BIOMASS COMBUSTION
Biomass Combustion

Combustion, or burning, is the most conventional method of obtaining heat from biomass. The chemical energy of biomass is converted into heat energy through a series of chemical reactions when biomass is burnt. The efficiency of combustion depends primarily on good contact between the oxygen in the air and the biomass. The main products of efficient biomass combustion are carbon dioxide and water vapour; however, tar, smoke, and alkaline ash particles are also produced.

1. Types of combustion systems

The most common type of combustion systems used in biomass power plants are fixed bed combustion, suspension burners, and fluidized bed combustion system.

1.1 Fixed bed combustion

In fixed bed combustion, primary air is supplied from below the grate and process of combustion happen on the grate. The combustible gases produced are burnt, when secondary air is supplied, usually in a combustion zone separated from the fuel bed. Temperatures in fixed bed systems typically reach 900–1400 °C.

Fixed bed combustion systems are of two types, grate furnaces and underfeed stokers.

Grate furnaces

Grate furnaces are appropriate for the biomass fuels with high moisture content, varying particle sizes and high ash content. A grate system is designed for homogenous distribution of fuel and bed over the grate areas. Grate furnaces are of various types: fixed grates, moving grates, travelling grates, rotating grates and vibrating grates.
- Fixed grate systems are only used in small-scale applications. In these systems, fuel transport is managed by fuel feeding and gravity caused by the inclination of the grate.
- Moving grate systems are of inclined and horizontal type. An inclined grate system consists of fixed and movable rows of grate bars. By alternating horizontal forward and backward movements of the movable sections, the fuel is transported along the grate, whereas horizontally moving grates have a horizontal fuel bed. This is made by diagonal position of the grate bars. This would help in controlling the fuel movement over the grate, which otherwise sometimes get uncontrolled due to gravity.

![Inclined/sloping grate combustion system](image)

- Travelling grate systems consist of grate bars forming an endless band (like a moving staircase) moving through the combustion chamber. Fuel is supplied on one end of the combustion chamber onto the grate. The fuel is transported through the combustion chamber by the help of grate.
- Vibrating grate systems consist of inclined finned tube walls placed on springs. Fuel is fed into the combustion chamber with the help of spreaders, screw conveyors or hydraulic feeders. Primary air is fed through the fuel bed from below through holes located in finned tube walls. Due to the vibrating movement of the grate at short periodic intervals (5-10 seconds every 15-20 minutes), the formation of larger slag particles is inhibited and hence suited for fuels showing sintering and slagging tendencies (e.g. straw, waste wood).

**Underfeed stokers**

Underfeed stoker combustion takes place on the grate. The primary air is fed below the grate. The secondary air is allowed at the top. When the biomass is burnt, it is pushed down by fresh biomass. The fresh biomass is pushed on the grate by means of rams. The ignition occurs downwards against the primary air flow. The light ash contents and combustion gases fly away to the atmosphere along with primary air. Heavier ash content comes down over the grate and ultimately falls into ash pit.
Underfeed stoker fixed bed combustion systems are suitable for biomass fuels with low ash content and small particle sizes (up to 50 mm). The systems have good partial load behaviour. Load changes can be achieved more easily and has simple load control.

1.2 Suspension burner

Suspension burners are used for dry biomass (less than 15% moisture) in the form of fine particles (less than 2 mm). These burners have higher specific capacity (i.e. produce more energy from the same reactor volume or space) and produce flame similar to oil fired burner, but require fuel to be prepared carefully and stored well (fixed bed systems, on the other hand, are less demanding in this respect).

However, suspension burners are not very efficient because they need more air to prevent slag formation in the combustion system and also because they end up producing large quantities of fly ash.
1.3 Fluidized bed combustion

A fluidized bed system consists of a cylinder with a perforated bottom plate filled with a suspension bed of hot, inert and granular material. Common bed materials are silica, sand and dolomite. The bed is fluidized by fans to blow air through the perforated bottom plate. Fluidization helps in faster transfer of heat by creating a large heat-transfer surface. The larger surface area ensures complete combustion and requires smaller quantities of (25% - 35%), resulting in high efficiency. Fluidized bed combustors can handle fuels of varying sizes and shapes, high moisture content (up to 65%) and high ash content (up to 50%).

Fluidized bed combustion systems are of two types - bubbling fluidized bed (BFB) or circulating fluidized bed (CFB).

In a BFB system, the combustor is divided into two zones, namely a zone containing free-moving sand bed particles supported by air flowing upwards, resembling a bubbling fluid, and a free-board zone above the fluidized bed.

![Bubbling fluidized bed combustion system](image1)

In a CFB system, due to stronger airflow, the lighter bed particles and fuel particles are carried by the flow in a circular motion, form a cyclone, and later return to the reactor. The lighter fuel particles burn while aloft and in circulation whereas the larger or heavier particles burn while they are stationary until they become light enough to join the circulating stream.

![Circulating fluidized bed combustion system](image2)
## 2. Advantages and disadvantages of biomass combustion systems

<table>
<thead>
<tr>
<th>Types of combustion technologies</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grate furnaces</strong></td>
<td>Low investment costs for plants &lt;20 MW</td>
<td>Combustion conditions not as homogenous as for fluidized furnaces</td>
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<td></td>
<td>Low operating costs</td>
<td>Need special designs for mixed fuels such as wood fuels and herbaceous fuels</td>
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<td></td>
<td>Low dust load in the flue gas</td>
<td>Excess oxygen (7-8 volume%) in the system decreases efficiency</td>
</tr>
<tr>
<td><strong>Underfeed stokers</strong></td>
<td>Low investment costs for plants &lt;6 MW</td>
<td>Suitable for biomass fuels with low ash content and high ash melting point</td>
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<td></td>
<td>Simple and good load control due to continuous fuel feeding</td>
<td></td>
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<tr>
<td><strong>Suspension burners</strong></td>
<td>High specific capacity</td>
<td>Requirement of biomass with &lt;15% moisture</td>
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<td></td>
<td></td>
<td>Fuel drying and size reduction is required to minimize emissions and unburnt particulate carryover</td>
</tr>
<tr>
<td><strong>Bubbling Fluidized Bed furnaces</strong></td>
<td>No moving parts in the hot combustion chamber</td>
<td>High investment costs, useful for plants&gt;20 MWth</td>
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<td></td>
<td>High flexibility concerning moisture content and type of biomass</td>
<td>High operating costs</td>
</tr>
<tr>
<td></td>
<td>Low excess oxygen (3-4 % by volume of gas) raises efficiency</td>
<td>High alkali biomass (e.g straw) may create bed agglomeration</td>
</tr>
<tr>
<td><strong>Circulating Fluidized Bed furnaces</strong></td>
<td>High specific heat transfer due to high turbulence</td>
<td>High investment costs, useful for plants&gt;30 MWth</td>
</tr>
<tr>
<td></td>
<td>High flexibility concerning moisture content and type of biomass</td>
<td>High alkali biomass (e.g straw) may create bed agglomeration</td>
</tr>
<tr>
<td></td>
<td>Very low excess oxygen (1-2 % by volume of gas) raises efficiency</td>
<td>High dust content in flue gas</td>
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3. Choice of condenser: water or air cooled

Combustion of the fuel produces steam in the boiler that powers a turbine/generator to generate electricity. After expansion in the turbine the steam is then returned to the liquid state in a condenser by removing the heat from the steam by circulating cooling water around the condenser tubes containing the steam. The condensed water is then recirculated to the boiler. This would not only help reducing the amount of makeup water that has to be supplied and treated but the heat contained in the condensate is also recovered.

Generally, cooling towers are classified as once-through and closed loop systems. Once-through systems take water from nearby sources (e.g., rivers, lakes, aquifers, or the ocean) and circulate into the condenser and the heated cooling water from the condenser is discharged directly to a receiving body of water. Once-through systems were initially the most popular because of their simplicity and low cost. But nowadays, very few power plants use once-through cooling because of requirement of large amount of water resources, instead steam is cooled using "closed loop" cooling tower systems, in which the cooling water is recirculated back to the condenser. The closed loop cooling systems are categorised as:

- Water cooled (WC) condensers
- Air cooled (AC) condensers

In the wet cooling towers, the warm cooling water returns to the top of the cooling tower and trickles downward over the fill material inside the tower. As it trickles down, it contacts ambient air rising up through the tower either by natural draft or by forced draft using large fans in the tower. This contact causes a small amount of the water to be lost as evaporation. Evaporation increases the salt concentration in the circulating cooling water. To address this, a portion of the water is blown down for disposal. Fresh water make-up is supplied to compensate for the loss of evaporated water and the blow down water. Thus these systems require relatively large quantities water in cooling towers.

![Figure: Water cooled condenser](image-url)
**Air cooled systems** operate by heat transfer through a surface that separates the working fluid from ambient air, utilizing convective heat transfer.

The finned tubes are generally arranged in the form of an ‘A’ frame (or delta) over a forced draft fan with steam distribution manifold connected horizontally along the apex of ‘A’ frame. Steam flowing down inside the tubes condenses due to the cooling effect of ambient air drawn over external finned surface of the tubes by the fans. The condensate drains from finned tubes into condensate manifolds and then drains into a condensate tank before being pumped to the conventional condensate cycle. To reduce pressure drop in steam conveying system, AC condenser needs to be installed close to the turbine hall.

The air cooled systems are becoming preferred option or appropriate choice in arid regions where water resources are limited. The water requirement for cooling the gas is reduced to 80% in these systems. Although, the systems require two and a half times more land area than water cooled systems and thermal performance is also less efficient than water cooled systems due to lower heat transfer coefficient of air than water and therefore also requires much larger heat transfer areas. The operational efficiency of air cooled systems is reduced by 5%. However, the Government of India provides additional financial incentives to air coolers to cover up the additional expenses incurred by biomass power plant considering the water conservation benefits as water scarcity is becoming an increasing challenge with biomass power plants too.
Following table gives comparison of water and air cooled systems

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Water cooled</th>
<th>Air cooled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site selection</td>
<td>Plant needs to be located closer to water bodies or river to have sufficient water availability round the year.</td>
<td>Wider freedom in site selection and needs relatively much lower water needed; Suitable for arid areas.</td>
</tr>
<tr>
<td>Ease of clearances</td>
<td>’Needs clearance for having access to river and water bodies</td>
<td>Easy clearance as relatively low water requirement</td>
</tr>
<tr>
<td>Water requirement</td>
<td>The typical water requirement in a biomass power plant is 145-170 m³/day/MW, out of that about 130-150 m³/day/MW is used in water cooled condenser. This shows water cooled condensers require large amount of water in the form of make-up water to compensate for the evaporation loss cooling water.</td>
<td>The typical requirement of water in air cooled condenser is about 25 to 35 m³/day/MW, out of that air cooled condenser only needs 11-15 m³/day/MW to compensate the blow down loss.</td>
</tr>
<tr>
<td>Area requirement</td>
<td>Relatively compact system requiring lower area</td>
<td>Requires almost 2-3 times larger areas</td>
</tr>
<tr>
<td>Auxiliary Power consumption</td>
<td>Slightly lower (1-2%) than air cooled</td>
<td>Slightly higher (1-2%) than water cooled</td>
</tr>
<tr>
<td>Capital cost</td>
<td>Slightly lower (~10%) than air cooled</td>
<td>Slightly higher (~10%) than water cooled</td>
</tr>
</tbody>
</table>

4. Various pollution control systems

In an effort to avoid or at least minimize the adverse environmental impacts number of pollution control devices are used at biomass power plants

- **Cyclone separator**: Particulate-laden combustion gas is forced to change direction; and gets separated from the gas stream due to inertia of the particles. Cyclones are efficient in removing large particles and are often used in combination with other devices. They are the most common, cheapest and most adaptable control method. The advantages of Cyclones are
  - Low capital cost
  - Can be used under almost any operating condition.
  - Low maintenance requirements.

  However, Cyclones are not very efficient with fine sized particulate matter

- **Baghouse filter**: This device utilizes fabric filter tubes or a cartridge to capture fly ash and other particulates from the combustion gases before getting released to the environment through a stack. The advantages of fabric filter are:
  - Very high collection efficiency
  - Can operate over a wide range of volumetric flow rates
  - Fabric Filter houses are modular in design, and

  There are certain disadvantages of Fabric Filters, which are
  - Require a large floor area.
• Get damaged at high temperature.
• Ordinary fabrics cannot handle corrosive gases.
• Cannot handle moist gas streams

• **Electrostatic precipitator**: Nowadays this is increasingly used to remove even very fine particulates by inducing a negative charge to the particles and collecting them on a positively charged or grounded plate and are very efficient (usually more than 99%). The advantages of ESP are
  o High efficiency
  o Able to handle large air flow rates
The disadvantages include
  o More expensive to install
  o Electricity is major operating cost

• **Wet scrubber**: High-energy liquid spray is used to remove particulate and gaseous pollutants from the combustion flue gases. The advantages of wet scrubbers are:
  o Can handle incoming streams at high temperature, thus removing the need for temperature control equipment
  o Can handle high particle loading
  o Loading fluctuations do not affect the removal efficiency
  o Can handle explosive gases with little risk.
  o Gas adsorption and dust collection are handled in one unit
The disadvantages of Wet Scrubbers are
  o High potential for corrosive problems
  o Effluent scrubbing liquid poses a water pollution problem

Amongst the different control technologies, ESPs are the most efficient method to control the particulate matter, however they are very costly by order of magnitude compared to cyclones, venture scrubbers, etc. Cyclones are cheaper solution, followed by venture scrubber and bag house filters.

5. **Indicative costs of biomass combustion based power plants**

Following are indicative capital costs for biomass combustion based power plants as given in the Central Electricity Regulatory Commission’s generic tariff order for FY 2015-16 for power generation using renewable energy sources.

**Biomass power plant (using rice straw and *Prosopis juliflora*)**

• Rs 6.10 crore/MW (Rs 61.0 million) with water-cooled condenser
• Rs 6.51 crore/MW (Rs 65.1 million) with air-cooled condenser

**Biomass power plant (using biomass other than rice straw and *Prosopis juliflora*)**

• Rs 5.58 crore/MW (Rs 55.8 million) with water-cooled condenser
• Rs 6.00 crore/MW (Rs 60.0 million) with air-cooled condenser

However, it should be noted that depending on site-specific requirements, the quantities of biomass of various types used, and the level of automation required, the cost can vary significantly. It is advisable to refer to the norms approved by the state electricity regulatory commission for applicable capital cost for a grid-connected biomass-combustion-based power plant.
6. Benchmark performance parameters

When an entrepreneur would like to set up a plant with capacity more than 2 MW, he/she should go for biomass combustion system. For 2 MW and above, biomass combustion systems are more useful because it is a proven technology. Variety of biomass (such as cotton stalk, paddy bales, mustard stalk etc.) has been tested on these systems and the results are appreciable.

Amongst the different combustion systems, an entrepreneur can choose design based on the capacity of the plant required and characteristics of fuel.

- Grate furnaces and bubbling fluidized boilers are used in units below 100 MW. For large size plants, CFBs are recommended.
- Grate furnaces should be used when the fuel content is alkaline such as straws, alkaline agro crops etc. because BFBs and CFBs can’t burn due to agglomeration.
- Grate units will achieve lower efficiencies, higher emissions and will yield higher maintenance costs as compared to fluidized bed systems.
- CFB has enhanced flexibility over BFBs for firing multi-fuels with high moisture content and significantly higher efficiency up to 95%.

Following are indicative performance norms of a biomass-combustion-based power plant, as given in the Central Electricity Regulatory Commission’s generic tariff order 2014 for power generation using renewable energy sources; these norms can vary depending on fuel type and the design of system components.

**Plant load factor**
- 60% during the initial stabilization period of 6 months
- 70% during the remaining months of the first year after stabilization
- 80% from second year onwards

**Auxiliary power consumption (as percentage of rated capacity)**

*Power plants using water-cooled condensers*
- 11% during the first year of operation
- 10% from second year onwards

*Power plants using air-cooled condensers*
- 13% during the first year of operation
- 12% from second year onwards

**Station heat rate (kCal/kWh)**
- 4200 for projects using travelling-grate boilers
- 4125 for projects using AFBC boilers