Combined Heat and Power Production in Finland

Seppo Silvonen, Director, MOTIVA, Information Centre for Energy Ef ficiency
Tero Mäkelä, M.Sc., Finnish District Heating Association

Synopsis

Finland saves annually 6% of all primary energy used in the country, or 20% of the total fossil fuel consumption by using cogeneration.

Abstract

Finland is the world's leading country in the combined production of heat and power (CHP). Cogeneration is applied widely in Finland for the heating of communities and for heat and power from the utilisation of waste fuels from industrial processes. The amount of energy Finland saves annually through CHP corresponds to 6% of all primary energy used in the country, or 20% of the total fossil fuel consumption.

Approximately 32% of the electricity used in Finland in 1996 was gained from CHP. Industrial power plants and district heating plants respectively accounted for 44% and 56% of the cogeneration. Industries consumed more than half of all electricity in Finland in 1996, and a quarter of their electricity came from CHP. As much as 75% of district heating was produced by CHP in 1996. District heating covers 46% of total Finnish space heating demand.

Anyone who conforms to the safety and environmental standards is permitted to build power plants in Finland. By contrast, nuclear power plants must be approved by the Parliament.

The high acquisition costs of energy have made it profitable for companies and communities to invest in cogeneration that saves energy. The high efficiency of CHP facilitates the use of inferior as well as expensive fuels. The most suitable fuels available at each particular locality are used for CHP.

CHP plants are built for financial gain. Cogeneration must be cheaper than the acquisition of corresponding amounts of power and heat with other methods. The profitability of different alternatives must be assessed for the whole life expectancy of a power plant. It is normally more costly to build but cheaper to operate a CHP plant than a plant employing other production methods.

1. Introduction

Finland is the world's leading country in the combined production of heat and power (CHP). Cogeneration is applied widely in Finland for the heating of communities and for heat and power from the utilisation of waste fuels from industrial processes. The amount of energy Finland saves annually through CHP corresponds to 6% of all primary energy used in the country.

Approximately 32% of the electricity used in Finland in 1996 was gained from CHP. Industrial power plants and district heating plants respectively accounted for 44% and 56% of the cogeneration. Industries consumed 56% of all electricity in Finland in 1995, and a quarter of this electricity came from CHP. As much as 75% of district heating was produced by CHP in 1996. District heating covers 46% of total Finnish space heating demand.

2. The Electricity Context in Finland

The need for energy per capita is among the highest in the OECD countries. This is above all explained by the large amount of energy-intensive industry compared with the size of the population. Therefore, the economical use and secured delivery of energy has always been under special scrutiny in Finland.

Nuclear power accounted for 27% of the electricity used in Finland in 1996, 32% was cogenerated, 17% produced with hydro power and 19% with conventional condensing power. In addition, import covered 5% of Finland's need for electricity.

There are several dozens of power producers in Finland. Most of them generate electricity for their own needs.

Extensive power transmission networks are owned by two transmission companies. One of them is state-owned and the other's shareholders are several industrial companies and cities. Both companies deliver electricity to industries and for common use, but do not distribute it. In the near future, the two transmission companies will merge, in order to form a public transmission company. The company will be owned by various parties, representing industries, other private companies and the state.

The distribution of electricity is managed by more than a hundred power distribution utilities, mainly independent companies owned by municipalities.

All the electricity networks operate according to the Third Party Access (TPA) principle. Electricity producers can sell the electricity to any customer, undepending on the geographical location of the power plant and the customer.

The power plants of all the producers are joined through transmission systems. Production and transmission companies have agreed on a set of rules that make up the framework for the production and transmission within the network.

Anyone who conforms to the safety and environmental standards is permitted to build power plants in Finland. By contrast, nuclear power plants must be approved by Parliament.

Finland is greatly dependent on imported energy. Imports cover 70% of the total energy consumption. There are no fossil fuels, neither is there uranium in Finland. The major domestic sources of energy are hydro power, wood and peat.

3. The Development of Cogeneration

The high acquisition costs of energy have made it profitable for companies and communities to invest in cogeneration that saves energy. The high efficiency of CHP facilitates the use of a wide variety of fuels, ranging from inferior to expensive fuels. The most suitable fuels available in each particular locality are used for CHP.

The first industrial cogeneration plants in Finland were built at the turn of 1920s and 1930s, and the first district heating plants in the 1950s. The aim was to increase economy and reliability in the power production, and local energy sources were often used as a starting point.

Industrial back-pressure power production is mainly based on waste liquors originating from pulp production, which is suitable for combustion because of the organic wood residue it contains. The production of pulp for the manufacture of paper was started in Finland as early as in the 1880s. However, the waste fuels were not utilized at that time but instead diluted and emitted into waterways.

The heat needed for the production of pulp and paper was generated mainly with wood and coal. Fuel prices went up sharply in the 1920s, which helped to promote the idea that pulp waste fuels could be utilized in heat

and power production. Although the systematic construction of hydro power was started in southern Finland in the 1920s, the lack of a power transmission network made it necessary to satisfy the need for power locally through condensing power capacity, which was also a motivation for the application of industrial waste fuels.

Initially, CHP plants were built and owned mainly by industries and municipalities which also consumed the power and heat generated. Power companies have also built CHP plants after the 1970s. Some plants are owned jointly by various parties.

4. Requirements for Cogeneration

CHP plants are built for financial gain. Cogeneration must be cheaper than the acquisition of corresponding amounts of power and heat with other methods. The profitability of different alternatives must be assessed for the whole life expectancy of a power plant. It is normally more costly to build but cheaper to operate a CHP plant than a plant employing other production methods.

The owner of the power plant may consume the power and heat, or they may be sold to other customers.

The environmental protection costs of power plants affect the economy of a CHP plant and its alternatives. Finland imposes the same environmental requirements on CHP plants as on other power and heat production plants of a corresponding size.

Cogeneration usually requires larger investments than alternate power and heat production methods. The counterbalance is a smaller consumption of primary energy. Therefore, the production costs of CHP may be lower than those of other generation forms.

Cogenerated thermal energy may be used for the heating and cooling of houses, for the production of warm household water, for air conditioning, or for industrial processes. They form the so-called heat load.

The transmission of heat for long distances is costly. The maximum economical distance is a few dozen kilometres. It would be ideal to consume the heat near the power plant. CHP plants are therefore preferably built close to the heat loads - communities or factories. The transmission of electricity is also most economical when power is produced near the consumption area.

The size of the heat load often defines the upper limit of the CHP output. However, the demand for electricity may also be a restricting factor. If the producer does not use all the power and heat, there must be a possibility to sell them to other consumers. This requires a connection to wider thermal and power networks and also a functioning heat and power trade.

4.1. District Heating

Because of the cold climate, it is necessary to heat houses in Finland for most of the year. About one fifth of the energy consumed in Finland goes to the heating of buildings. The major heating forms are district heating, individual oil heating and electric heating.

District heating was started in the big cities of Finland in the 1950s and 1960s, and in small towns after the oil crises of the 1970s. There are over 200 heat distribution utilities in Finland, and most of them produce at least part of the heat themselves. Most district heating utilities are owned by municipalities and operate within the owners' area. The sale of district heat is an extensive business. The turnover of district heating was more than 3600 million FIM (630 million ECU) in 1995. District heating systems cover practically all parts of Finland where the sale of district heat is profitable.

Large cities own power plants which produce both power and heat. Most of their output is consumed within the owner cities' area. Medium-sized and small towns purchase district heat from power plants or industrial plants

owned by other companies, or produce it themselves in heat-only boilers. The electricity for these towns is purchased from the public power network.

The aim of the construction of district heating systems has usually been the combined production of heat and power. The motivation is increased competition and self-sufficiency in a town's acquisition of electricity. However, the general practice for the construction of a district heating system in Finland is that the sale of district heat must be profitable even without CHP. On the other hand, the sales price of district heat must be competitive with other forms of heating.

It takes decades to build an extensive district heating system, and requires long-term planning. District heating is very capital-intensive. The fiscal position of the owner must be solid to bear the risk of financing the investment.

4.2. Industrial Cogeneration

The power output of industrial back-pressure plants totals approximately 1600 MW at the moment. The majority - nearly 85% - of the Finnish industrial cogeneration plants is connected to processes of the forest industry. The forest industry consumes about one quarter of all energy used in Finland, or 60% of the total energy used by industry.

The biggest electricity consumers in the pulp and paper industries are the grinding of wood, refining and pumping of pulp, and the transport of materials. The dissolving of pulp and paper and the agitation of pulp are considerable consumers of electricity. The biggest consumption of heat in the pulp and paper industries is the vaporization of water and the heating of process flows.

As stated above, the starting point of industrial back-pressure power is the need for heat of an industrial process. In forest industry, the manufacture of pulp - raw material of paper - produces combustible waste liquors. When black liquor, waste fuel from sulphate pulp production, is burned in a soda recovery boiler, the chemicals contained by black liquor can be recovered and reused. The heat generated during combustion can be used to vaporize water, and the vaporized water, steam, can be utilized in CHP.

The manufacture of metals and the processes of chemical industry also produce waste fuels that can be turned into heat and power through the water-steam CHP process. Furthermore, it is profitable in some cases for a plant to purchase fuel such as coal, natural gas, peat, oil or waste wood to be used as energy source.

In the manufacture of pulp the sulphite method was the most common chemical fibering method applied in Finland up to the 1960's. Nowadays, sulphite pulp accounts for only 4% of chemical pulp, sulphate process being the only one selected for new pulp plants after that period.

Modern soda recovery boilers function as steam generators in the manner of ordinary steam boilers and contribute to the production of high-pressure steam for pulp production and for the steam turbine. A soda recovery boiler is one of the most expensive components in the manufacture of pulp, but it facilitates the almost total self-sufficiency in chemicals and even a surplus of thermal and electric energy in the manufacture of pulp.

During the last couple of decades, ever more mechanical pulp has been produced which does not yield waste liquors and thus does not facilitate back-pressure production.

The power consumption in the manufacture of mechanical pulp is considerably higher than that of chemical pulp. The heat consumption in the manufacture of mechanical pulp is again lower. The electric energy needed for mechanical pulp in Finland is partly acquired by back-pressure power plants connected to the factory, using waste wood, natural gas, coal or peat as fuel, and partly from outside, from hydro, nuclear or coal power plants, or imported from the neighbouring countries.

5. Cogeneration is Environmentally Sound

Primary energy consumption in cogeneration as compared with corresponding generation in separate processes is lowered by approximately one third.

The decrease in fuel consumption reduces the burden of energy production on the environment. For instance, the carbon dioxide emission from firing of fossil fuels is reduced at the same rate as the use of fuels is reduced. The same goes for all other emissions, such as those from sulphur and nitrogen oxides.

In some cases releases of the condensing heat from power plants causes damage to the environment. In CHP plants the condensing heat is harnessed and there are no harmful emissions from it.

6. Technical Solutions

Mostly the CHP process is based on the use of steam or gas turbines or both (combined cycle power plant).

The electrical capacity of most steam turbine plants working on the back-pressure process is usually a few dozen megawatts. The power to heat ratio is normally about 0.3-0.5. The power capacity of gas turbine plants is usually slightly smaller than that of steam turbine plants by a few to few dozen megawatts. The power to heat ratio is often close to 0.5.

The power capacity of combined cycle plants is usually higher than that of steam turbine plants. The advantage of combined cycle plants is the high power to heat ratio, normally about one.

A typical annual efficiency of combined cycle plants is approximately 85%, or more than 90% in the modern plants.

The most common fuels are coal, natural gas, industrial waste wood and peat. Oil is used sparingly, usually only as a supplement to other fuels.

The amount of industrial back-pressure power depends on the heat consumption of a process and on the properties of high pressure, medium pressure and back-pressure steam. The major determining factor of the back-pressure steam production is the power to heat ratio.

In a district heating power plant the steam is condensed in the heat exchangers below the steam turbine and transmitted to consumers by circulating water. The steam from a back-pressure power plant again is fed to the factory where it surrenders its heat. The back pressure is lower in a district heating power plant than in industrial back-pressure plants. This explains why the power to heat ratio of industrial back-pressure power plants is lower than that of district heating power plants.

A combined cycle power plant is a more developed version of the cogeneration of heat and power. The heat from the exhaust gases of a gas turbine process is recovered for the steam turbine process. The benefit of the system is a high power to heat ratio and a high efficiency. The latest development in cogeneration, the gasification of solid fuel, has also been linked into combined cycle plants. A combined cycle power plant based on gasification has been planned in connection with an oil refinery in Finland. The fuel would be heavy oil residue with a high sulphur content. The gasification technique would reduce the sulphur and nitric oxide emission considerably lower in comparison with conventional combustion techniques.

7. The Future of Cogeneration in Finland

The cogeneration of heat and power, CHP, is considered an important part of the Finnish energy system also in future. The increased need for environmental protection will further emphasize the wide application of CHP. In

our energy policy, CHP has been given priority over new power production capacity. However, no subsidies or other legislative support are granted or planned to enhance the profitability of cogeneration. The priority position has been ensured by removing the barriers of CHP.

District heating will not increase any more in any considerable degree, as it is already being delivered practically speaking in all parts of the country where it is economically feasible. Along with the growth of the cities and towns the sale of district heating will go up about 2% annually.

Heat conservation in industry and in buildings will reduce heat loads and restrict the opportunities of establishing additional CHP capacity. Even now, heating in Finland is quite sparing in international comparison. For instance, the heating of Finnish houses consumes approximately the same amount of energy as in western Central Europe, although the Finnish climate is considerably colder.

The development of power plant techniques will lead to an improved power to heat ratio. An interesting outlook into CHP is revealed in the combined cycle power plant technique based on the gasification of solid fuels, under development also in Finland. In this process, the gas can be utilised in gas turbines and the waste heat from the gas turbine can be used in the steam turbine plant. The power to heat ratio can be close to one, instead of today´s value of about 0,5.

Maximum freedom in the trade of power and heat is a basic requirement for the full-scale exploitation of the possibilities of cogeneration. This is because very often the owner does not need all the energy produced in a plant. It must be possible, periodically at least, to sell power and heat to others. This has been ensured in Finland by the TPA procedure, that applies all producers and consumers.

The environmental advantages of CHP have emerged during the last few years. Nevertheless, the building of power plants is still based on financial considerations. The price of energy produced in a CHP plant must be competitive with other energy production forms. Only a solution which is economically sound is lasting in the long run.

If uniform environmental requirements are imposed on all methods of energy production, the financial status of CHP improves at least theoretically. Less fuel is used per net energy produced. For the same reason the rise in the price of energy favours in principle the combined production of power and heat.

By the year 2000, the cogeneration capacity is estimated to be 5730 MW, i.e. 960 MW more than in 1994. This is a forecast of the Ministry of Trade and Industry. More than half of the increase is based on district heating applications. Since the heat loads have already mostly been utilized, a significant increase in electricity production can only be achieved by increasing the power to heat ratio (alfa-value). The average alfa-value of district heating plants currently is 0,5, and somewhat lower in industrial applications.

In 1995, the Finnish electricity legislation has been renewed. The Open Access-principle was introduced in the electricity networks. The opening of the networks has been realised in two steps. Until 1997, the Open Access was allowed only for customers larger than 500 kW. From the beginning of 1997, the Open Access is applied to all customers. The opening will probably not affect the production side very much, since electricity production has traditionally been on a competitive basis. There has not been space for uneconomical plants. The reform has, however, affected some uncertainty for small energy companies, since the risks of the investments are growing, due to increased competition on the electricity supply. This could imply, that relatively more cogeneration schemes would be realised by larger companies in the future.

8. Summary

Finland is the world's leading country in the combined production of power and heat, CHP. It has taken dozens of years of determined development of heat loads and favourable conditions to create an extensive cogeneration system. Industrial processes and district heating of communities make up heat loads which facilitate CHP.

CHP is a decentralized production system where the production must occur close to the areas of heat consumption. The basis of the system is the possibility of those using power and heat to build power plants for their own needs. The basic requirement for the existence of such a system is an open power production structure providing companies with equal possibilities for operation. This is the most important policy instrument to encourage CHP.

The state does not interfere directly with the production and distribution of power or heat in Finland. The distribution of power and district heating is organized locally. Each company and municipality gets its power and heat in the way which they consider best.

The alternatives are the purchase of energy from outside producers, or own production. Usually the most economical solution is a combination of these two; part of the energy is produced and part of it is purchased. The upkeep of such a system is considered useful in Finland, because it maintains competition between different producers and techniques.

Also CHP plants must be economically profitable. The price of the energy produced must be competitive with other heat and power production options. It is essential that the saving in fuel costs gained in CHP is big enough to cover the higher investment costs.

Environmental protection speaks for CHP. However, it is not a sufficient argument for a decision to build a plant unless the basic requirements, profitability above all, are fulfilled.

References

1. District Heating in Finland in 1995. Finnish District Heating Association. Espoo 1996.
2. Energy Statistics 1995. Statistics Finland. Helsinki 1996.
3. Koivisto, H., Kortelainen, J., Mäkelä, T., Ruohonen, S., Rämö, J. Cogeneration of Power and Heat in Finland - Experiences and Conclusions. Paper in WEC 15th Congress. Madrid 1992.