BIOMASS GASIFICATION
Biomass Gasification

Biomass gasification, or producing gas from biomass, involves burning biomass under restricted air supply for the generation of producer gas. Producer gas is a mixture of gases: 18%–22% carbon monoxide (CO), 8%–12% hydrogen (H₂), 8%–12% carbon dioxide (CO₂), 2%–4% methane (CH₄) and 45%–50% nitrogen (N₂) making up the rest.

Gasification reactions

Producing gas from biomass consists of the following main reactions, which occur inside a biomass gasifier.

- **Drying**: Biomass fuels usually contain 10%–35% moisture. When biomass is heated to about 100 °C, the moisture is converted into steam.
- **Pyrolysis**: After drying, as heating continues, the biomass undergoes pyrolysis. Pyrolysis involves burning biomass completely without supplying any oxygen. As a result, the biomass is decomposed or separated into solids, liquids, and gases. Charcoal is the solid part, tar is the liquid part, and flue gases make up the gaseous part.
- **Oxidation**: Air is introduced into the gasifier after the decomposition process. During oxidation, which takes place at about 700–1,400 °C, charcoal, or the solid carbonized fuel, reacts with the oxygen in the air to produce carbon dioxide and heat.
  \[
  C + O₂ \rightarrow CO₂ + \text{heat}
  \]
- **Reduction**: At higher temperatures and under reducing conditions, that is when not enough oxygen is available, the following reactions take place forming carbon dioxide, hydrogen, and methane.
  \[
  C + CO₂ \rightarrow 2 CO
  \]
  \[
  C + H₂O \rightarrow CO + H₂
  \]
  \[
  CO + H₂O \rightarrow CO₂ + H₂
  \]
  \[
  C + 2H₂ \rightarrow CH₄
  \]

Advantages of biomass gasification technologies

- **Mature technology**: Biomass gasifier technology is a mature technology and gasifiers are available in several designs and capacities to suit different requirements.
- **Small and modular**: The technology is suitable and economical for small, decentralized applications, typically with capacities smaller than a megawatt.
- **Flexible operation**: A gasifier based power system, unlike those based on other renewable sources such as the sun and wind, can generate electricity when required and also wherever required. Whereas large thermal power plants and solar and wind based units are very location specific, biomass gasifier based systems can be set up at almost any place where biomass feedstock is available.
- **Economically viable**: For small-scale systems, the cost of power generation by biomass gasification technology is far more reasonable than that of conventional diesel based power generation.
- **Socio-economically beneficial**: Biomass gasifier based systems generate employment
for local people.

- **Mitigate climate change**: Biomass is a CO\(_2\) neutral fuel and, therefore, unlike fossil fuels such as diesel does not contribute to net CO\(_2\) emissions, which makes biomass based power generation systems an attractive option in mitigating the adverse effects of climate change.

**Types of gasifiers**

Gasifiers can be classified based on the density factor, which is a ratio of the solid matter (the dense phase) a gasifier can burn to the total volume available. Gasifiers can be (a) dense phase reactors, or (b) lean phase reactors.

**Dense phase reactors**

In dense phase reactors, the feedstock fills most of the space in the reactor. They are common, available in different designs depending upon the operating conditions, and are of three types: downdraft, updraft, and cross-draft.

**Downdraft or co-current gasifiers**

The downdraft (also known as co-current) gasifier is the most common type of gasifier. In downdraft gasifiers, the pyrolysis zone is above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow of air and gas is downwards (hence the name) through the combustion and reduction zones.

The term co-current is used because air moves in the same direction as that of fuel, downwards. A downdraft gasifier is so designed that tar, which is produced in the pyrolysis zone, travels through the combustion zone, where it is broken down or burnt. As a result, the mixture of gases in the exit stream is relatively clean. The position of the combustion zone is thus a critical element in the downdraft gasifier, its main advantage being that it produces gas with low tar content, which is suitable for gas engines.
Updraft or counter-current gasifier

In updraft gasifiers (also known as counter-current), air enters from below the grate and flows upwards, whereas the fuel flows downwards. An updraft gasifier has distinctly defined zones for partial combustion, reduction, pyrolysis, and drying. The gas produced in the reduction zone leaves the gasifier reactor together with the products of pyrolysis from the pyrolysis zone and steam from the drying zone.

The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has a higher calorific value, which makes updraft gasifiers more suitable where heat is needed, for example in industrial furnaces. The producer gas needs to be thoroughly cleaned if it is to be used for generating electricity.

Cross-draft gasifier

In a cross-draft gasifier, air enters from one side of the gasifier reactor and leaves from the other. Cross-draft gasifiers have a few distinct advantages such as compact construction and low cleaning requirements. Also, cross-draft gasifiers do not need a grate; the ash falls to the bottom and does not come in the way of normal operation.
Lean phase reactors

Lean phase gasifiers lack separate zones for different reactions. All reactions – drying, combustion, pyrolysis, and reduction – occur in one large reactor chamber. Lean phase reactors are mostly of two types, fluidized bed gasifiers and entrained-flow gasifiers.

Fluidized bed gasifiers

In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). The fuel is fed into the fluidized system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. During normal operation, the bed media is maintained at a temperature between 550 °C and 1000 °C. When the fuel is introduced under such temperature conditions, its drying and pyrolyzing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed to provide the heat source for the drying and devolatilizing reactions to continue.

Fluidized bed gasifiers are better than dense phase reactors in that they produce more heat in short time due to the abrasion phenomenon between inert bed material and biomass, giving a uniformly high (800–1000 °C) bed temperature. A fluidized bed gasifier works as a hot bed of sand particles agitated constantly by air. Air is distributed through nozzles located at the bottom of the bed.

Entrained-flow gasifiers

In entrained-flow gasifiers, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are 1200–1600 °C and the pressure is 20–80 bar. Entrained-flow gasifiers can be used for any type of fuel so long as it is dry (low moisture) and has low ash content. Due to the short residence time (0.5–4.0 seconds), high temperatures are required for such gasifiers. The advantage of entrained-flow gasifiers is that the gas contains very little tar.
Advantages and disadvantages of different gasifier types

<table>
<thead>
<tr>
<th>Gasifier type</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td><strong>Updraft</strong></td>
<td>Simple design</td>
<td>High amount of tar and pyrolysis products</td>
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<td></td>
<td>High charcoal burn-out</td>
<td>Extensive gas cleaning required if used for power application</td>
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<td></td>
<td>High fuel to gas conversion efficiency</td>
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<td></td>
<td>Accepts fuels with higher moisture content</td>
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<td></td>
<td>Accepts fuels of different sizes</td>
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<td><strong>Downdraft</strong></td>
<td>Low tar</td>
<td>Limited scale-up</td>
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<td></td>
<td>Best option for usage in gas engines</td>
<td>At low temperatures, more tar produced</td>
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<td>At lower loads, fewer particles in the gas</td>
<td>High amounts of ash and dust</td>
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<td><strong>Cross-draft</strong></td>
<td>Applicable for small-scale operations</td>
<td>High amount of tar produced</td>
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<td></td>
<td>Due to high temperatures, gas cleaning requirements are low</td>
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<tr>
<td><strong>Fluidized bed</strong></td>
<td>Compact construction</td>
<td>Gas stream contains fine particles of dust</td>
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<td>Uniform temperature profile</td>
<td>Complex system due to low biomass hold up in the fuel bed</td>
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<td>Accepts fuel size variation</td>
<td>Variety of biomass can be used but fuel flexibility is applicable for biomass of 0.1 cm to 1 cm size</td>
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<td>High ash melting point of biomass does not lead to clinker formation</td>
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<tr>
<td><strong>Entrained-flow</strong></td>
<td>Applicable to large systems</td>
<td>High investment</td>
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<td></td>
<td>Short residence time for biomass</td>
<td>Strict fuel requirements</td>
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Producer gas applications

The producer gas obtained can be used either to produce heat or to generate electricity.

**Thermal applications**

Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

- **Dryer:** The hot gas after combustion can be mixed with the right quantity of secondary air to lower its temperature to the desired level for use in dryers in the industries such as tea drying, cardamom drying etc.
- **Kilns:** Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.
- **Boilers:** Producer gas can be used as fuel in boilers to produce steam or hot water.
Power applications

Producer gas can be used for generating motive power to run either dual-fuel engines (which run on a mixture of gas and diesel, with gas replacement of up to 85% of diesel) or engines that run on producer gas alone (100% diesel replacement). In general, the fuel-to-electricity efficiency of gasification is much higher than that of direct combustion: The conversion efficiency of gasification is 35%–45% whereas that of combustion is only 10%–20%.

Generated electricity can be fed into the grid or can be used for farm operations, irrigation, chilling or cold storage, and other commercial and industrial applications.

Conditions and requirements for implementation

Biomass gasifier needs uniform-sized and dry fuel for smooth and trouble-free operation. Most gasifier systems are designed either for woody biomass (or dense briquettes made from loose biomass) or for loose, pulverized biomass.

Woody biomass:
- Pieces smaller than 5-10 cm (2–4 inches) in any dimension, depending on design
- Bulk density of wood or briquettes: less than 250–300 kg/m³

Loose biomass:
- Pulverized biomass, depending on design
- Moisture content up to 15%–25%, depending on gasifier design
- Ash content below 5% preferred; with a maximum limit of 20%
- Bulk density of loose biomass is less than 150 kg/m³

Indicative gasifier capital cost

Central Electricity Regulatory Commission (CERC) has specified the normative capital cost for biomass gasifier power projects as Rs 592.532 lakh per MW for FY 2015-16. After taking into account capital subsidy of Rs 150 lakh per MW, net project cost shall be Rs 442.532 lakh per MW for FY 2015-16.

For small-scale gasifier (100 kWe, decentralized), the cost of gasifier including engine cost is Rs 70,000 - 90,000 per kWe.

Please note that depending on site-specific requirements and the level of automation, the cost can vary significantly. For applicable capital cost, please refer to the norms approved by the state electricity regulatory commissions.
**Benchmark performance parameters**

Biomass gasifiers are appropriate for smaller capacities (few kilowatt to say 1-2 MW) and for decentralized application to exploit local renewable biomass (agro residue as well as woody) potential. In India, gasifier technology is available and successfully field demonstrated at sub megawatt level capacities. Biomass gasifiers are more appropriate for small-scale industries, where presently diesel or furnace oil based combustion systems are in use. Biomass gasifiers also hold huge potential technology for decentralized electricity generation in rural villages, both for captive power as well as tail-end grid augmentation power generating stations.

Following are indicative performance norms, which can vary depending on fuel type, its properties and the design of various system components and its operation:

- Calorific value of producer gas: Approximately 1,000-1,200 kCal/Nm³
- Specific gasification rate: Approximately 2-3 Nm³ producer gas per kilogram of air-dried biomass

Indicative performance of a gasifier based system to produce electricity:
- Approximately 0.9-1.1 kg biomass and 90-110 mL diesel per kWh electricity in dual-fuel engines
- Approximately 1.2-1.6 kg biomass per kWh electricity in engines run only on producer gas