PDHonline Course M536 (2 PDH)

Trigeneration

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2020

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Trigeneration - Combined Generation of Power, Process Heat and Chill Water

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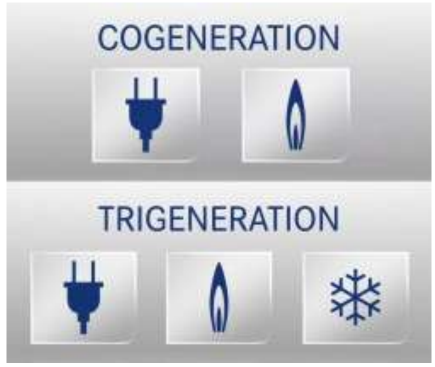
COURSE CONTENT

Introduction

Commercial building and Industrial plant owners are demanding for energy efficient technologies day by day. In recent years electricity rates has drastically increased and power reliability has decreased including blackouts (total unavailability), brownouts (partial unavailability), rolling blackouts (planned unavailability) and other interruptions. Competitive market also enforces manufacturer to use energy most effectively with reduced environment impact and minimum pollutant and greenhouse gas production. Thus in many countries eco-generation is becoming popular mean of dealing with energy.

Ecogeneration defines the optimization of economic and ecological benefits in the power generation process. Ecogeneration produces huge savings for our environment through the reduction, or even elimination, of pollution associated with power and energy production. Additionally, ecogeneration appeals to our customers' economic bottom line by providing them with significant fuel and electrical savings.

Energy technologies that fall under ecogeneration include: wind, solar, geothermal, hydrogen fuel, hydrogen fuel cells, soybean diesel fuels, ocean/tidal power, waste to energy/waste to fuel and waste to watts, combined cycle, district energy, cogeneration, trigeneration, and even quadgeneration power plants.



Quadgeneration encompasses the features of a trigeneration system, with combined electricity, heat and cooling but in addition includes the recovery of carbon dioxide from the exhaust gas. This carbon dioxide is scrubbed and can be used in industrial process or offers the potential for carbon sequestration.

There are two major ecogeneration initiatives and technologies - cogeneration and the newer technology, trigeneration. Trigeneration is one of the most attractive options, and is even more efficient and economically rewarding than cogeneration. Cogeneration, also known as combined heat and power (CHP), is the simultaneous production of electricity and useful heat, usually in the form of either hot water or steam, from one primary fuel, such as natural gas. It is also called as district energy, total energy, combined cycle, and simply cogeneration.

Trigeneration, as the name implies, refers to three energies, and is defined as the simultaneous production of heat and power, just like cogeneration, except trigeneration takes cogeneration one step further by also producing chilled water for air conditioning or process use with the addition of absorption or adsorption chillers. Trigeneration, also referred to as CHCP (combined heating, cooling and power), BCHP (building cooling, heating and power) and integrated energy systems, permits even greater operational flexibility at businesses with demand for energy in the form of heating and cooling. Just as a cogeneration power plant captures and makes use of the waste heat, absorption or adsorption chillers capture the waste (or rejected) heat and produce chilled water.

Trigeneration systems are found useful in commercial and industrial applications typically where there is a need for air conditioning or chilled water by the end users.

When a trigeneration power system is installed on-site, that is, where the electrical and thermal energy is needed by the customer so that the electrical energy does not have to be transported hundreds of miles away, and the thermal energy is fully utilized, system efficiencies can reach up to 90 percentage.

On-site trigeneration plants are much more efficient, economically sound, and environmentally friendly than typical central power plants. Because of this, customers' energy expenses are significantly lower, and the associated pollution is also much less than if the customer had an energy system supplied with electricity from the grid, along with water heaters and boiler systems on-site. Coupled with a four-pipe system, hot water/steam and chilled water can be produced simultaneously for circulation throughout the building or campus (which would be referred to as a district energy system).

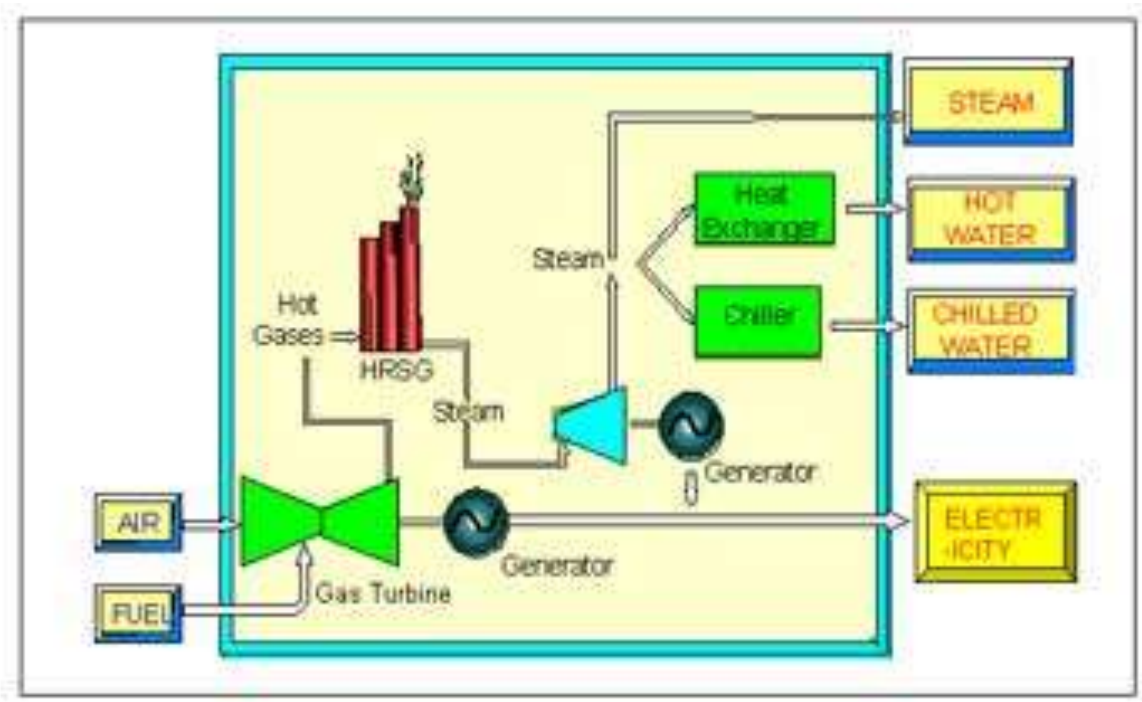


Figure 1. Schematic presentation of a gas turbine-based trigeneration facility.

And size is not an impediment, since trigeneration systems can be installed, for example, in small commercial settings, such as restaurants, hotels, schools, office buildings, and shopping centers, to large applications such as petrochemical plants, refineries, and in a city's downtown area, providing the energy requirements for multiple buildings. Schematic of gas turbine based trigeneration is shown in figure 1.

Trigeneration power plants with absorption and/or adsorption chillers have gained acceptance due to their capability of not only integrating with cogeneration systems but also because they can operate with industrial waste heat streams that can be fairly substantial. The benefit of power generation with absorption or adsorption cooling can be realized through the following example that compares it with a power generation system with conventional electric-driven compression systems. Following example shows effect on efficiency and energy saving due to use of trigeneration.

Example: A factory needs 1 MW of electricity and 500 Ton capacity refrigeration system.

Let us first consider the gas turbine that generates electricity required for the processes as well as the conventional electric-driven compression chiller. With an electricity demand of 0.65 kW/ton, the compression chiller needs 325 kW of electricity to obtain 500 ton of cooling. Therefore, a total of 1,325 kW of electricity must be provided to this factory. If the gas turbine has an efficiency of 30 percentage, primary energy (gas equivalent) consumption would be 4,417 kW.

However, a trigeneration system with absorption or adsorption chillers can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy.

In this example, the trigeneration power plant saves about 24.54 % of the primary energy needed compared to the cogeneration power plant with electric-driven compression chillers. Since many industries and commercial buildings can use combined power and heating/cooling, trigeneration systems have a high potential for industrial and commercial applications.

The advantages of a Trigeneration system

Following advantages are claimed through trigeneration system:

1. Using trigeneration to produce electricity, and specifically gas based, savings on energy costs in the order of up to 30% can be achieved, depending on the relative price of gas and electricity to the site.

2. Producing electricity on site using gas produces approximately 30% less greenhouse gases then using power from the grid for an equal amount of power output.

3. A trigeneration plant can provide a substantial proportion of a site’s power and in the case of a power failures, it can provide a proportion of the site’s energy requirements.

4. Installing a tri-generation plant provides a site with a level of independence

from the power grid. In some areas the capacity of the grid is constrained and in extreme conditions the grid may need to impose restrictions on use.

5. At some sites the grid constraints may be limited or the cost to the user to upgrade the grid so high that the use of the site is constrained. A trigeneration plant can overcome this constraint.

6. Worldwide the cost of energy from the grid is rising and will continued to rise into the foreseeable future. A trigeneration plant can be a buffer against some of this increase in energy costs.

7. The ratio of electricity produced and exhaust heat for the absorption chiller and then the ratio of cooling to heating can be varied to meet the specific site requirements.

8. Air conditioning is a major source of energy consumption with ambient temperatures reaching over 40°C in summer in some part of the world. Present cooling technologies are predominantly based on compression chillers which are driven by electricity from the grid. Due to losses in power generation and transmission, only 25 % of the primary energy used in a coal fired power plant reaches the end user. In comparison a cogeneration or Trigeneration system at the end users site, can reach overall efficiencies of 80%, as it can utilize the waste heat from power generation to cover the heating and cooling demand of the facility.

9. There are no transmission losses. The benefits are even higher, since the decentralized cogeneration and Trigeneration units are lowering peak power demand. They even could provide costly peak power and reduce damaging power cuts if they are allowed to sell to the grid.

10. A new trigeneration power plant may pay for itself in as little as 2-3 years.

Against a long list of advantages, disadvantages of trigeneration are very few.

1. Increased local pollution near to the site of trigeneration and hence it is not advisable to locate trigeneration plant in highly populated area.

2. Intimal investment is high as compared to grid electricity and central air conditioning plant.

3. Installation of trigeneration is recommended where all three types of energy are needed throughout the year.

4. Additional power supply system is required during shut down or maintenance of trigeneration plant.

Who can use Trigeneration?

Though applicable to all end electricity – process heat- refrigeration or air-conditioning users, some specific end users are listed here:

1. Hospital, nursing homes and health facilities
2. Hotels, cinemas, supermarkets and hospitality venues
3. Industrial, manufacturing, commercial and retail facilities
4. Schools, universities and research laboratories
5. Public utilities such as railways, airport terminals etc.
6. Government facilities and complexes
7. Data centers
8. Refrigerated warehouses, cold rooms and retail stores

Working of Trigeneration

A schematic diagram of Trigeneration system with various significant components is shown in Figure 2. It is based on Brayton cycle and vapor absorption refrigeration cycle comprising of an axial flow compressor, combustion chamber, turbine, counter current heat exchanger called heat recovery steam generator and vapor absorption refrigeration system.

Air after compression in the compressor enters the regenerator where its temperature is raised by utilizing the energy of the exhaust gases exiting from turbine, and then it enters to the combustion chamber where the fuel is added. Due to combustion of fuel the temperature of air further increases. Now the mixture of air & fuel known as combustion gas enters the turbine where the gases are expanded and produce the work output. The heat carried by the exhaust gases is recovered in the HRSG to generate the steam. Now the exhaust gases from HRSG enter the generator of vapor absorption refrigeration system where it gives the heat quantity to obtain refrigeration effect.

The maximum energy that can be recovered by the HRSG is limited by the effectiveness of the HRSG and the outlet temperature of the flue gas. The effectiveness of the HRSG is set to be 0.8, and the exhaust from the stack is set to be 130˚C to prevent the possibility of vapor condensation. Because of formation of vapor condensation leads to formation of Sulfuric acid that causes the acidic corrosion.

A typical single effect vapor absorption refrigeration system is used to cool the inlet air of the power generation system. The total heat required by the vapor absorption refrigeration system to cool the compressor inlet air is only a small fraction of the available energy.

Description of points in figure 2

1 Inlet air to Compressor

2 Compressor outlet or combustion chamber inlet

3 Combustion chamber outlet or turbine inlet

4 Exit from Gas Turbine or Entry to HRSG

5 Exit from HRSG or Inlet to Generator of VARS

6 Feed water inlet to HRSG

7 Steam outlet from HRSG

8 Inlet to solution heat exchanger

9 Exit from solution heat exchanger

10 Inlet to Pressure Reduction Valve

11 Exit from Pressure Reduction Valve or Inlet to absorber

12 Exit from Absorber or inlet to solution pump

13 Exit from solution Pump

14 Exit from solution heat exchanger

15 Inlet to condenser

16 Exit from condenser

17 Exit from throttle valve

18 Exit of evaporator

19 Cooling water inlet to evaporator

20 Chilled water outlet from evaporator

21 Exit of air heat exchanger

22 Cooling water inlet to absorber

23 Cooling water outlet from absorber

24 Cooling water inlet to condenser

25 Cooling water outlet from condenser

f fuel input to combustion chamber

1’ Inlet air to air heat exchanger

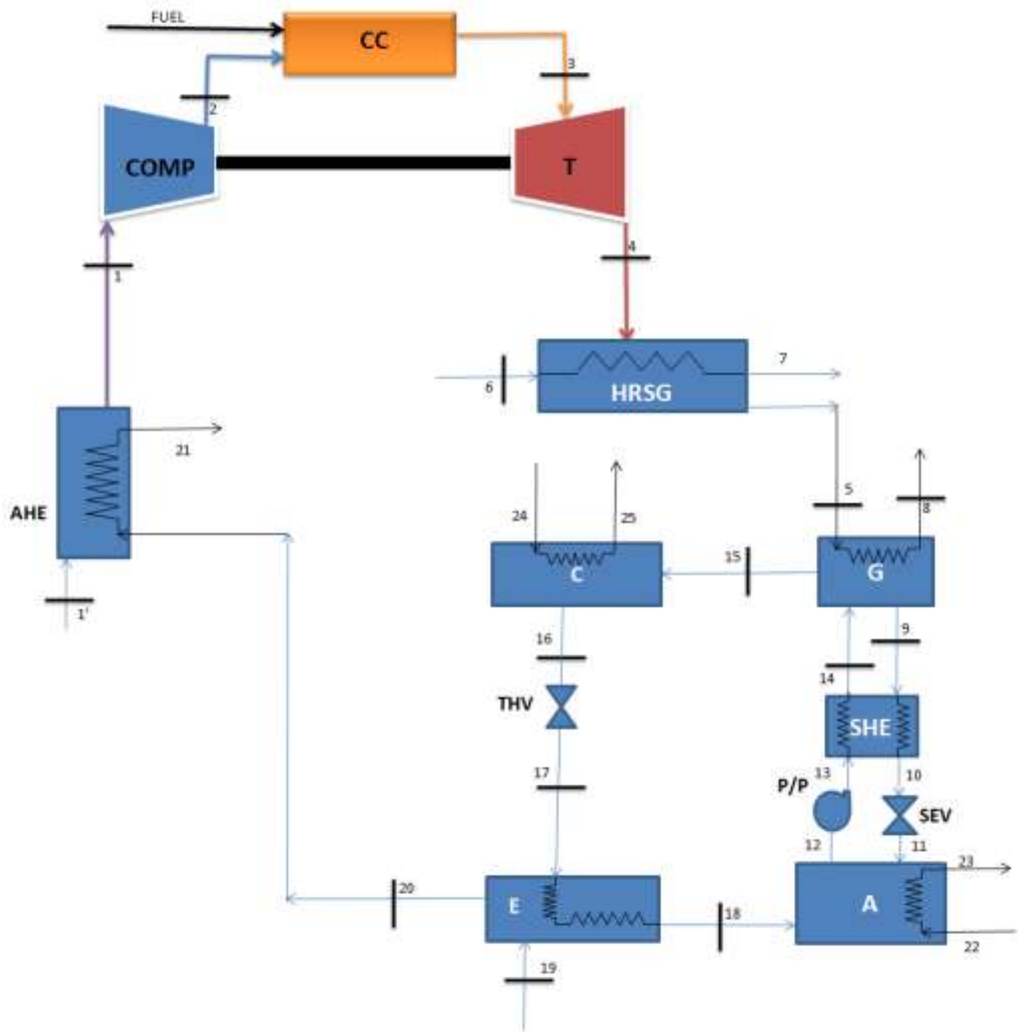


Figure 2 Schematic of Trigeneration system

The waste heat recovery process in heat recovery steam generator is shown on temperature profile diagram in figure 3. In this process water enters the boiler in the form of compressed liquid at feed water temperature T_{fw}. As the water receives heat from the hot exhaust gases, it becomes saturated, starts boiling, and is superheated. On the hot side, the exhaust gases leaving the turbine enter the steam generator and get cooled finally to the stack temperature. For maximum heat recovery, the stack temperature should approach the acid dew point of exhaust gases, while keeping the pressure drops as well as the size of boiler within desirable limits.

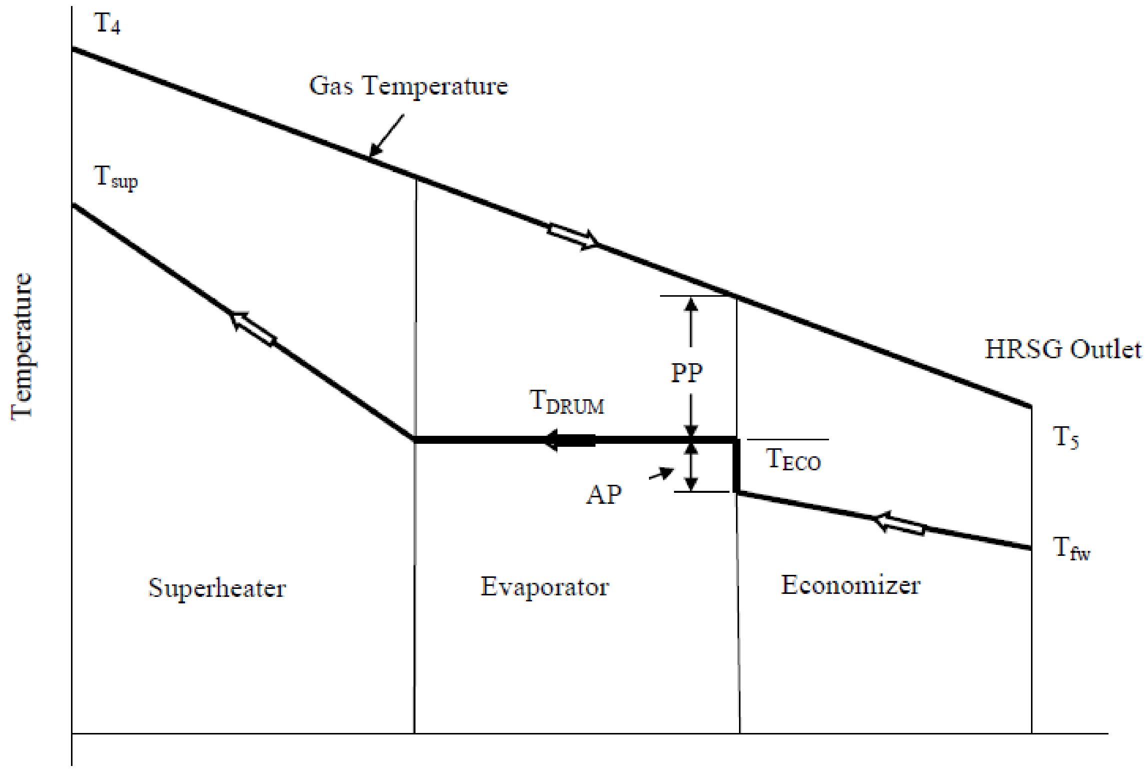


Figure 3 Waste heat recovery on temperature profile diagram

The factors which affect the cost and effectiveness of any HRSG are pinch point, approach point, allowable back pressure, stack temperature, steam temperature and pressure. The minimum temperature difference for heat transfer, which is known as pinch point plays an important role in identifying the optimum heat recovery and size of heat exchangers. Approach point is the difference between the saturation temperature and the temperature of water leaving the economizer; lowering approach point will increase probability of steaming in the economizer which may cause hammering and blanketing.

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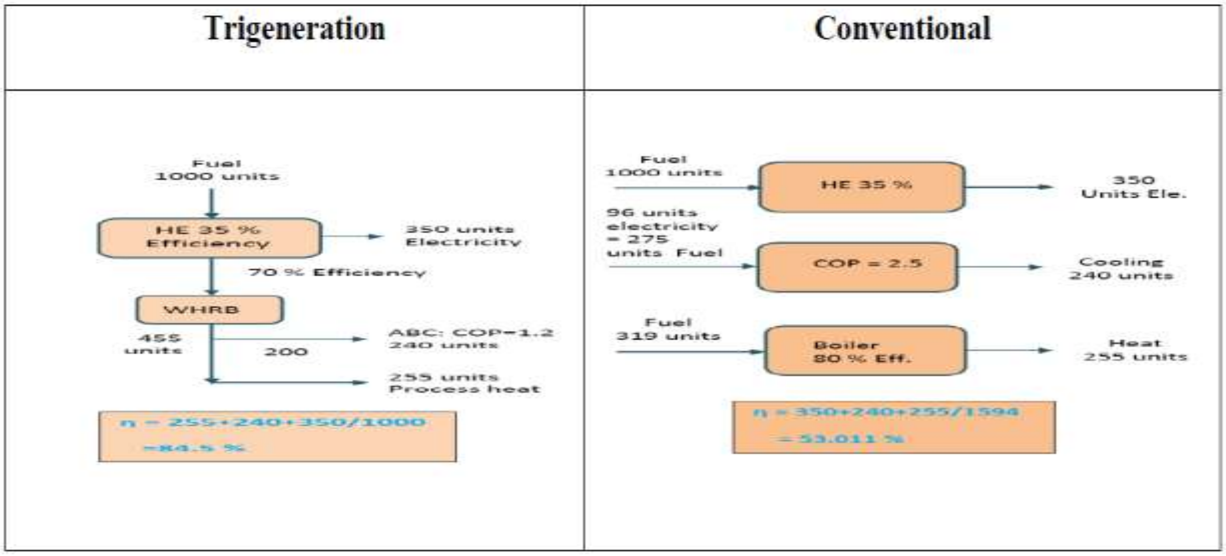

Figure 4 Comparison of Trigeneration and Conventional power generation

Figure 4 shows efficiency comparison of trigeneration and conventional power system. A trigeneration system having input of 1000 units of fuel, gives 350 units of electricity, 240 units of cooling and 255 units of process heat. So total exergy is 845 units and efficiency of system is 84.5 %. For same energy output of power, cooling and heating by conventional system the energy input required in terms of fuel is 1594 units, so efficiency of this system is 53.011 %.

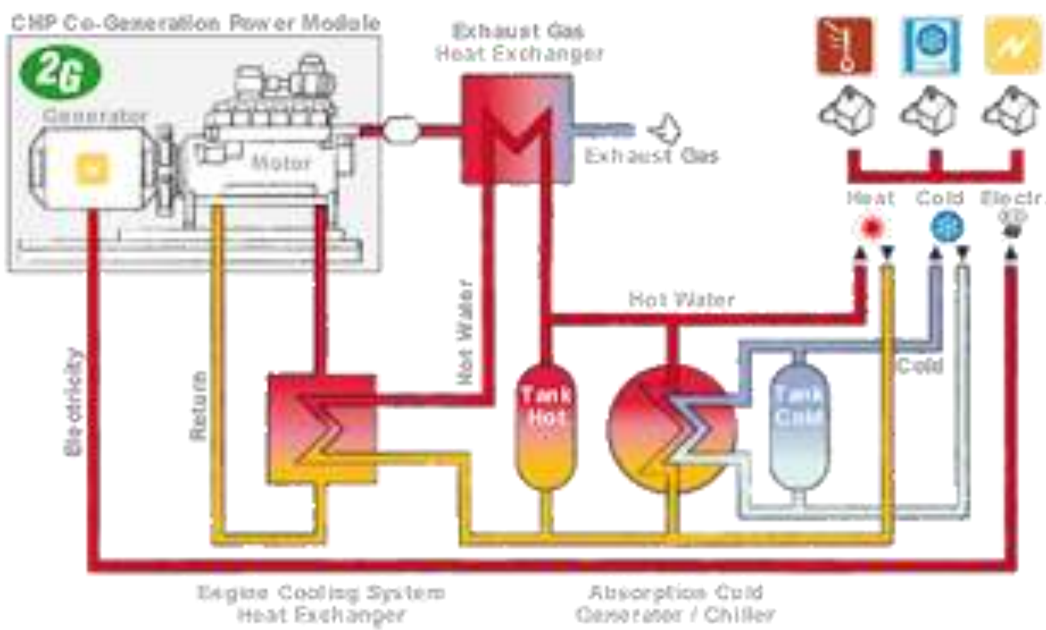

Figure 5 Diesel engine based trigeneration system

Apart from gas turbine, trigeneration concept is also applicable to reciprocating engine or steam turbine. Figure 5 shows Diesel engine based trigeneration system. Reciprocating engines are well suited to a variety of distributed generation applications, industrial, commercial, and institutional facilities for power generation and CHP and trigeneration. Reciprocating engines start quickly, follow load well, have good part- load efficiencies, and generally have high reliabilities. In many cases, multiple reciprocating engine units further increase overall plant capacity and availability. Reciprocating engines have higher electrical efficiencies than gas turbines of comparable size, and thus lower fuel-related operating costs. In addition, the first costs of reciprocating engine generator sets are generally lower than gas turbine of 3 to 5 MW capacity. Reciprocating engine maintenance costs are generally higher than comparable gas turbines, but the maintenance can often be handled by in-house staff or provided by local service organizations. Based on type of prime mover different types of chillers are installed as given in following table.

Chiller Type	Energy Source	Possible Heat Source
Steam Driven (Double Effect)	Steam at 8 bar	Boiler on GT or DG
Hot Water Driven (Double Effect)	Hot Water at 180 °C	Hot water Generator on GT or DG
Steam Driven (Single Effect)	Steam at 1 bar	Extraction/Back Pressure Turbine on GT
Hot Water Driven (Single Effect)	Hot Water at 90 ° C Exhaust gas + HW + Natural Gas	Hot Water, Jacket Water of any Engine

Thus trigeneration systems for commercial buildings are very profitable investments for building owners and industrial plants. A new trigeneration system can pay for itself in as little as two years, depending on local electric rates, natural gas (or other fuel) costs, and the load profile of the building. As mentioned earlier trigeneration systems help not only the building owner, but also benefit society in a number of ways, including:

- Increased power reliability
- Reduced power requirements on the electric grid and
- Reduced dependence on foreign oil.

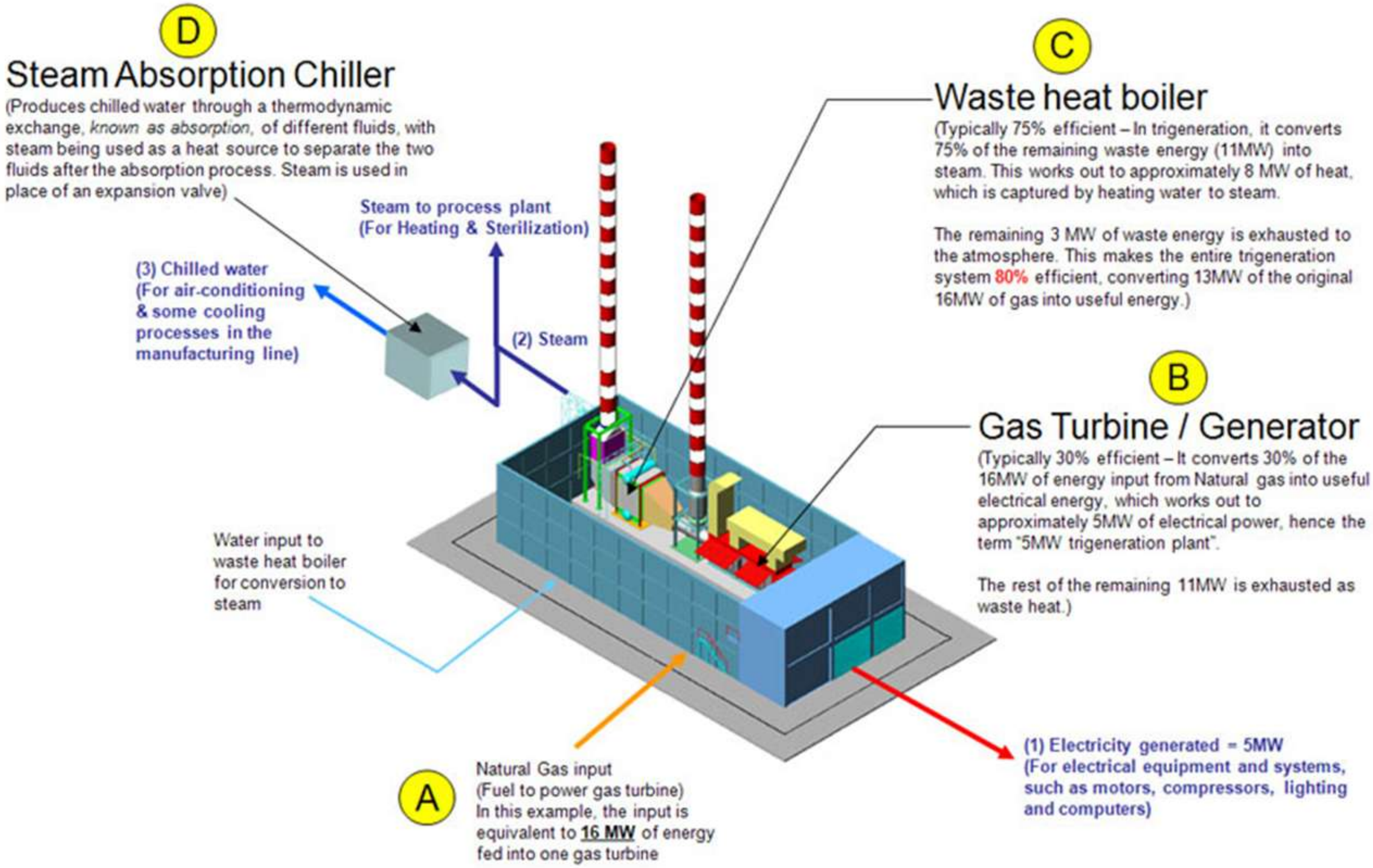

Figure 6 Energy Balance in 5 MW Trigeneration plant