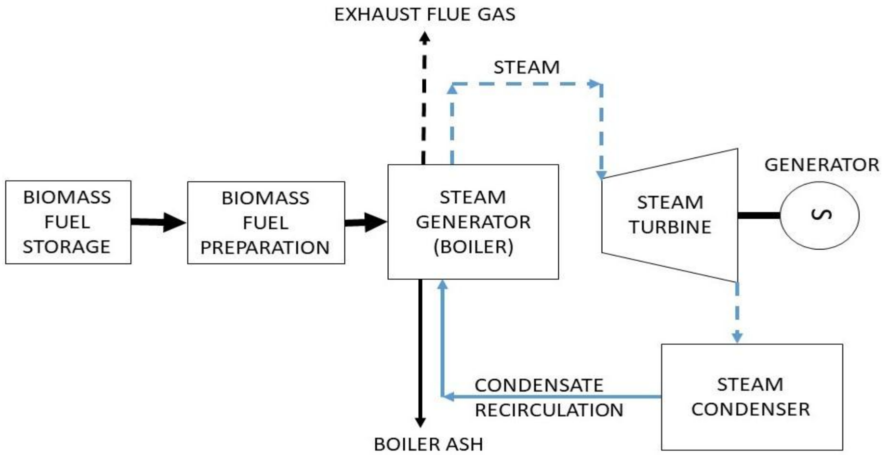

Fig. 4: Energy conversion pathway in a direct combustion biomass fired thermal power plant.

ume and its sources are scattered, so it is difficult to form a long-term stable acquisition of the fuel. The transportation, storage, and handling of the biomass pose some challenges as given below:

Due to its geographically scattered availability throughout the country, transporting the suitable biomass to the respective thermal power plants with the optimum mode of transportation is a challenge.

Dedicated fire preventive measures should be ensured, as it is highly inflammable more often due to the creation of methane gas because of the presence of microbes in the biomass residue.

The low density and high-volume nature of the biomass fuel require comparatively larger storage areas, which are required to be covered because of its hygroscopic nature.

The conveyer and storage facility should be covered adequately to restrict the spread of germs and dust into it. In addition, biomass fuel is required to be prevented from the ingression of water, which may lead to degradation of the quality of the fuel.

It is necessary to maximize the size of the storage. A bigger storage facility is also chosen because it encourages larger volumes to be bought at a sole time, resulting in a cheaper single price. In addition, it provides more suppleness in distribution preparation as well, and in the event of delayed delivery, acts as a replacement buffer.

Another critical aspect of dry biomass consideration is providing proper ventilation for avoiding condensation and mold protection, which can pose a significant health threat to spores when inhaled, as well as facilitating further drying and reducing the decay of biomass, which can result in the loss of energy content. To avoid high temperatures from becoming a fire threat, adequate ventilation is also necessary. The formation of carbon monoxide and other toxic gases is another threat that can be avoided by adequate ventilation.

CONCLUSION

With growing advancements in the power industry, renewable energy gained rapid prominence in terms of the feasible solution against environmental problems like depletion of fossil fuels, high pollution, and contamination levels, global climate changes, effect on living beings, and also fulfilling the increasing demand of power (electricity), heat or alternative liquid fuels required by the growing population. Biomass is a high potential renewable resource that could be very effectively utilized for the sustainable production of energy.

Biomass energy is based on the idea that living organisms, such as plants and animals, consume CO_2 from the atmosphere as they develop. As a result, when they are burnt, the amount of carbon released into the atmosphere is equal to the amount taken out earlier, a mechanism that could be termed carbon neutral. Thus, the agricultural/ forest residual waste which otherwise is burnt in an uncontrolled manner by the farmers could be efficiently utilized as biomass fuel. This approach would be cost-effective and provide sustainable waste management for the long-term renewable energy goals as well.

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