BIOMASS COGENERATION
Cogeneration – ‘generating together’ – refers to the process wherein we obtain both heat and electricity from the same fuel at the same time. The process is also referred to as CHP, short for combined heat and power. A variety of fuels can be used for cogeneration including bagasse, natural gas, coal, and biomass. A cogeneration plant consists of four basic elements: a prime mover, an electricity generator, a heat extraction or recovery unit, and a control panel.

Fuel is burnt in the system or prime mover to convert its chemical energy into heat energy, which, in turn, produces the mechanical energy to run a generator and ultimately produce electricity. Prime movers for CHP systems include steam turbines, gas turbines, reciprocating engines, micro-turbines, and fuel cells. The heat energy from the system is also used directly, as heat, or indirectly to produce steam, hot water, and hot air, thus making it a CHP or cogeneration system.

1. Cogeneration technologies

Different types of cogeneration technologies are used depending upon the end use or purpose. Some commonly used cogeneration technologies are:

- Steam Turbines
- Gas Turbines
- Reciprocating Engines

Steam turbine cogeneration is the commonly used technology in India. However, the other two technologies are also discussed for information.
1.1 Steam turbine cogeneration systems

Steam turbines work on the principle of the Rankine cycle, which consists of a heat source (boiler) that converts water into high-pressure steam. A multistage turbine allows the high-pressure steam to expand, which lowers its pressure. The steam is then transported to a condenser, which is like a vacuum chamber and thus has negative pressure and converts, or condenses, the steam into water. Alternatively, the steam may be transported to a distribution system that delivers steam at intermediate temperatures for different applications. The condensate from the condenser or from the steam utilization system returns to the feed water pump, and the cycle continues. These systems are suitable for capacities of 500 kW to 100 MW or even higher.

Most common steam turbines used in a cogeneration system are the back-pressure type or the extraction-condensing type. The choice between the two types depends on how much electricity and heat are required, steam pressure and temperature, and the economics of operation.

1.1.1 Back-pressure steam turbines

Steam at a pressure higher or equal to atmospheric pressure is extracted from the turbine to the thermal load that is the point at which heat is required. At that point, the steam releases heat and gets condensed, or turns into water. The condensate (water) returns to the system at a flow rate that can be lower than the steam flow rate if some steam is used in the process. This loss of steam is then compensated for in the cycle in the form of ‘make-up’ water fed into the boiler. It has to be noted that this turbine system does not have a separate condenser. Back-pressure steam turbines are the most efficient among all cogeneration systems; their cogeneration efficiency ranges from 84% to 92%.

Back-pressure steam turbine systems
1.1.2 Extraction-condensing steam turbines

In extraction-condensing steam turbines, steam is extracted at one or more intermediate stages at the required pressure and temperature. The remaining steam from the turbine is transported to the condenser at very low pressure, as low as 0.05 bar (5 kPa), corresponding to a condensing temperature of approximately 33 °C.

![Extraction-condensing steam turbine diagram]

1.2 Gas turbine cogeneration systems

Gas turbine cogeneration systems work on the principle of the Brayton cycle, in which atmospheric air is compressed, heated, and then expanded, producing more power than what is consumed by the compressor in compressing and heating the air. The capacity of gas turbines varies from a fraction of a megawatt to about 100 MW. A variety of fuels can be used: natural gas, light petroleum distillates such as gas oil and diesel oil, products of coal gasification, etc. Gas turbine cogeneration systems are often more useful than steam turbines because gas turbine systems are more flexible; they can operate at widely varying ratios of electrical output to thermal output as required by the intended use.

1.2.1 Open cycle gas turbine cogeneration systems

Most of the currently available gas turbine systems work on the open Brayton cycle, in which the compressor takes in air from the atmosphere and sends the compressed air to the combustor. The air temperature also increases because of compression. Older and smaller units operate at a pressure ratio (ratio of outlet air pressure to inlet air pressure) of 15:1, whereas the newer and larger units operate at pressure ratios approaching 30:1.

From the compressor, the air is delivered through a diffuser to a combustion chamber, where fuel is injected and burnt. Exhaust gases exit the combustor at high temperatures (about 600 °C). The highest temperature in the cycle is reached at this point; the higher this temperature, the higher the cycle’s efficiency. This temperature is limited – currently to
about 1300 °C – by the ability of the gas turbine material to withstand high temperatures and the efficiency of the cooling blades.

The exhaust gases at high pressure and temperature enter the gas turbine, supplying the mechanical energy to drive the compressor and the electric generator, which, in turn, produces electricity. The exhaust gases leave the turbine at considerably high temperatures (450–600 °C), which are ideal for high-temperature heat recovery. The heat is recovered by a heat-recovery boiler for extracting heat more efficiently.

The steam produced in the heat recovery boiler can be at high pressures and temperatures, which makes the steam suitable not only for thermal processes but also for running a steam turbine to produce additional power. The exhaust gases are finally released into the atmosphere, after extracting maximum heat in the various components of the cogeneration system.

[Diagram of cogeneration system with open cycle gas turbine]

**1.2.2 Closed cycle gas turbine cogeneration systems**

In the closed cycle system, the working fluid (usually helium or air) circulates within a closed circuit. The heat is supplied to the closed cycle through a heat exchanger, instead of direct combustion of the fuel in the working fluid circuit. This arrangement ensures that both the working fluid and the turbine machinery are isolated from both the combustion chambers (heat source). On exiting from the turbine, the working fluid cools down, releasing its useful heat in the form of mechanical energy to produce electricity. In the closed cycle gas turbine, the gas turbine exhaust is recycled to the compressor after being cooled and thereby forms a closed working fluid circuit. The source of heat can be the external combustion of any fuel (e.g. industrial wastes, municipal waste, solar energy or nuclear energy). The capacities of such systems range from 2 to 50 MWe.
1.3 Reciprocating engine cogeneration systems

A reciprocating engine, such as a diesel engine, can be combined with a heat-recovery boiler that supplies heat to the steam turbine to generate both electricity and heat.

Heat from reciprocating engines can be recovered from four potential sources: exhaust gases, water from the engine jacket used for cooling, lube oil used for cooling, and the turbocharger used for cooling. The first two are the major sources, which are also easy to use and hence more common. Of the total heat lost from an engine (depending on its operating efficiency), roughly half is in the form of exhaust gases (400–500 °C), which can be utilized for producing steam or for drying bricks, ceramics, animal feed, etc. The waste heat in the form of the water used for cooling the engine (20%–30%) can be utilized for pre-heating water or generating hot air. Heat from this source can be used for some industrial processes that require low-pressure steam, in hospitals for sterilizing surgical equipment, garments, etc., and in food processing. Reciprocating engine cogeneration plants can attain overall efficiencies of more than 80%–90%, and their capacities span a wide range, from as little as a few kW to MW, depending on the capacity of the internal combustion engine.
2. Classification of cogeneration systems
Based on priority in utilizing the available energy, electricity or heat, cogeneration systems are classified as topping cycle (where priority is for generating electricity) and bottoming cycle (where heat takes priority over electricity).

2.1 Topping cycle
The topping cycle is the most commonly used method of cogeneration. In this cycle, fuel is used first for producing electricity and then for heat. Steam turbine topping cycles are commonly used in the pulp and paper industry; heat recovery and combined cycle systems are used in many chemical plants; and gas turbine cycles are useful in central heating or cooling systems.

2.2 Bottoming cycle
In a bottoming cycle, fuel is first used to produce thermal energy, and the heat rejected from the process is used for generating power through a heat-recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes in which heat is rejected in large amounts and at high temperatures, typically in cement, steel, ceramic, gas, and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants.

3. Applications
- **Industrial** applications of cogeneration are found mainly in sugar factories, food-processing plants, pharmaceuticals, oil refineries, textile mills, and steel, cement, glass, and ceramics plants, which require both heat and electricity in substantial amounts.
- **Residential, commercial, and institutional** applications tend to be found in smaller systems, often based on ‘packaged’ units. These systems are commonly used in hotels, leisure centres, offices, smaller hospitals, and residential complexes. Larger applications are based on a technology similar to the cogeneration systems used in industry, gas turbines, or larger reciprocating engines. Such systems are used in large hospitals, large office complexes, universities, and colleges.
- **District heating** systems are used at airports, office and commercial buildings, and large housing complexes. The heat provided by cogeneration is ideal for space heating and for providing hot water for domestic, commercial, or industrial use. A feature of cogeneration-driven district heating systems is the option to use a variety of fuels to suit environmental, economic, or strategic priorities.
4. Advantages and disadvantages of various cogeneration systems

The advantages and disadvantages of different types of cogeneration systems are summarized below.

<table>
<thead>
<tr>
<th>Type of cogeneration system</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-pressure steam turbine</td>
<td>• Simple configuration&lt;br&gt;• Low capital cost&lt;br&gt;• High cogeneration efficiency</td>
<td>• Low electrical efficiency&lt;br&gt;• Low part-load performance&lt;br&gt;• Limited flexibility in design and operation</td>
</tr>
<tr>
<td>Extraction-condensing steam turbine</td>
<td>• Flexible in design and operation</td>
<td>• Cost intensive</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>• Good fuel efficiency&lt;br&gt;• Relatively low investment cost per unit of electric output&lt;br&gt;• Short gestation period&lt;br&gt;• Low emissions&lt;br&gt;• High flexibility in operation</td>
<td>• High fuel cost&lt;br&gt;• Poor efficiency at low loads&lt;br&gt;• Longer operation&lt;br&gt;• High maintenance cost</td>
</tr>
<tr>
<td>Reciprocating engine cogeneration system</td>
<td>• Low civil construction cost due to block foundations and least number of auxiliaries&lt;br&gt;• High power efficiency&lt;br&gt;• Better suited as a standby power source</td>
<td>• Low overall efficiency&lt;br&gt;• Availability of low temperature steam&lt;br&gt;• Highly maintenance prone</td>
</tr>
</tbody>
</table>

5. Indicative capital costs

Central Electricity Regulatory Commission (CERC) has specified the normative capital cost for biomass cogeneration projects as Rs 452.479 lakh/MW for FY 2015-16.

However, it should be noted that depending on site-specific requirements, type of cogeneration system used, type of industrial process, and level of automation required, the cost can vary significantly. For applicable capital cost for grid-connected bagasse based power plants, please refer to the norms approved by the state electricity regulatory commissions.

6. Benchmark performance parameters

6.1 Conditions and requirements

Cogeneration projects are most appropriate for process industries or applications where there is demand for both power and thermal process heat; for example sugar mills, rice mills, textile industries, food processing units, etc. Traditionally in India, cogeneration is mainly used in sugar mills as there is targeted government programme to exploit power potential of huge bagasse availability through technology upgradation (going for higher
pressure boilers) to generate maximum power from available in-house bagasse and export surplus power to local grids. However, cogeneration can also be easily implemented in other non-bagasse industries too; especially where the fuel resource is available in abundant amount either in-house or locally, resulting in lower transportation and processing cost of biomass for the power plant. The Government is also encouraging non-bagasse cogeneration plants through their schemes. The electricity generated will be used for both electrical and thermal purpose and surplus electricity (and even process heat in some case) can be exported to the grid or other industries to secure additional revenues.

Any sugar mill/investor with sugarcane crushing capacity of more than 2,500 tonnes per day (TCD) should go for cogeneration plant; and the Government is providing incentives for boiler above 40 bar pressure and minimum power export of 3 MW. The Government is providing higher incentives for higher boiler pressure and power export. Maximum fossil fuel input should not be more than 15% in terms of kCal thermal input level.

6.2 Benchmark performance parameters

The Gross Calorific Value (GCV) for bagasse shall be considered as 2,250 kCal/kg. The station heat rate norm for a non-fossil or biomass based cogeneration power plant, as given in CERC’s generic tariff order 2014, for power generation using renewable energy sources is 3,600 kCal/kWh (for the power component).

Following are the minimal performance parameters to be met by grid connected bagasse based cogeneration plants for eligibility vis-à-vis government schemes:

- Maximum 15% use of fossil fuel of total energy consumption in kCal
- Minimum 40 bar steam pressure (for private/cooperative/public sector sugar mill)
- Minimum 40 bar steam pressure and 3 MW power export (for existing cooperative sugar mill employing boiler modification)
- Minimum 60 bar steam pressure and 5 MW power export (for BOOT/BOLT model by Independent Power Producers/State Government Undertaking/Joint Venture Company)