

Cogeneration and Energy Savings

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Introduction

Cogeneration is the sequential generation of two different forms of useful energy from a single primary energy source.

The two different forms of energy may be:

- electrical energy and thermal energy or
- mechanical energy and thermal energy

An example would be an industry that needs both electricity and low pressure process steam. The difference between cogeneration and conventional separate generation of the two different forms of energy is shown in Fig. 1 .

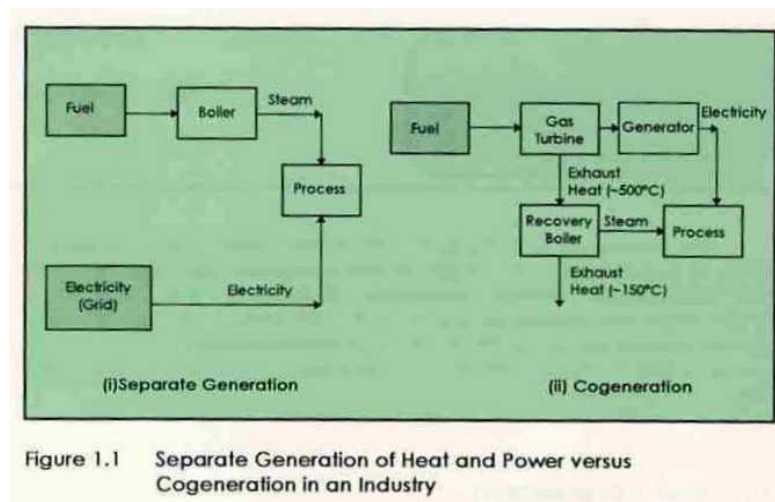


Fig. 1: Seperate generation of heat and power versus cogeneration in an Industry

The difference between a cogeneration power plant and a conventional power plant can be seen in Fig. 2 where a steam turbine is being used as prime mover.

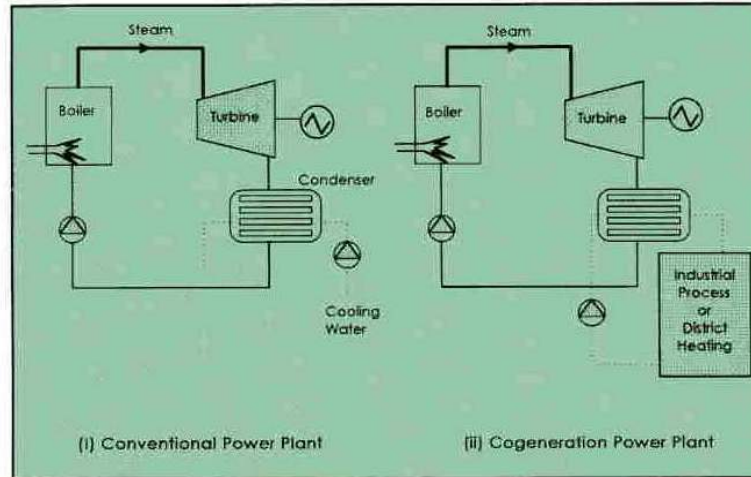


Figure 1.2 Schematic Diagrams of Conventional and Cogeneration Power Plants

Fig. 2 Schematic diagram of conventional and cogeneration power plants

Cogeneration is an energy efficient technology. It has an advantage of reducing the primary energy use, therefore possibly energy cost, while providing the same quantity of two different required forms of energy. Fig. 3 shows a comparison of the energy balance for a typical Cogeneration system and a conventional steam power generation system.

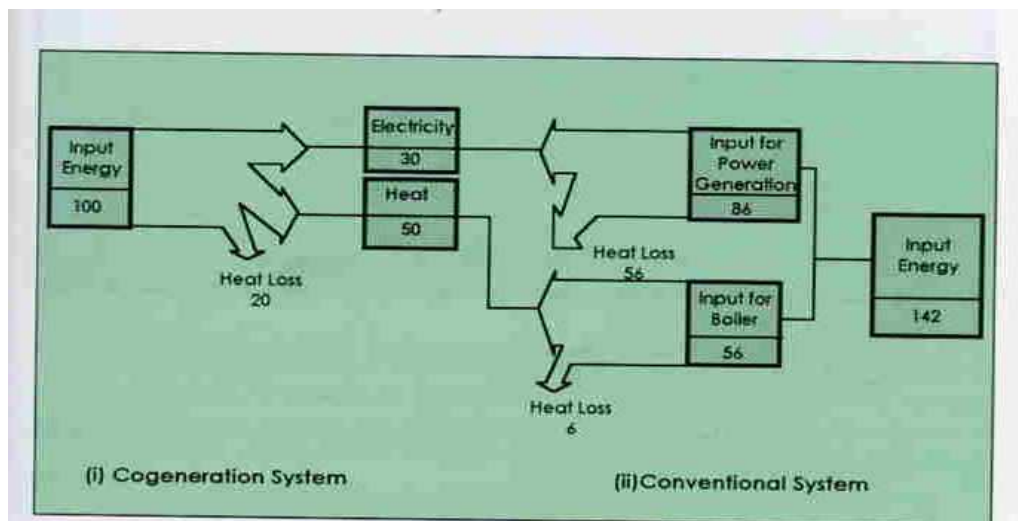


Figure 1.3 Comparison of Energy Balance for a Cogeneration System and a Conventional System

Fig. 3 Comparison of energy balance for a cogeneration system

The conventional energy supply system requires about 40% more primary energy than a cogeneration system to meet the same energy needs. Thus cogeneration technology could reduce the emission of pollutants.

Where there is a simultaneous need for heat and power [electrical or mechanical], there is a potential for Cogeneration. However, a significant saving in energy costs can be achieved and Cogeneration system can be more meaningful if the energy consuming facility has the following characteristics:

Characteristics of an ideal cogeneration facility

- Reliable power requirement
- Utilization of higher thermal energy than electricity
- Quite stable load patterns of thermal energy and electricity
- Long operating hours
- High price of grid electricity or inaccessibility to grid

The thermal energy need of a facility may be for the following purposes: drying, preheating, generation of process steam, driving energy recovery devices, producing chilled water, hot water, hot fluid, etc. Some of the application areas where cogeneration has been successfully practiced are listed below.

Typical cogeneration applications

- Utility Cogeneration
 - District heating and cooling
 -
- Industrial Cogeneration
 - Food processing
 - Pharmaceutical
 - Pulp and paper
 - Oil refinery
 - Textile industry
 - Steel industry
 - Cement industry
 - Glass industry
 - Ceramic industry
- Residential /Commercial/ Institutional Cogeneration
 - Hospital
 - University
 - Hotel

Cogeneration is also found to be a promising technology to reduce the energy bills of the facilities where there is a stable demand of both heat and power. Since cogeneration is an on-site energy supply system, the transmission and distribution losses, which are considerably large in some developing countries, could be reduced.

Nowadays, many developing countries are enjoying very high economic growth rates. The rapid industrialization leads to higher energy consumption. Many national authorities are finding it

increasingly difficult to cope with the ever rising energy demand. It is estimated that the investments required for power sector alone would be 20 to 30% of total public sector investments in some Asian developing countries.² The on-site heat and power generation at the energy consuming facilities could reduce, the burden on the public sector investments. Financial resources can then- be channeled to other socio-economic development activities. Cogeneration in industrial sector, residential and commercial buildings can offer the option of electricity export to the grid, which is widely practiced in industrialized countries, hence resulting in lower overall primary energy consumption.

The most common forms of cogeneration systems are based on the steam turbine, I.C. engine and gas turbine cycles. Of the three technologies mentioned, gas turbine cogeneration has probably experienced the most rapid development in recent years. A major client of gas turbine cogeneration is found to be the industrial sector.³ Gas turbine systems have the advantage of low maintenance cost.

I.C. engine cogeneration system is more popular with small energy consuming facilities which need much more electricity than thermal energy and quality of heat required is not very high, e.g. low pressure steam or hot water. Hospital and commercial buildings are sample clients of I.C. engine cogeneration systems. I.C. engine systems have the advantages of low initial investment cost and fuel flexibility. Furthermore I.C. engine systems are not sensitive to the ambient temperature like gas turbines, thus they lead to much lower initial investment in comparison with gas turbine systems in tropical countries.

Since many developing countries are undergoing rapid industrialization and development of infrastructure for natural gas supply, gas turbine and I.C. engine cogeneration systems appear to be interesting options today and are expected to propagate in the future.

Technical Overview of Cogeneration

Classification based on sequence of energy use

Topping cycle - Power generation first, and then utilization of thermal energy

Bottoming Cycle - Utilization of thermal energy first, and then power generation

Topping cycle system

In this cycle, the energy obtained from the combustion of a fuel is first used to produce power (electrical or mechanical), and the heat exhausted from power generation unit is used to satisfy process heat or other thermal energy requirements (Fig. 4). This thermal energy is usually in the form of low grade (i.e., low-pressure, low temperature) heat. Typical applications of this low grade heat include space heating and cooling, drying, distillation and concentration.

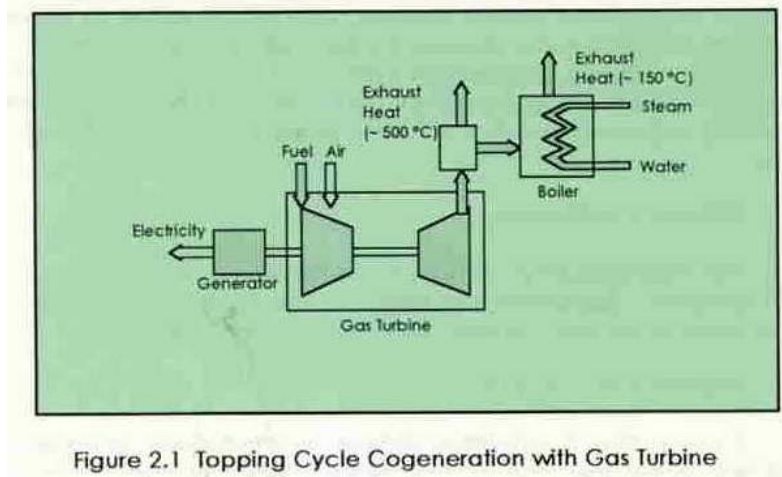


Figure 2.1 Topping Cycle Cogeneration with Gas Turbine

Fig. 4 Topping cycle cogeneration with gas turbine

Besides gas turbines, steam turbines and internal combustion engines can be used as prime movers in a topping cycle cogeneration system. The configuration of the cogeneration system can include one of the following:

- (i) Boiler/ steam turbine
- (ii) Gas turbine/ waste heat recovery boiler (or heat exchanger)
- (iii) I.C. engine/ waste heat recovery boiler (or heat exchanger) or
- (iv) Gas turbine/ waste heat recovery boiler/ steam turbine

The last one is more commonly known as combined cycle and is frequently used by power utilities to boost the overall power plant efficiency. Topping cycle cogeneration systems are widely used in food processing, pulp and paper industry, petroleum refining, textile industries, district heating, hospitals, universities and commercial buildings.

Bottoming cycle system

In this cycle, fuel is burnt first to satisfy process heat requirements, and the heat rejected from the process is used to generate power (electrical or mechanical). The thermal energy used in bottoming cycle is usually of high grade (i.e. high pressure, high temperature). The bottoming cycle systems are suitable for some manufacturing processes which require high temperature heat, for example in furnaces, and reject waste heat at still significantly high temperatures. This waste heat can be used to generate power in a number of ways.

Fig. 5 shows a typical bottoming cycle cogeneration system with a steam turbine as prime mover.

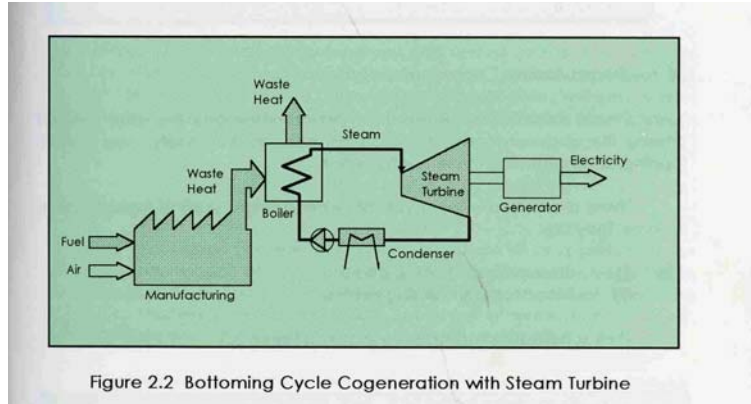


Fig. 5 Bottoming cycle cogeneration with steam turbine

There are basically two types of bottoming cycle cogeneration systems used in industrial applications:

- (i) Steam bottoming systems and
- (ii) Organic fluid bottoming systems

If a large amount of exhaust stream is available at a temperature higher than 250 °C, the steam bottoming systems are normally employed. If the temperature of available waste heat is lower than 250 °C, the organic fluid, which has lower boiling point in comparison with water, is used in the bottoming cycle. The most common organic fluids in use are R-11, R-13, R-14, ammonia, and a pyridine-water mixture.

Bottoming cycle cogeneration systems are used in cement, steel, glass and chemical industries.

Classification based on prime mover base

Cogeneration systems are sometimes classified by the type of prime mover employed. The most common systems are based on steam turbine, gas turbine, combined cycle and internal combustion engine.

Steam turbine cogeneration system

An advantage of the steam turbine cogeneration system is that a wide variety of fuels such as coal, natural gas, fuel oil and biomass can be used. The steam turbine cogeneration systems can provide more heat (kJ) per unit power output (kW-h) than other cogeneration systems. Steam turbines are mostly used for demands greater than 1 MW to a few hundreds of MW.

Gas turbine cogeneration system

The advantages of gas turbine cogeneration system are given below.

- Compact
- Low unit installation cost (\$/kW)

- Clean dry exhaust (hence can meet stringent pollution standards)
- High reliability and easy maintenance
- Short start-up time and possibility of intermittent operation

The fuels used in gas turbine cogeneration systems are natural gas, LPG and diesel fuel. The typical range of gas turbines varies from 0.1 to 100 MW.

Combined Cycle Cogeneration System

This system consists of two power generation units, gas turbine and steam turbine, and utilization of thermal energy. Combined cycle cogeneration is used when more power output is needed than thermal energy. Fig. 6 shows the schematic diagram of a typical combined cycle cogeneration unit.

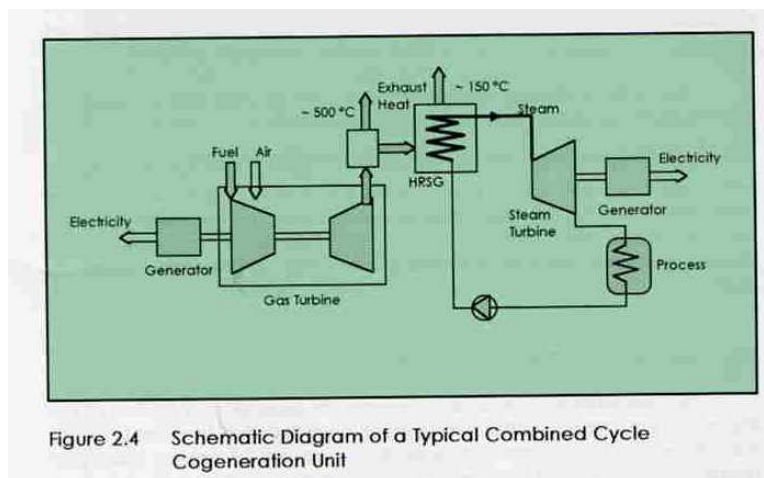


Fig. 6 Schematic diagram of a typical combined cycle cogeneration unit

The gas turbine is the prime mover in a combined cycle system. The exhaust gas from gas turbine is used to generate steam in the heat recovery steam generator (HRSG). The steam is passed through either a back pressure or a extraction-condensing steam turbine that generates additional electrical power. The exhaust steam or extracted steam from steam turbine provides the thermal energy required.

Combined cycle cogeneration systems are used by power utilities in some of the countries to supply electricity as well as for district heating due to their high overall thermal efficiency.

Internal combustion (I.C.) engine cogeneration system

This system covers both Otto engines and diesel engines. The I.C. engine cogeneration systems are suitable for low load and lower thermal energy requirement per unit power output. The energy from fuel is converted into mechanical work by rotating crankshaft which may be used to drive generator of other equipment.

Thermal energy is normally recovered from lube oil, jacket cooling water and exhaust gas. Fig. 7 shows a typical I.C. engine cogeneration system.

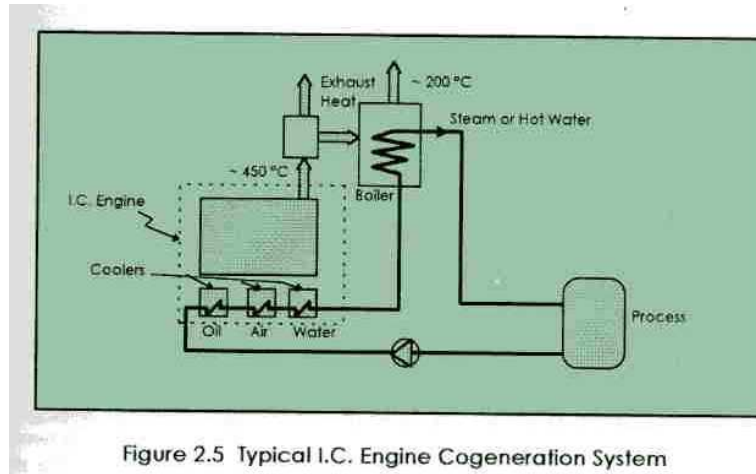


Figure 2.5 Typical I.C. Engine Cogeneration System

Fig. 7 Typical I. C. engine cogeneration system

The I.C. engines have higher power generation efficiencies (33-40%) in comparison with other prime movers. However, they need greater maintenance due to high wear and tear.

Fuel used by Otto cycle engines are either gasoline or gaseous fuel. Gas engines are nowadays finding an increasing market for utilization of biogas. The efficiency of an Otto process is generally lower than that of a diesel cycle since the compression ratio of an Otto engine must be restricted to prevent pre-ignition. The I.C. engines typically range from 50 kW to 50 MW.

Classification based on operating scheme

Base electrical load matching

- | | |
|----------------|--|
| Electricity | - Meets base electrical load
- Electricity purchase from grid during high demand period |
| Thermal Energy | - Met by cogeneration system
- (or) Met partly by auxiliary boilers
- (or) Exported to others (or discarded) |

The cogeneration plant is sized to meet the minimum electricity demand based on the historical demand curve. Rest of the needed power is purchased from the utility grid. The thermal energy requirement of the site could be met by the cogeneration system alone or by additional auxiliary boilers. If the thermal energy generated with the base electrical load exceeds the plant's demand and if the situation permits, excess thermal energy could be exported to the neighboring customers.

Base thermal load matching

- | | |
|-------------|--|
| Electricity | - Met by cogeneration system
- (or) Purchased partly from grid
- (or) Exported to grid |
|-------------|--|

- Thermal Energy - Meets base thermal load
 - Met by stand-by boilers or burners during high demand period

The cogeneration system is sized to supply the minimum thermal energy requirement of the site. Stand-by boilers or burners are operated during the periods when heat demand is higher. The prime mover installed operates at full load at all times. If the electricity demand of the site exceeds that which can be provided by the prime mover, then the remaining amount can be purchased from the grid. Likewise, if local laws permit, the excess electricity can be sold to the power utility.

Electrical load matching

- Electricity - Met fully by cogeneration system
 - No electricity purchased from grid
 Thermal Energy - Met by cogeneration system
 - (or) Met partly by auxiliary boilers
 - (or) Exported to others (or discarded)

In this operating scheme, the facility is totally independent of the power utility grid and all the power requirements of the site, including the reserves needed during scheduled and unscheduled maintenance, are to be taken into account while sizing the system. This is also referred to as a "stand-alone" system. If the thermal energy demand of the site is higher than that generated by cogeneration system, auxiliary boilers are used. On the other hand, when the thermal energy demand is low, some thermal energy is wasted. If there is a possibility, excess thermal energy is exported to the neighboring facilities.

Thermal load matching

- Electricity - Met by cogeneration system
 - (or) Purchased partly from grid
 - (or) Exported to grid
 Thermal Energy - Met fully by cogeneration system

The cogeneration system is designed to meet the thermal energy requirement of the site at any time. The prime movers are operated following the thermal demand. During the period when electricity demand exceeds the generation capacity, the deficit can be compensated by power purchase from the grid. Similarly, if the local legislation permits, electricity produced in excess at any time may be sold to the utility.

It can be seen that the choice of four operating schemes mentioned above is very much site-specific and largely depends on financial parameters, local regulations, etc.

Important Technical Parameters

The following are the important technical parameters in selecting a cogeneration system. These parameters determine the type and operating scheme of different alternative cogeneration systems.

- Heat-to-power ratio
- Quality of thermal energy needed
- Load patterns
- Fuels available
- System reliability
- Dependent system versus independent system
- Retrofit versus new installation
- Electricity buy-back
- Local environmental regulation

Heat-to-power ratio

Heat-to-power ratio is defined in a number of ways by different units of thermal and electrical energy such as Btu/kWh, kcal/kWh, lb/hr/kW, etc. However each definition reflects the ratio of thermal energy to electricity required by the energy consuming facility. Here, *heat-to-power ratio is defined as the ratio of thermal energy to electrical energy on the basis of same energy unit (kW).*

Heat-to-power ratio is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility should match with the cogeneration system which is planned to be installed.

Basic heat-to-power ratios of the different cogeneration systems are shown in Table 1 along with some technical parameters.

Table 1: Basic heat-to-power ratios and other parameters of cogeneration systems

Cogeneration System	Basic Heat- To-Power Ratio (kWth / kW _e)	Power Output (% of Fuel Input)	Overall Efficiency (%)
Back-Pressure Steam Turbine	4.0-14.3	14-28	84-92
Extraction-Condensing Steam Turbine	2.0-10.0	22-40	60-80
Gas Turbine	1.3-2.0	24-35	70-85
Combined Cycle	1.0-1.7	34-40	69-83
I.C. Engine	1.1-2.5	33-53	75-85

The steam turbine cogeneration system can offer a large range of heat-to- power ratios.

Quality of thermal energy needed

The quality of thermal energy required (temperature and pressure) also determines the type of cogeneration system.

Example:

- A sugar mill needs thermal energy at about 120°C. A topping cycle Cogeneration system can meet that thermal energy demand.
- A cement plant needs thermal energy at about 1450°C. A bottoming cycle Cogeneration system can supply both high quality thermal energy and electricity demand of the plant in an energy efficient manner.

Load patterns

The load patterns of heat and power demands affect the selection (type and size) of Cogeneration system. For instance, the load patterns of two energy consuming facilities shown in Fig. 8 would lead to two different sizes, possibly types also, of cogeneration systems.

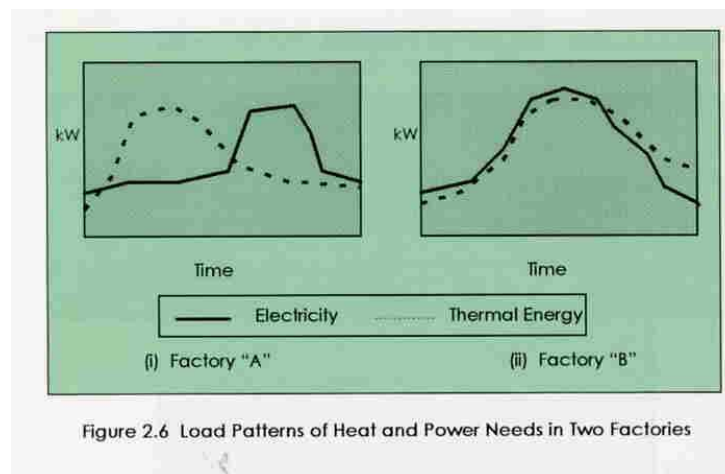


Fig. 8 Load patterns of heat and power needs in two factories

Fuels available

Depending on the availability of fuels, some potential cogeneration systems may have to be rejected. The availability of cheap or waste fuels at a site is one of the major factors in technical consideration because it determines the competitiveness of the cogeneration system.

Example:

A rice mill needs mechanical power for milling and heat for paddy drying. If a cogeneration system is considered, the steam turbine system would be the first priority because it can use the rice husk as a fuel which is available as a waste product.

System reliability

If an energy consuming facility requires very reliable power and/or heat, (for instance, pulp and paper industry cannot accommodate a prolonged loss of process steam), the cogeneration system to be installed must be modular, i.e., it should consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply.

A practical example is the steam turbine cogeneration system installed at an oil refinery in Japan. The system consists of a number of small modules of boilers and steam turbines as shown in Fig. 9.

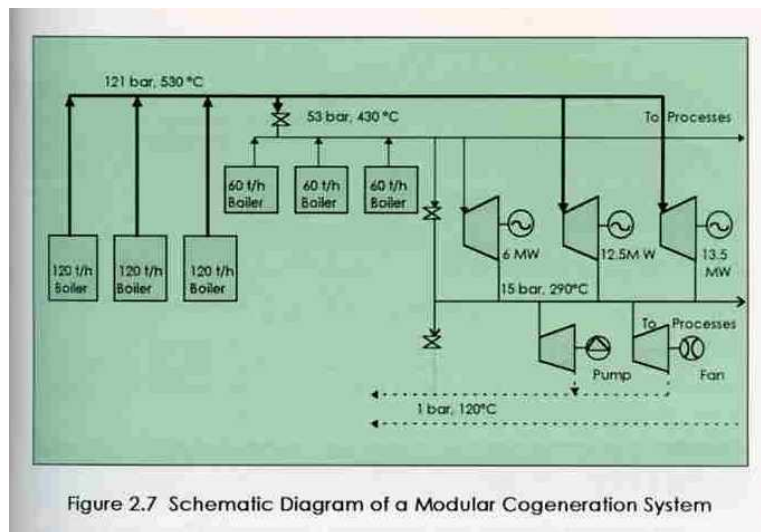


Fig. 9 Schematic diagram of a modular cogeneration system

Grid dependent system versus independent system

Dependent system means that the system can have access to the grid to buy or sell electricity. The independent system is also known as a "stand-alone" system which meets all the energy demands of the site. It can be seen that for a same energy consuming facility, the technical configuration of the cogeneration system designed as a dependent system would be different from that of an independent system.

Retrofit versus new installation

If the cogeneration system is installed as a retrofit, the system must be designed so that the existing energy conversion systems, such as boilers, can still be used. In such a circumstance, the number of options for cogeneration system would depend on whether the system is a retrofit or a new installation.

Electricity buy-back

The technical consideration of cogeneration system must take into account whether the local regulations permit the electric utilities to buy electricity from the cogenerators or not. The size

and type of cogeneration system could be significantly different if electricity is allowed to be exported to the grid.

Local environmental regulation

The local environmental regulations can limit the choice of fuels to be used for the proposed cogeneration systems. If the local environmental regulations are stringent, some available fuels cannot be considered because of the high treatment cost of the polluted exhaust gas and in some cases, the fuel itself.

Concept of Power Generation and Cooling

It would be wrong to assume that cogeneration is confined to sequential production of power and heat only. Cogeneration can provide power and cooling by incorporating absorption chillers. Absorption chiller is a device which, driven by a heat source, can provide cooling.

The concept of power and absorption cooling arises from the industries where there is a need for electricity and heating/cooling. Although cooling can be provided by conventional vapor compression chillers driven by electricity, low quality heat [i.e. low temperature, low pressure) exhausted from topping cycle cogeneration systems can drive the absorption chillers so that overall primary energy consumption is reduced.

Absorption chillers have recently gained widespread acceptance due to their capability of not only integrating with cogeneration systems but also because they can operate with industrial waste heat streams.

The benefit of power generation and absorption cooling can be realized through the following example which compares it with a power generation system with conventional vapor compression system.

Example

A factory needs 1 MW of electricity and 500 tons of refrigeration [RT). Let us first consider the gas turbine unit which generates electricity required for the processes as well as a conventional vapor compression chiller. Assuming a COP of 0.65, the compression chiller needs 325 kW of electricity to obtain 500 RT cooling effect and hence totally 1325 kW of electricity must be provided to this factory. If the gas turbine generator has an efficiency of 30%, the primary energy consumption would be 4417 kW. Schematic diagram of the system is shown in Fig. 8.10.

One ton of refrigeration (RT) is defined as the transfer of heat at the rate of 3.52 kW, which is roughly the rate of cooling obtained by melting ice at the rate of one ton per day.

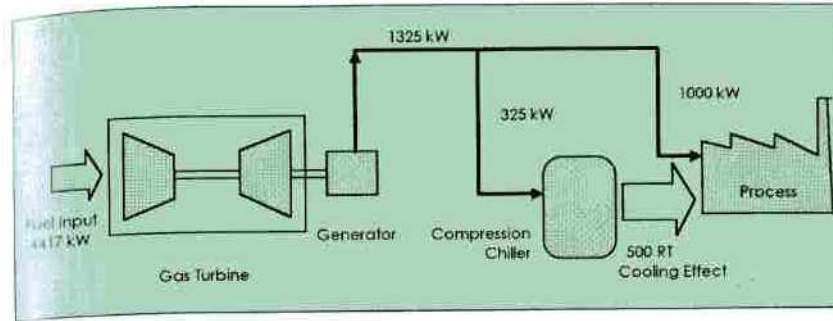


Figure 2.8 Schematic Diagram of Power Generation and Cooling with Electricity

Fig. 10 Schematic diagram of power generation and cooling with electricity

However, a cogeneration system with an absorption chiller can provide the same energy service (power and cooling) by consuming only 3333 kW of primary energy. A schematic diagram of the system is shown in Fig. 11.

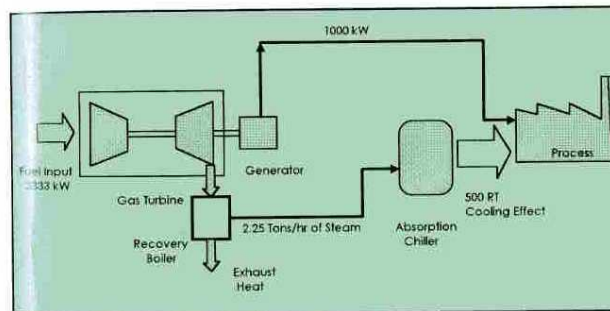


Figure 2.9 Schematic Diagram of Power Generation and Absorption Cooling

Fig. 11 Schematic diagram of power generation and absorption cooling

It can be seen that a cogeneration system absorption chiller can save about 24.5% of primary energy in comparison with only power generation system with vapor compression chiller. Furthermore, a smaller prime mover leads to not only lower capital cost but also less standby charge during the system breakdown because steam needed for the chiller can still be generated by auxiliary firing of the waste heat boiler.

Since many industries in tropical countries need combined power and heating/cooling, the cogeneration systems with absorption cooling has a very high potential of industrial application.

Incorporation of thermal storage system

Let us consider a sample cooling load pattern of an industry as shown in Fig. 12.

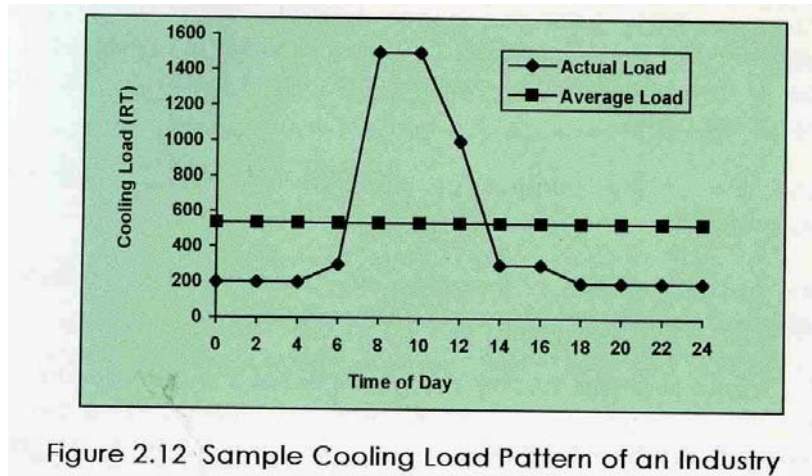


Figure 2.12 Sample Cooling Load Pattern of an Industry

Fig. 12 Sample cooling load pattern of an industry

Two options are possible to meet the cooling demand of the industry.

Option. 1 Install a chiller with the capacity of 1500 RT and supply the cooling according to the demand.

Option 2. Install a chiller with a capacity of about 550 RT and operate it steadily over the whole day. The excess cooling produced during low demand periods can be stored which can then be discharged from the storage when demand is high. The cool storage would be a buffer between the supply and demand (see Fig. 13).

If we compare the two options, the option 2 has the following advantages:

- Reduction in installed capacity
- Load shifting from the peak hours
- Ensuring emergency back-up
- Higher load factor

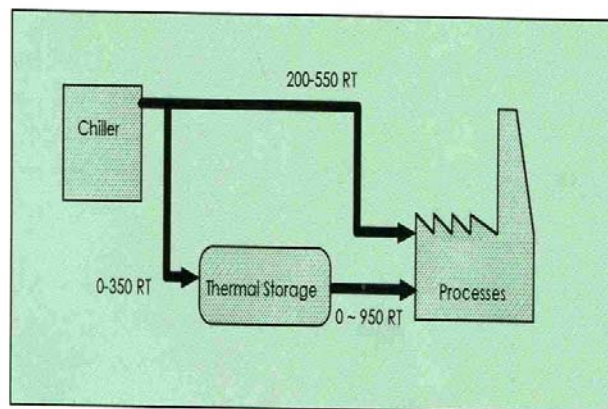


Figure 2.13 Schematic Diagram of Cool Thermal Storage Option

Fig. 13 Schematic diagram of cooling thermal storage option

Application of cool thermal storage in industries is not new. It was implemented in the dairy industry decades back. Milk was collected early in the morning from the farmers, transported in lorries to the milk cooperatives where it was poured into large containers, waiting to be bottled for final consumption or for making cheese, cream, etc. The whole chain had a weak point: due to the hygienic requirement, milk had to be chilled as rapidly as possible in order to avoid bacteria development. Cooling of large quantity of milk to a temperature of 4 to 6°C within a short time period (2 to 3 hours) was a big problem. Therefore, instead of installing large capacity chillers that would be used only for 2 or 3 hours per day, compression units were designed which were capable of producing ice. Smaller chillers were operated over 24 hours a day, producing ice which was used for rapid chilling of milk when it was delivered at the dairy.

In fact, the thermal storage systems do not in themselves save energy except for the fact that they help to avoid the part-load performance of the chiller. They can reduce the installed capacity cost and energy bills by shifting load from peak to off-peak hours. The principal elements of the economic driving forces of cool storage systems are the electricity demand charges and time-of-day tariffs.

Thermal storage in the context of cogeneration

There are many industries and commercial buildings which need combined heating, cooling and power generation such as textile industries and hotels. The thermal storage can be incorporated while designing such a facility, particularly when there are large variations in the load. The system can be designed based on the average loads so that during periods of low loads, excess cooling can be stored to be discharged during the high demand period. Thus, various equipment of the facility can operate efficiently closer to their design conditions all the time irrespective of the fluctuations in the actual demands.

The integration of cool thermal storage in a cogeneration system is highlighted in the following practical example.

Example:

The system is the cogeneration/district heating and cooling network operated by Trigen Energy Corporation in Trenton, New Jersey.

Electricity Trigen-Trenton cogenerates 12 MW of electricity which is sold to the local utility, Public Service of Electric and Gas. The power generators are driven by two diesel engines.

Heating Heat recovered from the two diesel engines and two oil/gas fired boilers is distributed to a total of 31 customers at 3 different temperatures as follows:

- High temperature water at 200 °C
(4.8 km of piping)
- Medium temperature water at 175 °C
(9.7 km of piping)
- Low temperature water at 95 °C
(3.2 km of piping)

The total amount of heat sold amounts to 112,000 MWh annually.

Cooling Chilled water is produced with a combination of chillers as follows:
 - 5 compression chillers (one of 2,000 RT, two of 1,000 RT and two of 650 RT)
 - 3 double effect absorption chillers (850 RT)

About 9,600 million ton/hour of chilled water is distributed to 20 customers through a 4.8 km network.

Problem Trigen company faced two problems while trying to meet the cooling load:
 - The expected cooling load to be served was larger than the output of the existing chilling equipment;
 -The cogenerating plant produced waste heat 24 hours a day while the chilling load duration was only 10 hours per day

Solution To overcome these constraints, Trigen opted for cool thermal storage using a chilled water storage tank of almost 10,000 m³ volume with 20,000 tons of cooling capacity.

Operation The installation of cool thermal storage allowed the absorption cooling units to be operated at night to fill the tank with chilled water, then operated during the day while the cold water stored in the tank could also be used to cool the buildings. The off-peak electricity was used to drive the vapor compression chillers at night and store chilled water in the tank. The hot water and chilled water distribution systems use variable speed pumping to provide better control and better return temperatures.

Case Studies

Three cases have been presented respectively for a hotel, paper recycling mill and a commercial building.

Nomenclature for first two cases

CF = Cash flow for specific year

AF = Annuity factor

i = Discount rate

n = Predicted economic life of the plant

I = Investment

IP = Installed power (kW)

FC = Fuel consumption (TJ/Yr)

EG = Electricity Generated (MWh)

HG = Heat generated (TJ/yr)

E/DP = Excess/deficit(-) power(MWh/yr)

EPHR = Equipment power-to-heat ratio

TI = Total investment (million Taka)

NPV = Net present value (million Taka)

ST = Steam Turbine
GE = Gas Engine
GT = Gas Turbine
TM = Thermal Match
PM = Power Match

Case 1: Cogeneration in a hotel

Pre feasibility of cogeneration in a hotel in Bangladesh was carried out. Information on steam and electricity consumption in a hotel were collected through site visits and surveys via questionnaire. Historical energy consumption data shows that the power to heat ratio of the plant was 0.35. For average power to heat ratio of 0.35, three types of the prime movers i.e. steam turbine, reciprocating engine and gas turbine cogeneration system was considered. From the sensitivity analysis the potential cogeneration alternatives of the hotel, the reciprocating engine power match option meeting power requirement of 525 kW to be the most suitable co-generation system. It represents an initial investment of 0.034 billion Taka (1 US \$ = Tk 58) and leads to an internal rate of return of 41.8%.

Energy class of the plant

The hotel requires both electrical and thermal energy. Electricity to the hotel is supplied from the national grid and natural gas is used to generate steam in a low pressure boiler, which is mainly consumed for processing. Energy utilization in machinery's can be economized for better efficiency and for low production cost. The industry operates 24 hrs/day and about 340 days a year.

Current energy consumption

Electricity consumption

Analysis of the monthly electricity consumption by the 1997 is shown in Fig. 14

Maximum Electricity Consumption (Jan): 740 MWh
Minimum Electricity Consumption (Aug): 480 MWh
Maximum Electricity Demand: 875 kW
Minimum Electricity Demand: 1,100 kW
Total Electricity Consumption in 1997: 7,433 MWh

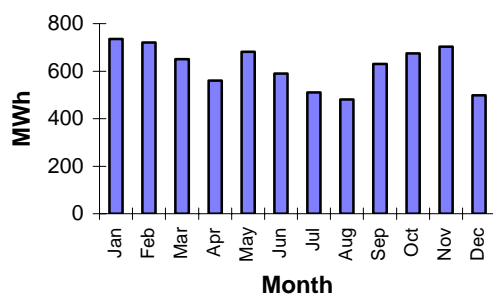


Fig. 14 Electricity consumption

Steam consumption

Analysis of the monthly steam consumption by the year 1997 is shown in Fig. 15

Maximum steam consumption (Jun): 3,872 Tons = 5,563 kg/hr

Minimum steam consumption (Jul): 2,366 Tons = 3,400 kg/hr

Total steam consumption in 1997: 9,868 Tons

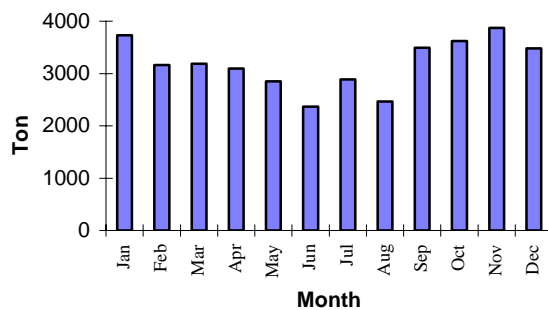


Fig. 15 Monthly steam consumption

Power to heat ratio

Analysis of the power to heat ratio by the year 1997 is shown in Fig. 16

Maximum power to heat ratio (Jun): 0.35

Minimum power to heat ratio (Dec): 0.27

Average power to heat ratio: 0.31

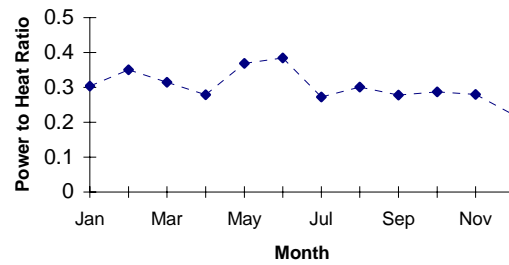


Fig. 16 Power to heat ratio

Assumptions used in pre feasibility study

Assumptions used in pre feasibility study in the spreadsheet analysis are given in Table 2.

Table 2 Assumptions used in pre feasibility study

Exchange rate	Taka/US\$	58
Tax rate	%/Year	35
Service life of the cogeneration plant	Year	15
Purchased price of electricity	Taka/kWh	3.6
Buy-back rate	%	80
Fuel price escalation rate	%	5-13
Electricity price escalation rate	%	6-13
Stand by rate	Taka/kW	80
Purchased cost of fuel (natural gas)	Taka/Cubic Meter	1.68

Assumed installation cost of a CHP plant:

For a steam turbine: US\$ 1200/kW
 for a gas turbine: US\$ 1000/kW
 for a reciprocating engine: US\$ 900/kW

The net present value (NPV) of cogeneration plant has been estimated as follows:

$$NPV = (CF)(AF) - (I)$$

$$AF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

The NPV estimates the gain or loss resulting from the proposed investment. Therefore if NPV is positive, the investment should be made because the relevant revenues exceed the financing cost. If NPV is negative, the plant is not proposable.

Methodology

Data on base electricity demand, steam demand, annual electricity consumption, annual thermal energy requirement were the initial inputs to the spreadsheet analysis. The spreadsheet of its own estimate the related parameters required for cogeneration analysis.

The steam turbine, reciprocating engine and gas turbine options with thermal match and power match results are shown in a computer print out of the spreadsheet analysis in a table. The results in the table also shows the internal rate of return on net investment for each option. Lastly three alternatives were considered for sensitivity analysis.

Common data

Power to heat ratio (required):	0.35
Actual operating hours:	8,160 hrs
Peak electricity demand:	1100 kW
Peak steam demand:	5,663 kg/hr
Base electricity demand:	875 kW
Base steam demand:	3,400 kg/hr
Site electricity requirement:	7433 MWh
Thermal energy requirement:	89.3 TJ
Fuel:	Natural gas
Calorific value of fuel:	38 MJ/m ³

Discussion

The results are presented in Table 8.3. From Table 3 it is observed that the steam turbine option does not seem: (i) with steam turbine thermal match (STTM), less than 21% of the power requirement is generated (ii) with steam turbine power match (STPM), 89% excess power and 172% excess heat is generated. This should not be considered for sensitivity study.

Table 3 Summary of results

Major Para-meters	ST		GE		GT	
	TM	PM	TM	PM	TM	PM
IP (kW)	238	875	4157	875	1873	875
FC (TJ/Yr)	88.9	326.1	382.5	88.5	205.7	97.7
EG (MWh)	1849	6783	32226	6783	14284	6783
HG (TJ/yr)	73	267.8	73	15.4	73	34.7
E/D(-) P (MWh/yr)	-5548	-650	24793	-650	6851	-650
E/DH (TJ/yr)	-16.3	151.8	-16.3	-73.9	-16.3	-54.6
EPHR	0.09	0.09	1.87	1.87	0.8	0.8
TI (million Taka)	13.7	50.4	179.59	37.8	88.4	42
NPV (million Taka)	16.9	20.3	234.1	68.4	110.8	64.5
IRR (%)	33.2	21.3	34.1	40.8	33.4	37.2

With the reciprocating engine thermal match (RETM) option, 320% excess power is generated. The project profitability will depend on the buy-back rate. This may not be a good option as the main purpose is not to earn from electricity sale. Reciprocating engine power match (REPM) option seems as almost all power need can be met though heat generated is less than 78% of the requirement. There is a need to have auxiliary boiler.

With gas turbine thermal match (GTTM) option, about 87% excess electricity is generated which not be acceptable. Gas turbine power match (GTPM) option is also good as heat deficit is around 62% which can be met by auxiliary natural gas firing in the recovery boiler and the total installation cost of GTPM is 51% less than GTTM.

Therefore, sensitivity analysis may be limited to REPM and GTPM options.

Sensitivity analysis

The sensitivity analysis carried out to see the impacts of the increase in the investment, fuel and electricity price escalation was limited to STPM, REPM and GTPM options. Figs. 17, 18, 19 are the curves obtained from the sensitivity analysis.

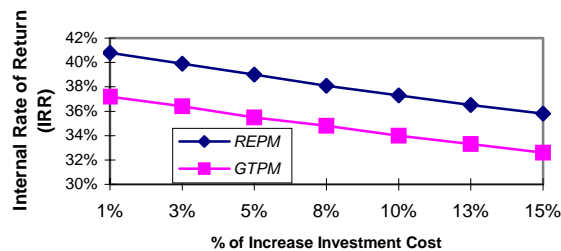


Fig. 17 IRR vs. investment cost increases

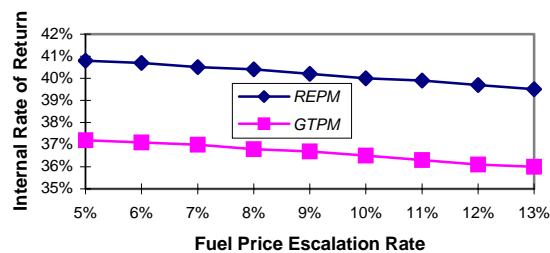


Fig. 18 IRR vs. fuel price escalation rate increase

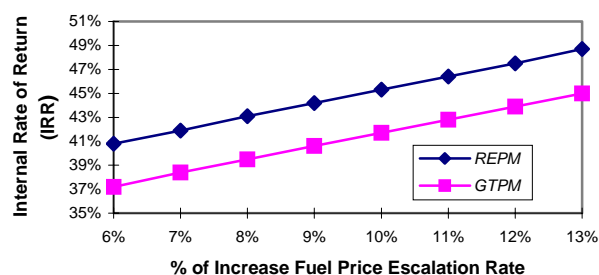


Fig. 19 IRR vs. electricity price increase

Conclusion

From the sensitivity analysis the potential cogeneration alternatives of the hotel, the reciprocating engine power match option meeting power requirement of 875 kW to be the most suitable co-generation system. It represents an initial investment of 37.8 million Taka and leads to an internal rate of return of 41.8%.

Case study-2: cogeneration in a paper recycling mill

Pre feasibility of cogeneration in a paper recycling mill in Bangladesh was carried out. Information on steam and electricity consumption in a paper recycling mill were collected through site visits and surveys via questionnaire. Historical energy consumption data shows that the power to heat ratio of the plant was 0.35. For average power to heat ratio of 0.31, three types of the prime movers i.e. steam turbine, reciprocating engine and gas turbine cogeneration system was considered. From the sensitivity analysis the potential cogeneration alternatives of the paper recycling mill, the reciprocating engine power match option meeting power requirement of 525 kW to be the most suitable co-generation system. It represents an initial investment of 0.037 billion Taka and leads to an internal rate of return of 41.8%.

Pulp and paper mills are often large and complex facilities that may produce several pulp and paper qualities from both softwood and hardwood feedstocks. However, it is possible to get an idea of relative energy performance across the industry by focussing on single-product facilities. Bleached and unbleached kraft pulping processes are essentially the same except bleached pulps are cooked to achieve a higher level of delignification in the digester, after which the pulp is bleached. As in most industries, new or modernized plants typically use less energy than old plants. Also, the industry has been more effective in reducing steam demand than electricity demand in new and retrofitted mills. State-of-the-art bleached kraft pulp mills use about 40% less steam and 5% less electricity than typical mills installed in the 1980s

Energy class of the plant

The paper recycling mill requires both electrical and thermal energy. Electricity to the factory is supplied from the national grid and natural gas is used to generate steam in a low pressure boiler, which is mainly consumed for processing. Energy counts about 38% of the production cost of the industry. Energy utilization in machinery's can be economized for better efficiency and for low

production cost. The industry operates 24 hrs/day and about 340 days a year.

Current energy consumption

Electricity consumption

Analysis of the monthly electricity consumption by the 1997 is shown in Fig. 20

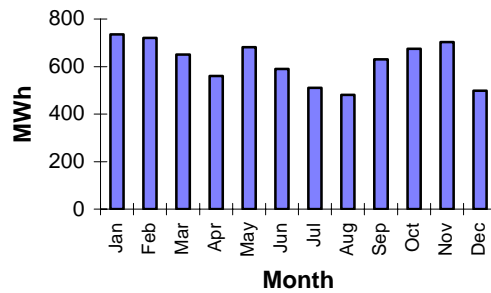


Fig. 20 Electricity consumption

Maximum Electricity Consumption (Jan): 740 MWh

Minimum Electricity Consumption (Aug): 480 MWh

Maximum Electricity Demand: 875 kW

Minimum Electricity Demand: 1,100 kW

Total Electricity Consumption in 1997: 7,433 MWh

Steam consumption

Analysis of the monthly steam consumption by the year 1997 is shown in Fig. 21.

Maximum Steam Consumption (Jun): 3,872 Tons = 5,563 kg/hr

Minimum Steam Consumption (Jul): 2,366 Tons = 3,400 kg/hr

Total Steam Consumption in 1997: 9,868 Tons

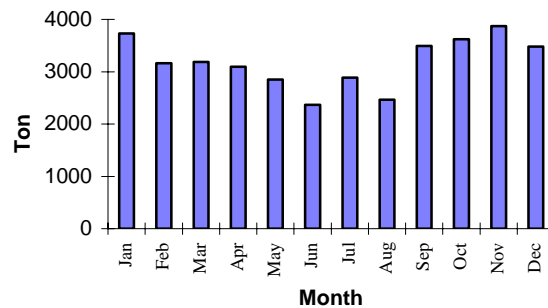


Fig. 21 Monthly steam consumption

Power to heat ratio

Analysis of the power to heat ratio by the year 1997 is shown in Fig. 22.

Maximum Power to Heat Ratio (Jun): 0.35

Minimum Power to Heat Ratio (Dec): 0.27

Average Power to Heat Ratio: 0.31

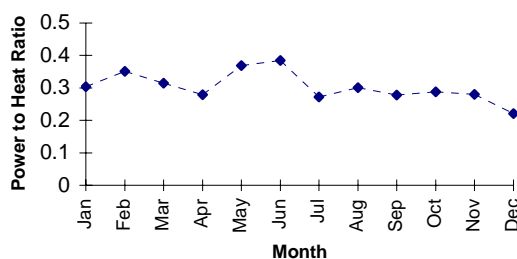


Fig. 22 Power to heat ratio

Assumptions used in pre-feasibility study

Assumptions used in pre feasibility study in the spreadsheet analysis are as follows:

Exchange Rate	Taka/US\$	48
Tax Rate	%/Year	35
Service Life of the Cogeneration Plant	Year	15
Purchased Price of Electricity	Taka/kWh	3.6
Buy-back Rate	%	80
Fuel Price Escalation Rate	%	5-13
Electricity Price Escalation Rate	%	6-13
Stand by Rate	Taka/kW	80
Purchased Cost of Fuel (Natural Gas)	Taka/Cubic Meter	1.68

Assumed installation cost of a CHP plant:

For a steam turbine: US\$ 1200/kW

for a gas turbine: US\$ 1000/kW

for a reciprocating engine: US\$ 900/kW

The net present value (NPV) of cogeneration plant has been estimated as follows:

$$NPV = (CF)(AF) - (I)$$

$$AF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

The NPV estimates the gain or loss resulting from the proposed investment. Therefore if NPV is positive, the investment should be made because the relevant revenues exceed the financing cost. If NPV is negative, the plant is not proposable.

Methodology

Data on base electricity demand, steam demand, annual electricity consumption, annual thermal energy requirement were the initial inputs to the spreadsheet analysis. The spreadsheet of its own estimate the related parameters required for cogeneration analysis.

The steam turbine, reciprocating engine and gas turbine options with thermal match and power match results are shown in a computer print out of the spreadsheet analysis in a table. The results in the table also shows the internal rate of return on net investment for each option. Lastly three alternatives were considered for sensitivity analysis.

Common data

Power to Heat Ratio (Required):	0.31
Actual Operating Hours:	8,160 hrs
Peak Electricity Demand:	1100 kW
Peak Steam Demand:	5,663 kg/hr
Base Electricity Demand:	875 kW
Base Steam Demand:	3,400 kg/hr
Site Electricity Requirement:	7433 MWh
Thermal Energy Requirement:	89.3 TJ
Fuel :	Natural gas
Calorific Value of fuel:	38 MJ/m ³

Summary of results

Major Para-meters	ST		GE		GT	
	TM	PM	TM	PM	TM	PM
IP (kW)	238	875	4157	875	1873	875
FC (TJ/Yr)	88.9	326.1	382.5	88.5	205.7	97.7
EG (MWh)	1849	6783	32226	6783	14284	6783
HG (TJ/yr)	73	267.8	73	15.4	73	34.7
E/D(-) P (MWh/yr)	-5548	-650	24793	-650	6851	-650
E/DH (TJ/yr)	-16.3	151.8	-16.3	-73.9	-16.3	-54.6
EPHR	0.09	0.09	1.87	1.87	0.8	0.8
TI (million Taka)	13.7	50.4	179.59	37.8	88.4	42
NPV (million Taka)	16.9	20.3	234.1	68.4	110.8	64.5
IRR (%)	33.2	21.3	34.1	40.8	33.4	37.2

Discussion

The steam turbine option does not seem: (i) with steam turbine thermal match (STTM), less than 21% of the power requirement is generated (ii) with steam turbine power match (STPM), 89% excess power and 172% excess heat is generated. This should not be considered for sensitivity study.

With the reciprocating engine thermal match (RETM) option, 320% excess power is generated. The project profitability will depend on the buy-back rate. This may not be a good option as the main purpose is not to earn from electricity sale. Reciprocating engine power match (REPM) option seems as almost all power need can be met though heat generated is less than 78% of the requirement. There is a need to have auxiliary boiler.

With gas turbine thermal match (GTTM) option, about 87% excess electricity is generated which not be acceptable. Gas turbine power match (GTPM) option is also good as heat deficit is around 62% which can be met by auxiliary natural gas firing in the recovery boiler and the total installation cost of GTPM is 51% less than GTTM.

Therefore, sensitivity analysis may be limited to REPM and GTPM options.

Sensitivity analysis

The sensitivity analysis carried out to see the impacts of the increase in the investment, fuel and electricity price escalation was limited to STPM, REPM and GTPM options.

- What if the Investment Cost increases?

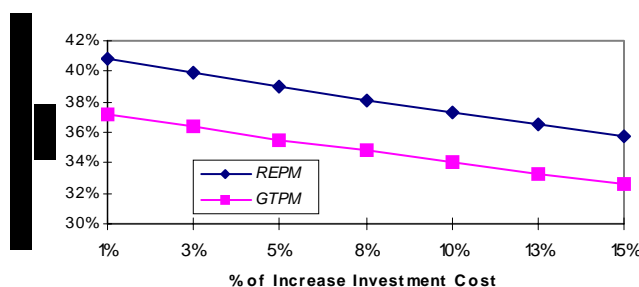


Fig. 23 IRR vs. investment cost increases

What if the Fuel Price Escalation Rate increase?

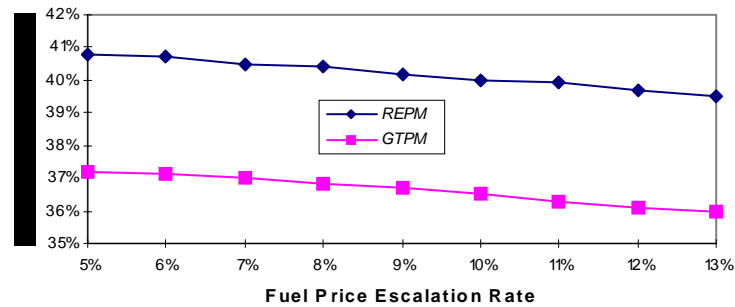


Fig. 24 IRR vs. fuel price escalation rate increases

What if the Electricity Price Increase?

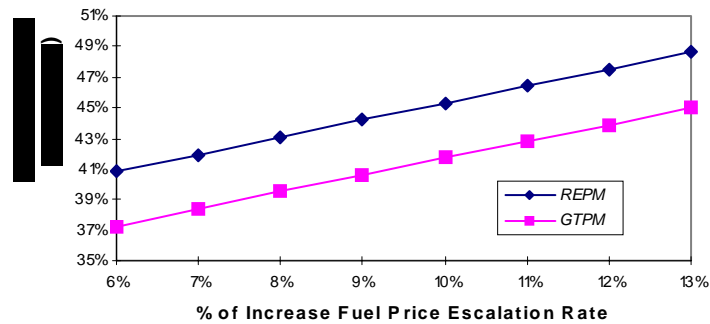


Fig. 25 IRR vs. electricity price increases

Conclusion

From the sensitivity analysis the potential cogeneration alternatives of the textile processing mill, the reciprocating engine power match option meeting power requirement of 875 kW to be the most suitable co-generation system. It represents an initial investment of 37.8 million Taka and leads to an internal rate of return of 41.8%.

Case study-3: cogeneration in commercial buildings

Nomenclature

AF	-	Annuity factor
CHP	-	Combined heat power
CF	-	Cash flow for specific year
GTMM	-	Gas turbine thermal match
GTPM	-	Gas turbine power match
I	-	Investment
i	-	Discount rate
IRR	-	Internal rate of return
n	-	Economic life of the plant
NPV	-	Net present value

RETM -	Reciprocating engine thermal match
REPM -	Reciprocating engine power match
STTM -	Steam turbine thermal match
STPM -	Steam turbine power match
TR -	Ton of refrigeration
VAC -	Vapour absorption chillers
VCC -	Vapour compression chillers

The cogeneration potential in a commercial building (another hotel) in Bangladesh was carried out. Information on steam and electricity consumption in a commercial building was collected through site visits and surveys via questionnaire. Historical energy consumption data shows that the power to heat ratio of the plant was 0.23. For average power to heat ratio of 0.23, three types of the prime movers i.e. steam turbine, reciprocating engine and gas turbine cogeneration system were considered. From the sensitivity analysis the potential cogeneration alternatives (assuming vapour compression chillers) of the commercial building, the reciprocating engine power match option meeting power requirement of 800 kW appears to be the most suitable co-generation system. It represents an initial investment of 35.6 billion Taka and leads to an internal rate of return of 43.5%. By using vapour absorption cooling for the commercial building electricity demand may be reduced sharply.

Energy consumption of the hotel

The hotel operates throughout the year without any stop. Electrical energy is required for air conditioning, lighting, and pump motors whereas a lot of steam is used in various applications like kitchen, laundry etc. The energy consumption pattern of this hotel is shown in Fig. 26. From the Fig. 8.26 it is evident that 85% electrical energy is consumed by VCC.

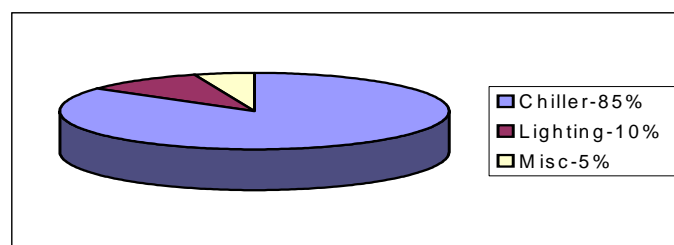


Fig. 26 Electric power consumption of the hotel

Electricity consumption

The monthly average electricity consumption for the year 1998 is shown in Fig. 27.

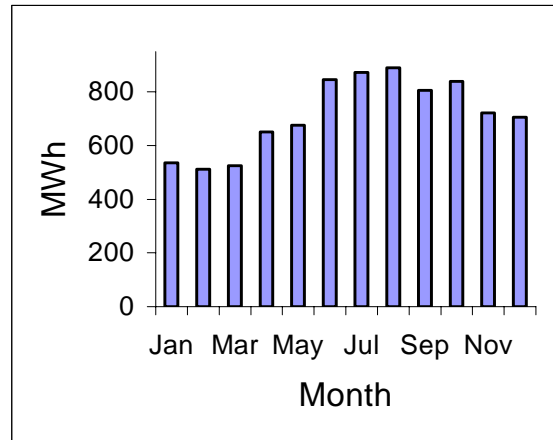


Fig. 27 Monthly average electricity consumption for the year 1998

Analysis of Fig. 27 shows that:

Maximum electricity consumption (Aug)	: 890 MWh
Minimum electricity consumption (Mar)	: 513 MWh
Maximum electricity demand	: 1000 kW
Minimum electricity demand	: 900 kW
Total electricity consumption	: 8580 MWh

Steam consumption

The monthly average steam consumption for the year 1998 is shown in Fig. 28.

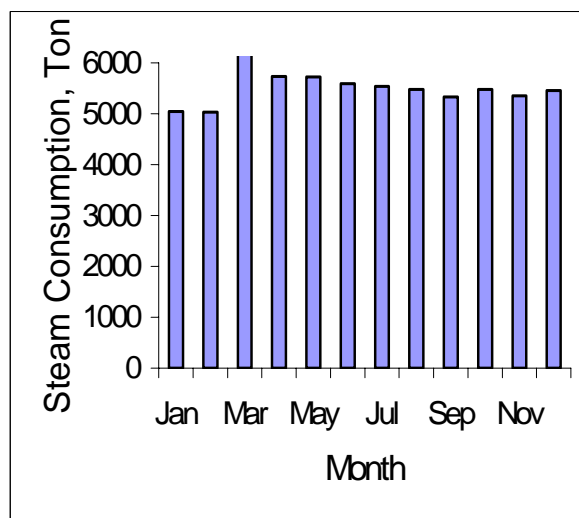


Fig. 28 Monthly average steam consumption for the year 1998

Analysis of Fig. 28 shows that:

Maximum steam consumption (Mar)	: 6317 Ton
Minimum steam consumption (Feb)	: 5033 Ton
Total steam consumption	: 60615 Ton

Power to heat ratio

The monthly average power to heat ratio by the year 1998 is shown in Fig. 29.

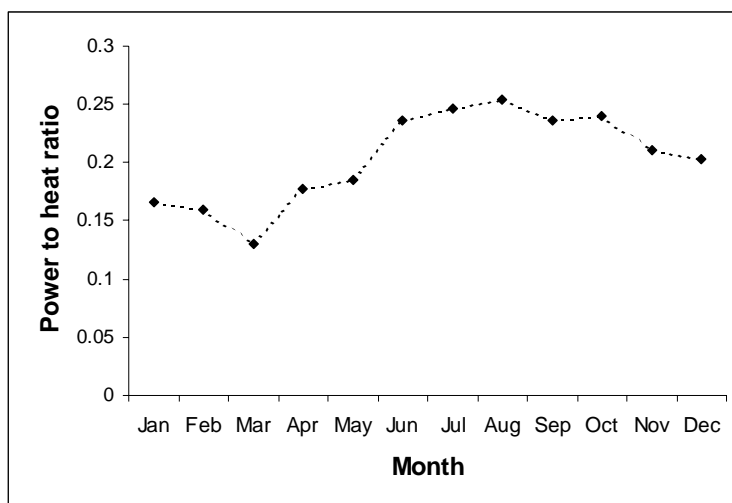


Fig. 29 Monthly average power to heat ratio for the year 1998

The power-to-heat ratio of the site was calculated to be 0.23 for 1998. Typical cogeneration system suitable for this site would be based on steam turbine. However, reciprocating engine and gas turbine cogeneration systems were also considered as potential alternatives.

Assumptions used in the study

Assumptions used in the study are as follows:

Exchange Rate	Taka/US\$	48.5
Tax Rate	%/Year	35
Service Life of the Cogeneration Plant	Year	15
Purchased Price of Electricity	Taka/kWh	3.6
Buy-back Rate	%	80
Fuel Price Escalation Rate	%	5-13
Electricity Price Escalation Rate	%	6-13
Stand by Rate	Taka/kW	80
Purchased Cost of Fuel (Natural Gas)	Taka/Cubic Meter	3.65

Assumed installation cost of a CHP plant:

For a steam turbine	:	US\$ 1200/kW
For a gas turbine	:	US\$ 1000/kW
For a reciprocating engine	:	US\$ 900/kW

The net present value of cogeneration plant has been estimated as follows:

$$NPV = (CF)(AF) - (I)$$

$$AF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

The NPV estimates the gain or loss resulting from the proposed investment. Therefore, if NPV is positive, the investment should be made because the relevant revenues exceed the financing cost. If NPV is negative, the plant is not proposable.

Methodology

Data on base electricity demand, steam demand, annual electricity consumption, annual thermal energy requirement were the initial inputs to the spreadsheet analysis. The related parameters required for cogeneration analysis were estimated using the spreadsheet.

Summary of the results obtained by using VCC as the cooling option

The steam turbine, reciprocating engine and gas turbine options with thermal match and power match results are shown in a computer print out of the spreadsheet analysis in Table 4. The results in the table also show the internal rate of return on net investment for each option. Lastly three alternatives were considered for sensitivity analysis.

Table 4 Summary of the study of the hotel

Major Parameters	Steam Turbine		Gas Engine		Gas Turbine	
	Thermal Match	Power Match	Thermal Match	Power Match	Thermal Match	Power Match
Installed power (kW)	653	900	10,137	900	4,339	900
Fuel consumption (TJ/Yr)	230	317.5	1,001.5	88.9	520	107.9
Electricity generated (MWh)	5,400	7,490	84,376	7,490	36,112	7,490
Heat generated (TJ/yr)	184.6	254.6	184.6	16.4	184.6	38.3
Surplus/deficit(-) power (MWh/yr)	-3,149	-1,090	75,796	-1,090	27,532	-1,090
Surplus/deficit(-) heat (TJ/yr)	47	92.1	47.6	-120.6	47.6	-98.7
Equipment power-to-heat ratio	0.106	0.11	1.87	1.87	0.8	0.8
Total investment (million Taka)	37.59	51.84	438.00	38.88	208.29	43.20
Net present value (million Taka)	41.11	44.61	597.67	78.61	249.30	74.83
IRR (%)	31.2	28	34.9	43.5	32.6	39.8

Discussion

The steam turbine option is found to be not suitable: (i) with steam turbine thermal match (STTM), less than 65% of the power requirement is generated and the hotel will have to depend on the utility grid; (ii) with steam turbine power match (STPM), only a small amount of excess heat is generated. [5, 6]

With the reciprocating engine thermal match (RETM) option, 900% excess power is generated. The project profitability will depend on the buy-back rate. This may not be a good option as the purpose is not to earn from electricity sale. Reciprocating engine power match (REPM) option seems good as almost all the power needed can be met though there will be small (15%) shortage in the heat supply. There is no need for an auxiliary boiler as this shortfall can be easily made up by auxiliary natural gas firing in the recovery boiler.

With gas turbine thermal match (GTTM) option, about 320% excess electricity is generated, which has to be sold as in the RETM option. Gas turbine power match (GTPM) option takes care of all the power needs though heat deficit is as high as 60%. This will require the adoption of auxiliary natural gas firing in the recovery boiler.

Accordingly, the sensitivity analysis carried out to see the impacts of the increase in the investment, fuel and electricity price escalation was limited to STPM, REPM and GTPM options.

Scope of the alternative cogeneration system

The above results of the hotel were obtained by assuming VCC. Cogeneration can provide power and cooling by incorporating VAC also. The cooling load demand of the hotel is 1500 TR which is achieved by driving a VCC. The required electricity demand of the hotel is 900 kW which is used to drive the VCC. On the other hand this cooling effect may be achieved by driving a VAC which will require electricity of 150 kW only [4].

It can be seen that a cogeneration system incorporating a VAC can save about 25% of primary energy in comparison with only power generation system with VCC [3]. Furthermore, a smaller prime mover leads to not only lower capital cost but also less standby charge during the system breakdown because steam needed for the chiller can still be generated by auxiliary firing of the waste heat boiler. Again, the proposed system is independent of national grid which is already overburdened.

Sensitivity analysis

The sensitivity analysis of the studied commercial building is shown in Figs. 30, 31 and 32.

Fig. 30 shows that internal rate of return linearly decreases with increases of the investment cost for all alternatives. As the investment cost increases from 1% to 15%, IRR varies from 43.5% to 38.8% for REPM, 39.8% to 34.9% for GTPM and 28% to 24.89% for STPM.

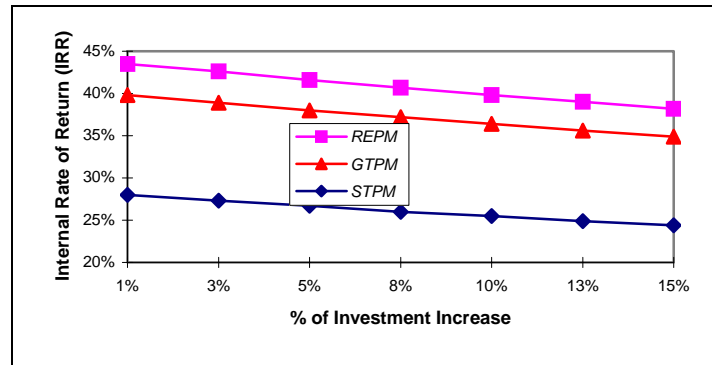


Fig. 30 Internal rate of return versus investment cost

Fig. 31 shows that internal rate of return linearly decreases with increases of the fuel price escalation rate for all alternatives. As the fuel price escalation rate increases from 5% to 13%, IRR varies from 43.5% to 38.8% for REPM, 39.8% to 34.9% for GTPM and 28% to 24.89% for STPM.

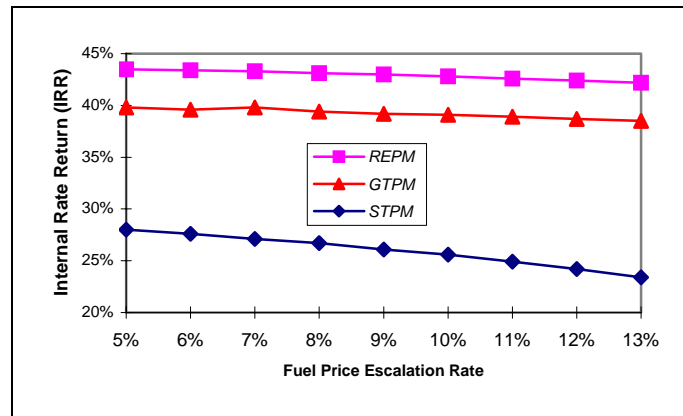


Fig. 31 Internal rate of return versus fuel price escalation rate

Fig. 32 shows that internal rate of return linearly increase with increase of the electricity price escalation rate for all alternatives. As the electricity price rate increases from 6% to 13%, IRR varies from 43.5% to 52.3% for REPM, 39.8% to 44.6% for GTPM and 28% to 34.7% for STPM. The increasing trend of the internal rate of return is found mainly due to the increasing revenues generated from the displaced electricity and from the selling of excess electricity.

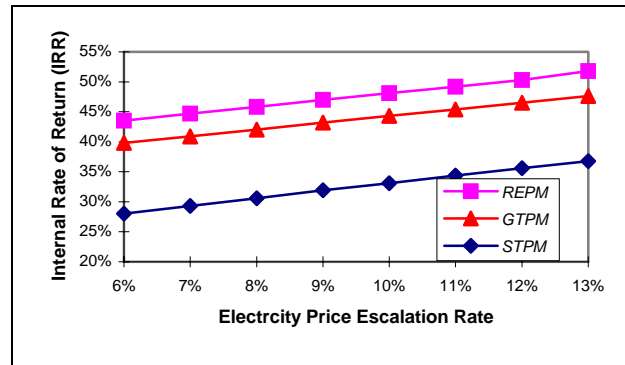


Fig. 32 Internal rate of return versus electricity price escalation rate

Conclusion

- The power demand of this commercial building by assuming VCC as cooling option is 1000 kW which is not very high. This type of plant is always suitable for gas based reciprocating engine which is available in the local market.
- From the sensitivity analysis of the potential cogeneration alternatives for the commercial building, the reciprocating engine power match option meeting power requirement of 800 kW is found to be the most suitable cogeneration system. It represents an initial investment of 35.6 Million Taka and leads to an internal rate of return of 43.5%.
- In the commercial buildings VAC need to be promoted instead of VCC to reduce electrical power requirement.
- In spite of the significant techno-economic potential for cogeneration applications in Bangladesh, cogeneration has not been widely adopted in the country due to several reasons. The foremost among them is the low level of awareness at all levels about the technological alternatives, economic merits, environmental benefits and business opportunities related to the application of cogeneration as an efficient energy use option. No systematic study has been undertaken so far to assess cogeneration potential by taking into account factors such as energy demand patterns, plant size, power-to-heat ratio, access to gas pipeline etc. There is practically no interaction between the energy utilities and the energy users to explore the cogeneration option though the government is serious about encouraging private investment in the power sector.
- When giving permission to new industrial/commercial facility having small-scale electricity demand the relevant authority should give due considerations to the use of co-generation is an alternative to grid power.
- With respect to the present socio-economic condition existing in Bangladesh dependability for power with national utility may hamper the reliability of planned production and services. In this aspect self- captive generation in prospective cogeneration sites may improve reliability and efficiency as well as reducing the burden to already stressed national grid.

Such cogeneration process may immune the plant from unaccounted system losses of national utility.

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